energetics

Renewable gas for the future

Policies to support Australia's sustainable and affordable gas network

Energy Networks Australia

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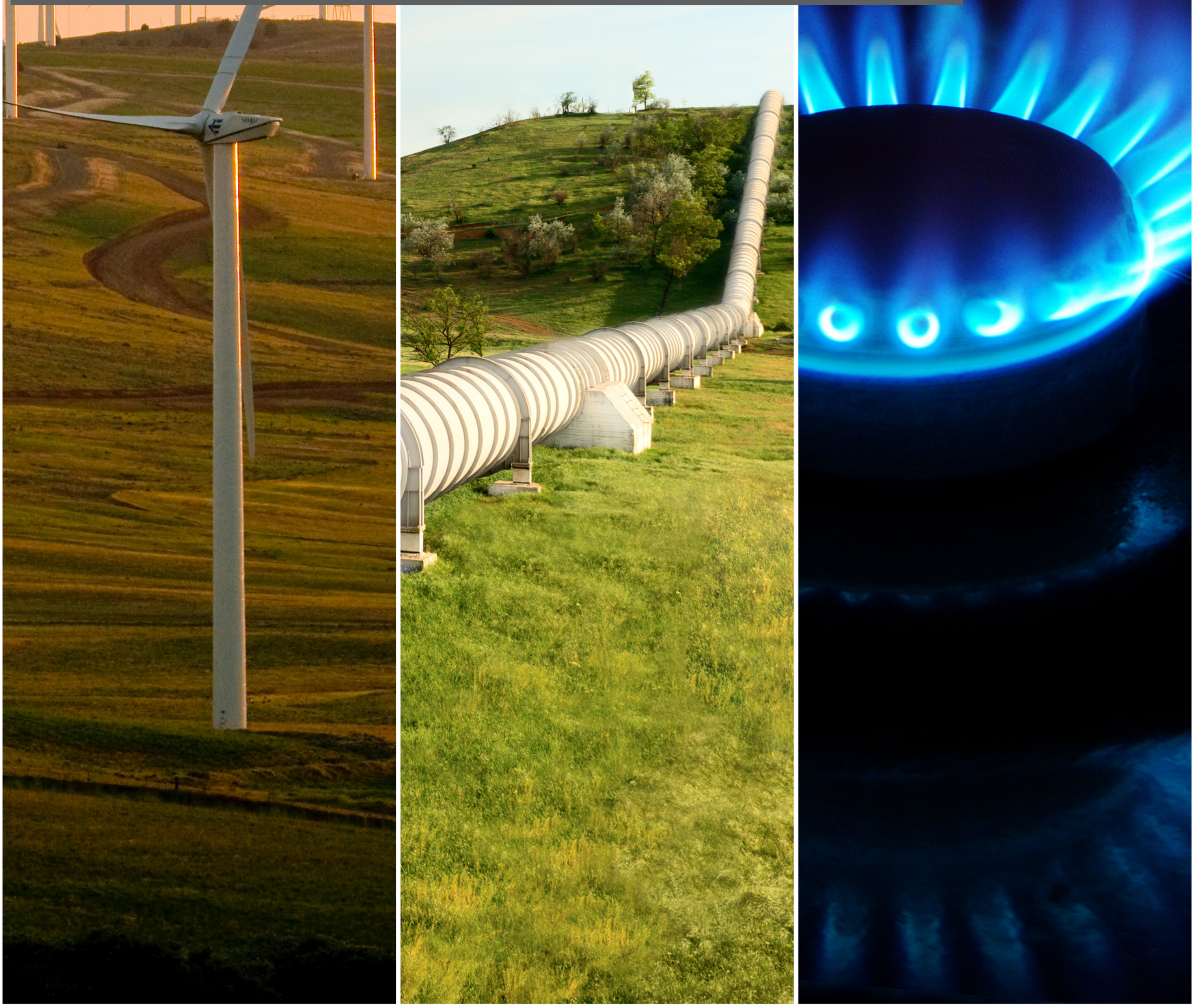

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- Be leaders. Develop and implement strategy
- Be informed. Make data-driven decisions
- Be efficient. Drive business improvement and realise savings
- Buy better. Leverage energy supply and carbon markets

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Executive summary

As countries around the world begin planning for longer term carbon reduction targets to align with a 1.5 degree world, deep decarbonisation pathways for all forms of energy use must be considered and implemented as soon as possible[1]. This is particularly urgent for Australia, as our emissions trajectory shows a widening gap between the reductions that can be delivered through the current suite of government policies and the volume of abatement required for Australia to meet our obligations under the Paris Climate Agreement.

To date, Australia's emissions reduction measures have focussed on the development of renewable sources of electricity, with the opportunities for renewable gas – specifically biogas and hydrogen – receiving little or no attention.

This paper examines the features of renewable gas and its potential value; the support for renewable gas in other government jurisdictions across the world; relevant federal and state government policies here in Australia, and the extent to which those policies either support the development of a renewable gas industry or present barriers. Based on this analysis, a series of recommendations is made for advancing the case for renewable gas and the immediate next steps identified.

Understanding the opportunity

Natural gas plays a key role in powering Australia today. Its use currently accounts for 25% of national energy consumption which is supported by an extensive network of transmission and distribution pipelines across the country. Several recent studies such as the National Hydrogen Roadmap[2] have discussed the opportunities offered by clean hydrogen with a focus towards the export opportunities and hydrogen's use in the decarbonisation of transport. The role of renewable hydrogen and other renewable gases in reducing Australia's greenhouse gas emissions was not emphasised in the Roadmap but served as an underlying assumption. Other studies[3] have highlighted the economic case for renewable gas as an option for decarbonising heating.

Based on a review of policies from around the world, Energetics found

- There is international momentum in research and development of hydrogen-based energy use and feedstock
- Global policy makers are investigating the potential uses of hydrogen throughout the value-chain, from serving as inter-seasonal storage for excess renewable energy to the export of hydrogen to energy importing countries such as Japan and South Korea
- There are well-developed standards in place that allow for the injection of biogas into gas networks across Europe. The use of biogas has been supported through feed in tariffs and government subsidies. The effectiveness of these policy levers is evident with France seeing the development of 59 biogas projects and 290 on the waitlist in the last 5 years.

[1] We note the UNFCCC's release 8.10.2018 of its special report on the impacts of global warming of 1.5C above pre-industrial levels, and the urgency for action: ***http://www.ipcc.ch/report/sr15/***
[2] CSIRO (2018), National Hydrogen Roadmap
[3] "Implications of Policy-Driven Residential Electrification", An American Gas Association Study prepared by ICF, July 2018.

Further, the use of biogas or hydrogen to decarbonise existing natural gas networks are primarily driven by policies that target:

- Lower emissions heating for households and industries
- The provision of inter-seasonal storage and balancing for renewable electricity grids
- Supply for the chemical manufacturing industry
- Supply for hydrogen fuel cell electric vehicles (hydrogen FCEV)
- Supply for hydrogen fuel-cell heating at a residential and commercial level
- Export of hydrogen as a renewable fuel alternative

We note that while hydrogen production using electrolysis is an established technology, the goal of large-scale cost-effective electrolysis is yet to be achieved. Instead, policies around the world focus on boosting the industry aim to address bridging the technology 'valley of death'.

Recognising the potential for hydrogen in the economy, in December 2018 the Chief Scientist of Australia presented a proposal for the development of a national hydrogen strategy to the COAG Energy Council. As a result, the COAG Hydrogen Working Group was formed and a discussion paper was released in March 2019: the first step in a series of consultations and papers to inform the development of the strategy. According to the timeline established by the COAG Energy Council, the National Hydrogen Strategy will be delivered to the Ministers in December 2019[4].

Policy measures that can support the renewable gas opportunity in Australia

There is currently a gap of 93 $MtCO_2$-e between Australia's current policy scenario for carbon reduction and Australia's Paris Target of achieving reductions of below 26%-28% on 2005 levels by 2030[5]. By adapting Australia's current policy framework to include hydrogen and biogas as low-emission alternatives, existing gas network can contribute to our Paris goals because:

- The decarbonisation of heating would make a meaningful contribution to reducing Australia's emissions. Approximately 45% of the natural gas used in Australia is used for heating in the manufacturing industry, in buildings and in homes.
- Fuel-switching from natural gas to biogas or biomethane could be the low-cost option for decarbonising heating in some instances[6]. Further, 10-15% of our natural gas supplies can be substituted with renewable gas without modification[7] to either pipelines or end-use appliances
- As our electricity sector decarbonises and variable renewables gain ground, our grid will require more sources of reliability. Renewable gas (hydrogen and biogas) is a possible means of providing long-duration, inter-seasonal storage, beyond the minutes, hours and days that could be met by batteries, or the limited locations where pumped storage could

[4] https://consult.industry.gov.au/national-hydrogen-strategy-taskforce/national-hydrogen-strategy-request-for-input/supporting_documents/nationalhydrogenstrategyrequestforinputdiscussionpaper.pdf
[5] See https://climateworks.com.au/sites/default/files/documents/publications/climateworksaustralia-tracking-progress-report-2018.pdf
[6] https://www.energynetworks.com.au/sites/default/files/054496_tg_decarbonising_australias_gas_network_final.pdf
[7] Hydrogen Strategy Group (2018), Hydrogen for Australia's Future – A briefing paper for the COAG Energy Council.

work. It could be used to absorb excess renewable output, balance and smooth peak power production and demand, and satisfy greater energy demand.

In pursuing these opportunities and by prioritising the development of a domestic renewable gas industry over the export of hydrogen, Australia can ensure its efficacy, establish critical networks and infrastructure, and demonstrate its economic value ahead of investing in the development of export facilities.

Recommendations

Energetics takes a technology neutral position in our assessment of policies that support the creation of a renewable gas network. We assessed existing measures that either:

- Address areas where the existing policy landscape in Australia unfairly omits consideration of renewable gas and renewable gas networks, and/or
- Highlight where there is active discrimination against renewable gas and gas networks

A comparison of renewable gas with renewable electricity incentives shows that there are key elements missing for encouraging a transition to renewable gases, such as a national target that will drive investment, and mechanisms that allow renewable gas project developers to participate in Australia's renewable energy markets.

To raise Australia's policy development for renewable gas up to international standards, we found that the following steps should be considered:

- Establish a near term aspirational target for cost-effective renewable gas injection into the gas networks by 2030. The target should be informed by a cost-benefit analysis that looks at the use of renewable gas to decarbonise the use of natural gas.
- Establish a method for the creation of Australian Carbon Credit Units for projects that inject renewable gas into existing gas transmission and distribution infrastructure. This method would provide a financial opportunity for renewable gas projects to inject into the gas networks.
- Entrench best practice regulatory framework for hydrogen and biogas production, storage and use, including a health, safety, design and metering standard for hydrogen.
- Build on the existing momentum at Federal and State level for the development of a hydrogen economy to explore options for both the domestic use of hydrogen employing existing infrastructure for distribution of the gas, the use of hydrogen as a transport fuel and the export of hydrogen.

While the provision of feed-in-tariffs for renewable gas would also be a mechanism to support the injection of renewable gas into networks, we note that Australia is currently moving away from such policies. While broadening the Renewable Energy Target (RET) to also cover the injection of renewable gas into the gas networks could be beneficial, the RET is due to expire in 2020 under current Commonwealth Government policies. Further, the current RET will be fully met by existing renewable energy projects. Should the RET be extended and expanded, the option of including renewable gas under the RET could be re-examined.

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1. Introduction

Climate science tells us that the world must reach net-zero emissions by the second half of the century (as early as 2050) to have a chance of averting catastrophic climate change. As a signatory to the Paris Agreement, Australia has committed to reducing its greenhouse gas emissions by 26-28% below 2005 levels in the year 2030 and pursuing efforts to limit warming to 1.5 degrees above pre-industrial levels. Achieving these emissions reductions will require major changes to Australia's energy mix.

However, the emissions projections associated with Australia's current policy suite have shown that the policy measures in place will not be enough to drive the achievement of the Paris target in 2030. Electricity and building emissions are set to fall however industry and transport emissions are projected to continue to rise, with the net result being that emissions remain steady, as illustrated in Figure 1.

We see too in Figure 1 that the emissions reduction challenge is growing as the gap widens between existing policies in Australia which are predominantly focused on decarbonising the electricity sector in the medium-term, and our ambitious view towards a net-zero emissions scenario in the long term. In 2030, there would be a gap of around 93 $MtCO_2e$ per annum and growing between the proposed policies scenarios and Australia's Paris Target of below 26%[8].

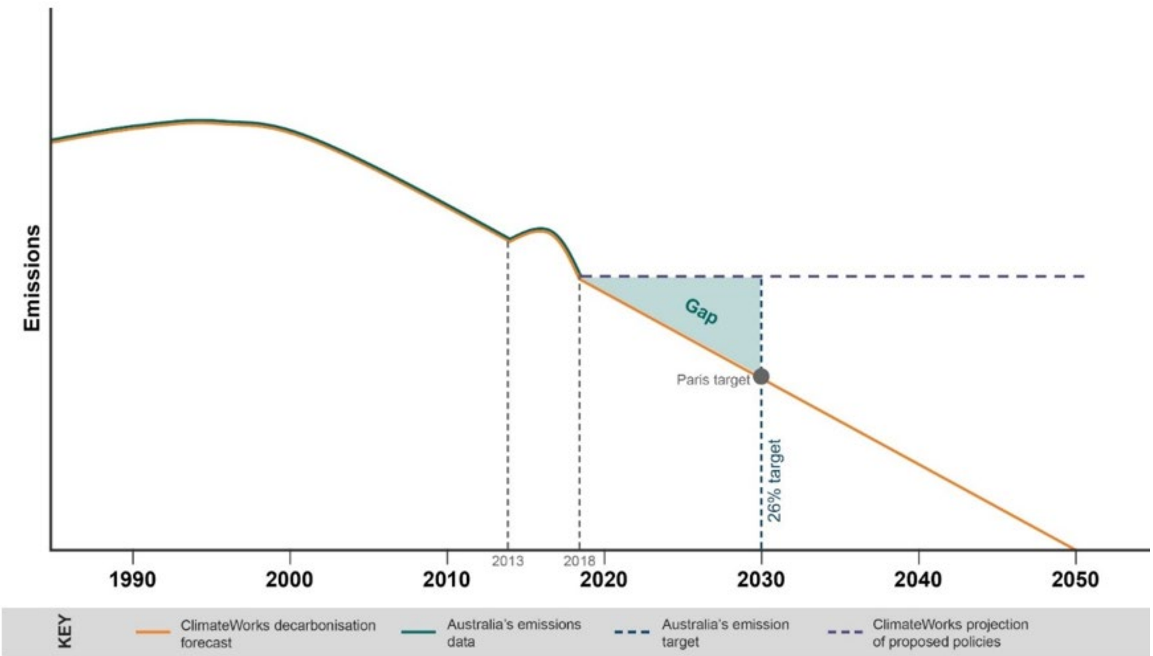


Figure 1: Australia's emissions projection[9]

Closing the gap will require emissions reduction across all sectors of the economy, not just electricity.

[8] See https://climateworks.com.au/sites/default/files/documents/publications/climateworksaustralia-tracking-progress-report-2018.pdf

[9] ***https://climateworks.com.au/sites/default/files/documents/publications/climateworksaustralia-tracking-progress-report-2018.pdf***

With abundant local supplies, natural gas plays a key role in powering Australia today across all sectors of the economy. The gas industry outlined its pathway for decarbonising gas in Australia with Gas Vision 2050[10], and it describes how a combination of technologies will allow Australia to continue to reap the social and economic benefits of gas. Importantly, Gas Vision 2050 also allows Australia to continue to gain the economic returns from its investment in the gas distribution networks. These are large, long-lived assets.

Gas Vision 2050 explained how three transformational technologies can lead to the decarbonisation of gas in Australia:

- *Renewable hydrogen production* offers a potential new source of zero emissions fuel and a way to further exploit Australia's abundant renewable energy resources
- *Renewable biogas production* can upgrade organic waste streams
- *Carbon capture and storage* allows Australia to continue to use its natural gas resources. The figure below, taken from Gas Vision 2050, explains how these technologies combine to deliver zero emissions gas by 2050.

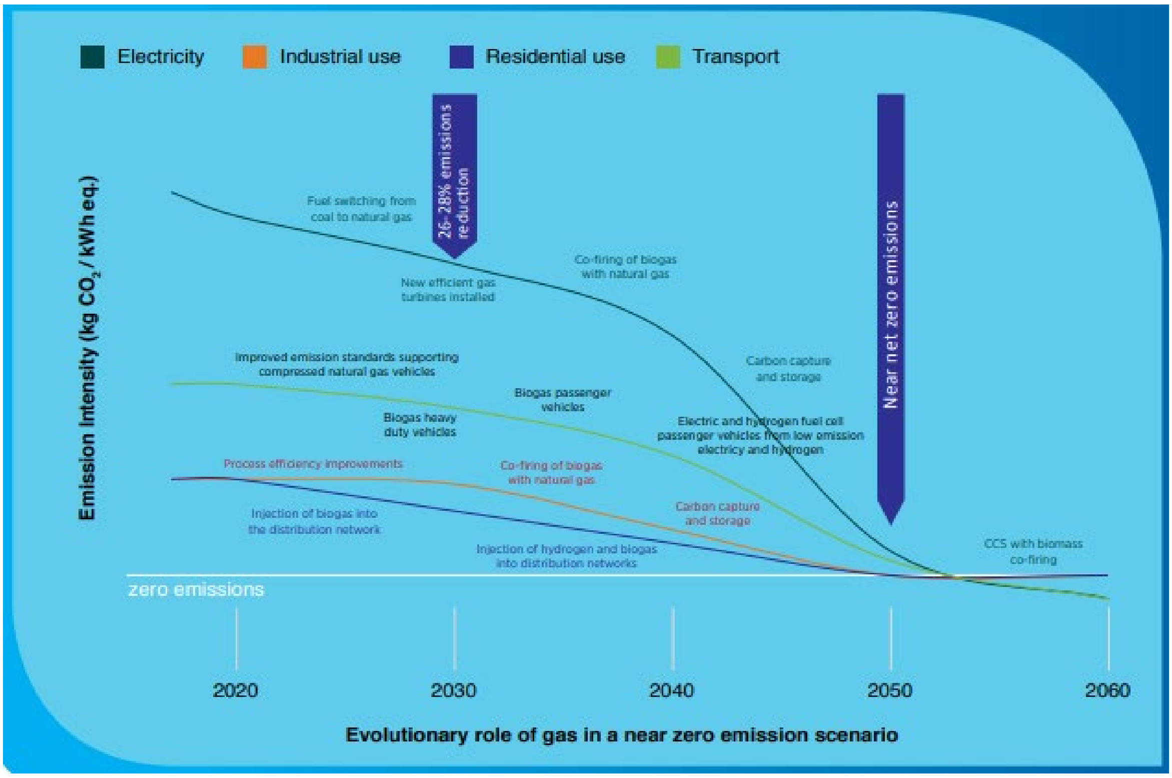


Figure 2: Gas Vision 2050 - a vision of renewable gas in Australia

Beyond Australia, other countries have both acknowledged the role that the production and use of renewable gases play in achieving zero emissions by 2050 and many have begun implementing policies that encourage the development of new technologies and industries. As Australia does not yet have a cohesive and responsive policy environment that promotes the use of renewable gas within Australia, Energy Networks Australia commissioned Energetics to identify policies that draws upon the experience internationally and promotes the use of renewable gas locally. This report summarises the outcomes of the study.

[10] *https://www.energynetworks.com.au/gas-vision-2050*

Understanding this report

Energetics conducted a desktop review of current or past climate change and energy policies designed to support and promote the production and use of low emissions gases. This review spanned both domestic and international jurisdictions. We then analysed relevant policies which resulted in 30 international case studies.

A summary was produced of existing Australian policies and recommendations for reducing carbon emissions. This provides a point of comparison to international policies and a qualitative evaluation of their effectiveness. A complete bibliography of primary and secondary research documents is contained in Appendix B.

2. Australia's decarbonisation policy gap

This section of the report addresses two key aspects of policy design for renewable gas networks. The first examines the arguments in favour of renewable gas and is based on a considerable body of research. It also looks at the role that renewable gas can play in decarbonising Australia's energy. The second aspect look at the nature of the policy landscape in Australia and how existing policies can provide the platform to support renewable gas.

2.1. The role of renewable gas in decarbonising our economy

The potential value of renewable gas (that is gas that has low or zero carbon emissions) in Australia's decarbonisation pathway is well recognised. The Finkel Review[11] identified fuel switching to low-emissions gas as one option that could bring a large volume of emissions reductions. Specifically, biogas and (renewable) hydrogen were identified as low-emissions gas alternatives with the following opportunities described:

- Renewable hydrogen can be produced from renewable electricity and can be injected into the existing gas networks. Studies have shown provided the concentration of hydrogen does not exceed 10% (and in some studies up to 15%) the existing infrastructure, gas networks and appliances can be used without modification[12].
- Biogas extracted from renewable sources including landfill, wastewater and agricultural waste can be injected into the existing gas network without restriction and with only minor upgrades required[11]. It enables Australia to obtain an economic benefit from waste streams that would otherwise be discarded and worse, contribute to the nation's greenhouse gas emissions.

Importantly, the development of large-scale renewable hydrogen production facilities for domestic consumption provides a test bed for similar production facilities aimed at the export market[13]. With no such facilities currently in operation or piloted in Australia, the development pathway and associated costs of new production plants are largely unknown. Should renewable gas receive government and commercial support, the gas industry could begin with the aim of fully optimising and demonstrating the economics of renewable hydrogen production for the domestic market, before building costly export facilities such as liquefaction trains.

In addition to its domestic and export market potential, the other argument in favour of renewable gas relates to its delivery. In particular, the continued use of Australia's existing, large transmission and distribution assets.

Optimising our gas assets vs. electrification

Natural gas accounts for 25% of Australia's energy consumption. While electrification of applications and especially heating applications that use gas is a path for decarbonisation, it may

[11] "Independent Review into the Future Security of the National Electricity Market: Blueprint for the future" (June 2017).
[12] Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D, Hartley P (2018), National Hydrogen Roadmap. CSIRO, Australia.
[13] "Opportunities for Australia from Hydrogen Exports", ACIL Allen Consulting for ARENA, 2018.

be more expensive than a switch to renewable gas in some circumstances. Several studies[14,15] have shown that electrification requires a significant expansion of both the generation capacity and the network infrastructure, which carries a significant cost. A study by the American Gas Association[16] showed that the cost of emissions reduction through electrification in the residential sector was as high as $US806 per tonne of CO_2 abated. A similar outcome was found by the Australian Gas Infrastructure Group[17], which showed that the cost of decarbonisation of heating in Victoria via electrification was 40% more expensive than using renewable hydrogen. Shifting the energy content of all gas demand to electricity networks could require investments of greater than $30 billion in electricity network upgrades[18].

At the same time, electrification would see the country walk away from its existing investment in the gas transmission and distribution infrastructure. Instead, gas infrastructure could play a crucial role in decarbonising the industrial, transport and building sectors[19].

A range of sustainable routes to renewable gas are available. Figure 3 provides an overview of the pathways to the production, distribution and end use of renewable gas. It is not within the scope of this report to examine technical and economic aspects of these pathways in detail, including questions of the economic viability of the renewable gas pathways compared to other decarbonisation routes. We simply note that there is increasing recognition of the opportunity for innovation in biogas and hydrogen as a fuel replacement for existing natural gas. Whether these fuels are zero-emissions largely depends on how they are generated[20]. Currently the cleanest way to generate hydrogen is via electrolysis as a way of using up surplus wind and solar power, and the impact of biomass gasification's depends on the source of the biomass stock, and whether it is a residue or energy crop.[21]

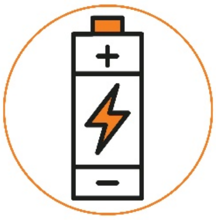
A decarbonised gas network has several applications with varying degrees of competitiveness, we summarise their benefits in the table below.

[14] "U.S. National Electrification Assessment", Electric Power Research Institute, April 2018
[15] Mai Trieu et al, "Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-71500, 2018 (https://www.nrel.gov/docs/fy18osti/71500.pdf)
[16] "Implications of Policy-Driven Residential Electrification", An American Gas Association Study prepared by ICF, July 2018.
[17] "Using hydrogen to decarbonise natural gas consumption in Victoria is 40% less expensive than full electrification", Australian Gas Infrastructure Group, August 2018
[18] "Decarbonising Australia's Gas Networks", Deloitte Access Economics, November 2017
[19] https://www.energy.gov.au/sites/g/files/net3411/f/energy-update-report-2017.pdf
[20] ARENA, https://arena.gov.au/about/funding-strategy-investment-plan/renewables-for-industrial-processes/, accessed 3 June 2017
[21] Balcombe et al, 'The carbon credentials of hydrogen gas networks and supply chains' *Renewable and Sustainable Energy Reviews* 91 (2018) 1077-1088.

Table 1: Deriving benefits from renewable gas networks

Target application	Current scenario	Future scenario
Deliver lower emissions heating for households and industries 	Approximately 45% of the natural gas used in Australia is used for heating in the manufacturing industry, in buildings and in homes[22]. Therefore, the decarbonisation of heating would make a meaningful contribution to reducing Australia's emissions.	Biomethane can be used without restrictions for heating. The use of biogas or biomethane to replace natural gas can lead to significant reductions in greenhouse gas emissions. Best practice production allows over 80% greenhouse gas savings compared to fossil fuel alternatives[23]. The substitution of up to 10% of natural gas with hydrogen can be done without any changes to the gas distribution networks and to end use equipment. In the long term, networks could be fully decarbonised using 100% hydrogen.
Provide inter-seasonal storage and balancing for renewable electricity grids 	As our electricity sector decarbonises and variable renewables gain ground, our grid will require more sources of reliability. Hydrogen is a possible means of providing long-duration, inter-seasonal storage, beyond the minutes, hours and days that could be met by batteries, or the limited locations where pumped storage could work[24]. It could be used to absorb excess renewable output, balance and smooth peak power production and demand, and satisfy greater energy demand.	By transforming renewable electricity to hydrogen through electrolysis, hydrogen can be stored in existing gas networks (up to 10%), made into methanol or some other higher value liquid fuel. It can provide large loads of reliable energy required by energy intensive industries, and used in our energy, chemical and industrial systems.
Supply the chemical manufacturing industry 	Hydrogen is used in a wide range of industries and applications, ranging from removing sulphur from fuels when refining oil, which are intermediates in the production of plastics and pharmaceuticals, to making ammonia for fertilisers and mining explosives.	In time, Australia's gas infrastructure is upgraded to transport higher proportions of hydrogen, and the hydrogen is used in industrial applications.

[22] Australia's Energy Statistics – total natural gas consumption less gas used for power generation and by the oil and gas industry (where it is predominately used for motive power).
[23] ***http://task40.ieabioenergy.com/wp-content/uploads/2013/09/t40-t37-biomethane-2014.pdf***
[24] See Hydrogen for Australia's Future, pg38 at https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf

	Iron and steel production which currently use coal could be replaced with hydrogen.	Pure hydrogen could be stored in salt caverns[25] and transported to industrial plants using upgraded pipelines.
Supply hydrogen fuel cell electric vehicles 	Fuel-celled vehicles (FCEV) are emerging although lagging battery electric vehicles (BEV) in the light vehicle market, where BEV are close to being cost competitive. However, the weight and size of batteries that are necessary for long transport systems (such as ships, trains, and long-distance busses and trucks) makes the case for batteries in heavy vehicles much less compelling.	Hydrogen FCEVs are being recognised as a solution to decarbonising the transport sector, particularly for heavy vehicles.
Supply hydrogen fuel cell heating at a residential and commercial level 	Homes and industries in remote locations, such as islands, with no connection to central grids, or are connected to a weak central grid still require storage solutions that offer resilience. Typically, these off-grid systems rely on diesel generation for electricity and often need storage beyond the time that batteries can readily provide.	Hydrogen fuel-cells could be used in an off-grid power generation system to meet large electrical loads and providing storage for wind or solar generators.
Hydrogen export 	Nations like Japan and South Korea that import most of their energy are looking to reduce their CO_2 emissions by importing clean hydrogen, produced with renewable energy. Yet, there are no large-scale exporters of clean hydrogen.	This is a significant opportunity for Australia, given our ample renewable energy potential and the dependence of our economy on our energy exports. Existing gas networks could be upgraded to become pipelines that transport hydrogen to the export facilities.

[25] https://www.storengy.com/countries/unitedkingdom/en/ourcompany/news/167-eti-study-on-use-of-salt-caverns-to-store-hydrogen-now-released.html

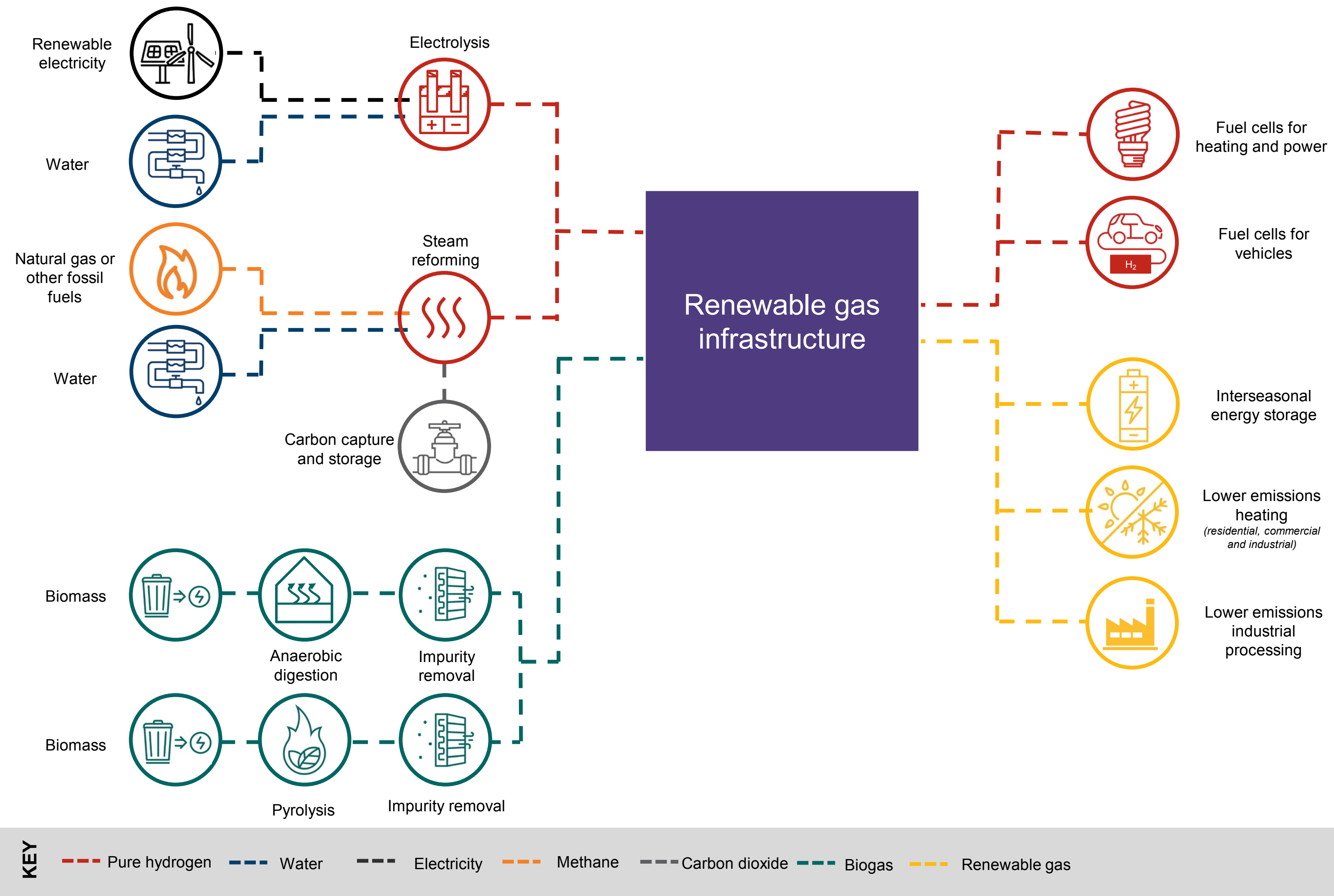


Figure 3: Production and consumption pathways for low-emissions gases

2.2. Current policy landscape in Australia

This section looks at the policy initiatives that are currently in operation and which could be adapted to promote the contribution of renewable gas to Australia's decarbonisation journey. We also discuss how some policy measures have actively discouraged the development of a renewable gas industry.

The Australian Government has the prime role in meeting our international commitments including our agreed emissions reduction target. To fulfil our climate obligations, the emphasis has been on renewable power generation through the renewable energy target (RET) as the electricity sector accounts for 35% of Australia's emissions[26]. But as Table 12 outlines, the RET is nearing its end date and the Safeguard Mechanism is the key policy instrument that will drive abatement to 2030.

The Australian Government also supports the two major agencies that provide financial support for decarbonisation activity and which could support initiatives linked to the renewable gas network. These are outlined in Table 3.

Some state level policies in Australia can provide a more specified direction on the pathway to a low emissions future compared to current federal policies. Relevant policies are described below.

[26] Australian Greenhouse Emissions Information System (***http://ageis.climatechange.gov.au/***)

Table 2: Australian Government policies to drive reductions in Australia's emissions

Policy	Aim	Features and the extent to which low emissions gas is supported
Safeguard Mechanism, the Emissions Reduction Fund (ERF) and the Carbon Farming Initiative (CFI) methods[27]	These are the elements of a broad policy that essentially creates a carbon trading scheme in Australia.	These act through the creation and surrender of Australian Carbon Credit Units (ACCUs). ACCUs are created for undertaking proscribed activities and demonstrating to the Clean Energy Regulator (CER) that emissions abatement has occurred due to the activity. The ERF established contracts between a party undertaking a proscribed activity and the Commonwealth for the purchase of ACCUs over a ten-year period. The ERF therefore created a market for ACCUs. Under the Safeguard Mechanism, large greenhouse gas emitters purchase and acquit ACCUs if their emissions exceed a baseline. The volume of ACCUs purchased is currently small but is anticipated to grow as baselines are adjusted to reflect Australia's emissions reduction commitment. On 5 March 2019 the federal government announced a 'Climate Solutions Package'. This includes a $2 billion top-up and expansion of the Emissions Reduction Fund (ERF) over 10 years from 2020, rebadged as the Climate Solutions Fund.[28] The use of low emissions gas is supported by a couple of the proscribed abatement methods: the Industrial Electricity and Fuel Efficiency method and the Landfill and Alternative Waste Treatment methods. However, these methods do not readily support the use of low emissions gas transported in a natural gas pipeline.
Renewable Energy Target (RET)	Federal policy to ensure at least 20%of Australia's electricity comes from renewable sources by 2020.	The RET requires electricity retailers to surrender to the Clean Energy Regulator (CER) a volume of renewable electricity certificates (LGCs) that is proportional to the quantity of electricity that they sell. The proportion is derived from the target of 33.5TWh of renewable electricity in 2020.[29] The RET expires in 2020 although a certain number of LGCs will need to be surrendered until 2030. It is a market-based scheme with trading of LGCs and we expect that the price of LGCs will fall significantly after 2020.

[27] The Carbon Farming Initiative (CFI) methods are the methods by which ACCUs are created. The use of the term CFI reflects the enabling legislation that established the methods and does not mean that they only relate to land-based methods. They are sometime referred to as ERF methods.
[28] https://www.environment.gov.au/climate-change/climate-solutions-package
[29] There are other elements of the RET such as the support for small scale generation (rooftop solar PV) and various exemptions for specific industries.

Policy	Aim	Features and the extent to which low emissions gas is supported
		Note that LGCs will continue to be created by suitable renewable energy projects but the market size for the LGCs will be fixed at the 2020, 33.5 TWh target. Electricity generated from suitable low emissions gas consumed on site is covered by the RET and the operators of these facilities were issued LGCs. For instance, many landfill gas capture systems include on-site generation for export to the grid.

Table 3: Funding agencies supporting the transition to a zero-carbon world

Agency	Aim	Summary
The Australian Renewable Energy Agency (ARENA)	ARENA supports the development of local renewable energy technology by providing funding to researchers, developers and businesses that have demonstrated the feasibility and potential commercialisation of their project. Both biomass and hydrogen are currently supported by ARENA's R&D funds.	ARENA works through investment priorities, which reflect major national energy challenges and opportunities. The current priorities are delivering secure and reliable electricity, accelerating solar PV innovation, improving energy productivity and exporting renewable energy. The use of low emissions gas for purposes other than power generation falls within the scope of improving energy productivity, where ARENA is seeking: • "Accelerated improvements in energy productivity and adoption of renewable energy by industry, particularly applications with a significant share of emissions. • Innovative building technology and designs to increase energy productivity of the built environment. • Improved energy productivity in the transport sector, including electrification and fuel switching. • Opportunities to improve energy productivity and integrate renewable energy by optimising value chains across sectors."[30]

[30] "Innovating Energy, Arena's Investment Plan" 2017

Agency	Aim	Summary
		Earlier ARENA initiatives saw the funding to accelerate the development of a potential renewable energy export supply chain centred around hydrogen and related carrier materials[31], studies into hydrogen for export[32] and renewable energy options for industrial gas users[33]. ARENA is also a supporter of ATCO's renewable hydrogen micro-grid in Jandakot, WA. ARENA has also support bioenergy projects although most have focused on the use of biomass in general and have skipped over opportunities for biogas to support renewable gas. For instance, the study into alternatives to natural gas[33] made no mention of renewable gas as substitute for natural gas that does not require major changes to gas using equipment. Most options in the report discussed require significant investment by the gas user (such as conversion to biomass boilers or installation of solar thermal units).
Clean Energy Finance Corporation (CEFC)	The CEFC is responsible for investing $10 billion in clean energy projects on behalf of the Australian Government. It invests in renewable energy, energy efficiency and low emissions technologies. The CEFC's Clean Energy Innovation Fund is also available to invest in early-	The CEFC is available to support low emissions gas projects, and it has already invested in several bioenergy and waste management projects. For instance, CEFC invested $30 million with Resource Co to build two new plants that transform commercial and industrial waste into Processed Engineered Fuel. They also supported investments in systems to better manage landfill gas. To date, the focus has been on solid fuels or fuels for power generation. However, their study into the domestic bioenergy and energy from waste market[34] did point to applications where gas generated from waste is used for heating applications.

[31] https://arena.gov.au/funding/programs/research-development-program/hydrogen/
[32] "Opportunities for Australia from Hydrogen Exports", ACIL Allen Consulting for ARENA, 2018.
[33] "Renewable Energy Options for Australian Industrial Gas Users", IT Power for ARENA, 2015
[34] "The Australian bioenergy and energy from waste market", CEFC, November 2015

Agency	Aim	Summary
	stage clean energy companies.	

Table 4: The policy contribution of the state and territory governments

Policy measure	Summary
Energy efficiency schemes	NSW, the ACT, Victoria and SA operate schemes that promote the implementation of measures that reduce energy consumption. Most are market-based schemes with tradable certificates that are created when approved measures are implemented. Energy retailers must deliver a quantity of certificates to state regulators at the end of each year. The volume of certificates to be surrendered is proportional to the volume of electricity sold by the retailer. These schemes have a strong bias towards lowering electricity use but do not exclude gas, and there is some for the phasing out of electric resistance space and hot water heating and their replacement by gas heating. Approved methods include measures that promote upgrading to more efficient gas appliances. Reflecting its zero emissions electricity, the ACT scheme is now encouraging the electrification of heating. A project to introduce low emissions gas for heating at industrial sites could generate certificates in the NSW and Victorian schemes through their general project-based methods. However, the injection of low emissions gas into the gas network would struggle to meet the requirements of the energy efficiency schemes.
Policies targeting the use of waste as a fuel source	In NSW, the Energy to Waste Policy (2015)[35] facilitates the use of waste fuels for energy recovery via thermal treatment (combustion, thermal oxidation, thermal or plasma gasification, pyrolysis, and torrefaction). Eligible fuels have been defined as primarily forms of organic matter (e.g., biomass from agriculture, forestry residue, wood waste, green waste). With anaerobic digestion being defined as outside the scope of the policy, an opportunity is lost as organic waste materials could be used for biogas production.

[35] https://www.epa.nsw.gov.au/~/media/EPA/Corporate%20Site/resources/epa/150011enfromwasteps.ashx

Policy measure	Summary
	The Victorian Metropolitan Waste and Resource Recovery Plan[36] is the most targeted policy to encourage the recovery of energy from organic waste in Melbourne with the plan setting ambitious targets of minimising up to 600,000 tonnes of organic waste annually. The plan is aligned to Melbourne's infrastructure needs to effectively manage and recover energy from waste. The plan however is seemingly more driven towards minimising the need for landfills and fugitive methane emissions rather than incentivising the production of biogas and so once again allows the market to determine the most feasible way of energy recovery from waste. The Victoria Waste to Energy infrastructure fund[37] aims to incentivise the use of waste as a fuel and redirect waste from the landfill. The fund has been used to fund several bioenergy projects but only a few Victorian waste to energy facilities feed electricity to the grid or supply heat/fuel to other energy users[38]. This suggests that there continues to be either regulatory, financial or technical factors which limit the production of biogas to be exported to the grid.
Policies driving the renewable energy mix	The NSW Renewable Action Plan (2013)[39], SA Renewables (2017)[40], Powering Queensland Plan (2017)[41]and the Victoria Renewable Energy Action Plan (2015)[42] are all ambitious, detailed plans to increase renewable energy generation in NSW, SA and Victoria respectively. A common theme across these plans include the need to fund and promote innovation in renewable energy and low carbon technologies. Both SA Renewables and the Victoria Renewable Energy Action plan also highlight the need to support the integration of energy storage solutions with a focus on battery storage. SA maintains the most ambitious plan as the only policy within Australia which focuses on developing a Hydrogen Road Map for SA. The state has outlined a vision in which it sees the integration of hydrogen into gas networks. This has led to SA developing objectives to encourage the uptake of H_2 vehicles, supporting research and attracting investment in hydrogen production using renewable energy amongst other initiatives. The SA roadmap also highlights some of the regulatory drivers need to be identified and considered such as the Dangerous substances Act, Environmental Protection Act 93, Gas Act 97, Electricity Act 96, National Resource Management Act 2004, Development Act 1993 and Australian and international standards related to gas in pipelines.

[36] https://mwrrg.vic.gov.au/about-us/strategic-framework/the-metropolitan-waste-and-resource-recovery-implementation-plan/
[37] http://www.sustainability.vic.gov.au/About-Us/Grants-and-Funding/Waste-to-energy-infrastructure-fund
[38] https://s3.ap-southeast-2.amazonaws.com/hdp.au.prod.app.vic-engage.files/9415/0897/9363/Turning_waste_into_energy_-_Final.pdf
[39] ***https://www.energy.nsw.gov.au/renewable-energy/renewable-energy/renewable-energy-action-plan***
[40] http://www.renewablessa.sa.gov.au/
[41] https://www.dnrme.qld.gov.au/energy/initiatives/powering-queensland
[42] https://www.energy.vic.gov.au/renewable-energy/victorias-renewable-energy-action-plan

Policy measure	Summary
	Queensland has allocated funds for a feasibility study into producing hydrogen from electricity derived from solar PV. The Hydrogen Energy Supply Chain project in Victoria will contribute to proving supply chain logistics, including moving hydrogen from points of production to export terminals, compression and liquefaction, bulk transportation and offloading.

In looking at the policies listed in Table 2 to Table 4 we draw the following conclusions:

- We see policies that operate at a high level to promote the creation of markets to drive outcomes. This has been clearly demonstrated in the performance of the state-based energy efficiency trading schemes. Signs are emerging that the Safeguard Mechanism will operate in the same manner. In 2017 some covered facilities exceeded their Safeguard Mechanism baselines which required them to acquire and acquit to the Regulator some 450,000 ACCUs. The growing role of the Safeguard Mechanism as the only policy in Australia specifically aimed at reducing national emissions provides a platform for initiatives to support the development of renewable gas.
- We also noted that the funding bodies established by the Australian Government have provided support for renewable gas to date although not specifically a renewable gas network. The research work by ARENA (and others) on the hydrogen economy has been interesting as this work has a bias towards the export opportunities offered by hydrogen without giving a fair account to the role that renewable hydrogen could play in reducing Australia's emissions.
- State government policies offer a range of possibilities to support renewable gas but in some cases, they work against its promotion.

2.3. Missed opportunities – how existing policies work against the use of renewable gas

Despite support from industry and academia, the lack of a cohesive policy framework that encourages hydrogen and biogas products is a key barrier to market activation. For example, Australia is the only OECD country that hasn't implemented a large-scale scheme to manage its waste via sustainable methods, for example to create biogas. As Australia's Chief Scientist's Hydrogen Strategy Group[43] noted, industry is investing but is held back by both the lack of secure supplies and markets.

> *"Elements such as electricity generation, carbon sequestration, pipelines, electrolysers, refuelling stations and regulations depend on progress in the others. The federal, state and territory governments can provide the leadership to help these interdependent players make collective progress"*
>
> Hydrogen for Australia's future

In contrast, many countries have committed to supporting a decarbonisation of gas networks and fuels which then in return, create a 'market pull' for investments. More detail can be found in Section 3. The barriers that must be overcome in Australia to support the uptake of renewable gas are examined in the following section.

Issue to address: State based policies encourage the use of renewables but not the diversification of renewable energy sources

Support for a renewable energy mix is favoured towards the low-cost energy solutions which have the greatest investment potential. Like federal policies, state-based policies are choosing to let the market decide the renewable energy mix. The result has been the rapid development of solar and wind.

With the increase in solar and wind generation, policy makers have recognised the need for energy storage solutions to support these variable energy sources. This has resulted in the purchase of batteries such as the Hornsdale Power Reserve. Hydrogen storage offers an alternative to batteries with the significant potential advantage of providing for a greater volume of energy stored and therefore could enable a more diverse energy mix.

Issue to address: State based renewable energy and gas plans highlight the requirement for a more secure and reliable provision of natural gas.

We also see some state energy plans incorporating objectives to maintain a secure gas supply. The implication is that natural gas is needed to support the movement towards renewable energy and will continue to be a part of Australia's energy mix for some time. The role of gas can be supported into the future if its associated emissions fall with the injection of hydrogen or biogas. With the Powering Queensland Plan choosing to ensure secure gas supply through issuing additional gas tenure for supply to the Australian market, investment in gas infrastructure is likely to continue.

[43] https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf

Issue to address: Policies in Australia encourage the diversion of organics from landfills to minimise fugitive methane emissions, but do not directly support the use of biogas in the gas networks

Some policies (e.g. the Renewable Energy Target) in Australia support the production of bio-energy from waste. The term bio-energy has been loosely defined and encompasses forms of thermal and biological organic waste treatment which can lead to production of electricity and heat. The technologies available to produce bio-energy result in competing uses for organic waste which do not always lead to the production of bio-gas.

Bio-energy is encouraged as an additional fuel for renewable energy generation. Ambiguity however remains on how this energy can be distributed and incentives outside of government-based funding to set up projects remain weak. There are currently no biogas projects feeding into the gas grid, the uptake and operation of biogas should be reviewed to understand the limitations. As demonstrated in France, supportive policy settings can lead to an increase in biogas projects that feed into the gas grid. In the last 5 years, France has gone from 0 to 59 projects with a further 290 on the waitlist to commence injection into the grid.

Finally, gas legislation does not directly prohibit the injection of bio-methane into gas pipelines[44], with the Victorian Gas Safety Act 1997 indicating that gas needs to comply with the AS 4564[45]. Should the right incentives be made available to biogas producers, this could promote the injection of bio-methane into pipelines.

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[44] This standard has been developed to encompass the transmission and distribution of natural gas from biogas and outlines compositional specifications that need to be met prior to injection (i.e. the conversion of biogas to bio-methane).
[45] https://ablis.business.gov.au/service/vic/australian-standard-as-4564-specification-for-general-purpose-natural-gas/24426

3. International policy landscape

In the earlier parts of this report, we have described the gap between Australia's projected greenhouse gas emissions and the nation's commitment to reduce emissions. We then explained how the decarbonisation of heating is essential if Australia is to meet its commitment and how renewable gas is a cost-effective route to zero emissions heating, as well as playing a role in decarbonising transport. Australian governments have constructed a policy landscape that supports aspects of the journey to a low emissions future but that misses a key part of that journey which is the renewable gas network. In this section, the report looks at the international policy landscape, looking for examples that show how targeted government initiatives can drive investment in renewable gas networks.

Over 30 case studies were collected on various forms of incentives for decarbonising gas by biogas and hydrogen injection, including those that encourage the overall end-use of low emission gases. Common elements are summarised in Table 6 below. Full collection of the case studies is attached in Appendix A.

From Table 6, we observe six categories of policy incentives that aim to drive low-emission gas production and integration into the gas networks, and we have assigned the international policies to these categories. The categories are:

1. Integration of low emissions gas policies into renewable energy incentives
2. Technical standard setting and guidance
3. Goals and targets
4. Feed in tariffs
5. Financial incentives (funds, grants, subsidies)
6. Other financial instruments (Direct investment, Private public partnerships)

We conducted a qualitative evaluation of examples of international policies that incentivise low-emissions gas production and integration against the Australian context and have included the conclusions from the evaluation in Table 6. We employed the criteria set out by the International Renewable Energy Agency (IRENA) in its policy brief 'evaluating policies in support of the deployment of renewable power'[46]. IRENA's framework for performance evaluation against policy objectives are set out and defined below.

Table 5: How we assessed the international policies

Criteria	Icon	What it means	If it meets the criterion	If it doesn't meet the criterion
Effectiveness	●	The extent to which intended objectives are met, for instance, the actual increase of output of renewable	The policies have achieved its intended objectives. For most policies we found that they were effective.	The policies did not achieve the intended objectives

[46] http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/Evaluating_policies_in_support_of_the_deployment_of_renewable_power.pdf3

		electricity generated or shares of renewable energy in total energy supplies within a specific period.		
Efficiency	●	The ratio of outcomes to inputs, for example, renewable energy targets realised for economic resources spent, mostly measured at one point of time (static efficiency). This is sometimes called the cost-effectiveness	The policies had a positive ratio with lower costs and higher benefits than others. Where possible, we found secondary academic analysis of the cost-benefit ratio. In general, we found public financing in the form of investment, guarantees or loans to be less efficiency than price driven regulations such as FiT.	The policies may have incentivised some activity but have not resulted in many completed projects.
Equity	●	The incidence and distributional consequence of a policy, including dimensions such as fairness, justice, and respect for the rights of indigenous peoples	The policy levels the playing field for either the technology provider, or for consumers of lower socio-economic class.	(n/a) The policy had no bearing on equity for either providers or consumers
Institutional feasibility	●	The extent to which a policy or policy instrument is seen as legitimate, able to gain acceptance and able to be adopted and implemented	The policy instrument's legitimacy is not controversial in Australia	The policy instrument's legitimacy has been controversial in the past or is currently controversial in Australia
Replicability	●	The extent to which successful policy can be reproduced by another country. This can only be judged by an analysis of factors that made a policy successful given the context and what this	Australia has similar technical and policy frameworks that will allow the policy to be replicated	Australia's technical and policy framework is drastically different and replicating the policy will be difficult

		might imply under different condition		

Our evaluation is summarised in Table 6, where it indicates (through the icons in the previous table) where policies meet the respective evaluation criterion. Where specific existing literature exist on the effectiveness and efficiency of certain policies, we have inserted their reference in the footnotes.

Table 6: Snapshot of international policy drivers

Goal	Policy drivers	Case studies	Commentary	Evaluation
Deliver lower emissions heating for households and industries	Integration of low emission gas policies with renewable energy incentives[47]	• Denmark has set a target of meeting at least 50% of their energy demand with renewable energy and being a low emission society by 2050. With this target being directed at the entire energy supply for electricity, heating, industry and transport, innovation and partnerships are being promoted across all sectors. • The Green Gas Certification Scheme in Ireland is aimed at facilitating biomethane trading for renewable heat and transport markets	Market factors are left to determine which renewable option is most cost effective and governments may choose provides additional support in the industries which they see the most promise. With governments directing a large proportion of funding towards the development of demonstration plants and subsidies to make hydrogen more cost effective, it can be expected that hydrogen uptake will form a greater proportion of the renewable energy uptake soon.	Effectiveness Efficiency Equity Institutional feasibility Replicability
	Technical standard setting and guidance	• Grid injection enables the biomethane to be stored at lower cost and allows its use at the places where it is needed. The European Committee for standardisation has set up a technical committee to harmonise standards for injection into the natural gas grid to support the development of biomethane.[48] • In 2014, Germany released a renewable energy law that reduce the use of energy	For the hydrogen and biogas industry to gain trust and support of politicians and consumers, it must demonstrate it is sustainable and safe. In the case of biomass, sustainability standard setting is crucial to capture the synergy between waste management and decarbonising gas networks.	Effectiveness Institutional feasibility Replicability

[47] https://doi.org/10.1016/j.renene.2018.03.006
[48] https://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:853454&cs=174897F88F3A6DE65FFC3CA2671DBF515

	crops for biomass to drive refocus on waste-derived feedstocks. • Safe levels of hydrogen injection into the network is currently being tested. The Finkel review suggest 10% injection into the Australian gas network is possible. A handful of pilot and demonstration projects exist in Europe that explore this approach.	In the case of hydrogen, safety standards and frameworks for injection should be tested and researched.	
Goals and Targets[49]	• Denmark has a target to supply the gas grid with 100% green gas by 2035 • As a part of Japan's hydrogen society, there are goals to supply 1.4 million hydrogen fuel-cell heating units to homes.	The success of policy targets depends largely on whether it is fit for purpose. Denmark's target has helped rapidly increase the production of biogas, where it is expected to more than triple from 2012 to 2020. In the future, it is expected that a greater share of the produced biogas will be upgraded to biomethane and delivered into the natural gas grid.[50] Whereas Japan's targets for achieving a hydrogen society have faced additional competition from renewable electric alternatives with the sharp decline in the price of solar power and electric vehicles.	● Effectiveness ● Equity ● Institutional feasibility ● Replicability
Feed in tariffs into the gas network	• In France, Denmark, UK and Netherlands, a feed-in subsidy covers the difference between production costs and income.	The UK provides a good example of how government policy can stimulate rapid growth in biomethane upgrading. In 2011, there was just one biomethane plant in the country. The introduction of Carbon Price Support from 2013,	● Effectiveness ● Efficiency

[49] Patterson, T., Esteves, S., Dinsdale, R. and Guwy, A. (2011). An evaluation of the policy and techno-economic factors affecting the potential for biogas upgrading for transport fuel use in the UK. Energy Policy, 39(3), pp.1806-1816.
[50] https://www.ieabioenergy.com/wp-content/uploads/2018/04/green_gas_web_end.pdf

	• A feed-tariff for heat on top of gas price. This support scheme is applied in the UK and Denmark.	as well as a Feed-In Tariff per kWh of biomethane injected into the grid under the Renewable Heat Incentive, resulted in 20-30 new plants per year coming onstream between 2014 and 2016, and it is estimated that around 100 new plants could be in operation before 2018[51] The UK Renewable Energy Association points out that there is a need for clarity on policy beyond 2020/21 if major new projects are to be planned	Equity Institutional feasibility Replicability
Financial incentives (funding, grants. subsidies)	• In France, the Heat Fund supports the use of heat generated from renewable sources while the Waste Fund provides direct subsidies for biogas production investments. A reduced VAT rate (5.5%) is applied to networks that supply heat mainly produced from renewable or recovered energy.[52] • In Austria and Sweden, biogas and biomethane production are sometimes incentivised by reduced interest rates on loans or the provision of a grant to cover a proportion of the investment	Financial incentives have increased the biogas share in biomass heating from only 1% in 2005, to 3.7% in 2015. The leading countries in the use of biogas heat in 2014 were Germany, Italy and Denmark, while important growth is expected in France, UK, and the Netherlands.[53]	Effectiveness Equity Institutional feasibility Replicability

[51] UK REA presentation to Biosurf, Paris, November 2016. See http://www.biosurf.eu/wordpress/wpcontent/uploads/2015/06/BIOSURF_Roadmap-for-UK_REA-RM-additions-GH.pdf
[52] https://www.ieabioenergy.com/wp-content/uploads/2018/04/green_gas_web_end.pdf
[53] ***https://doi.org/10.1016/j.renene.2018.03.006***

Provide inter-seasonal storage and balancing for renewable electricity grids 	Financial incentives (funding, grants. subsidies)	• In Germany, a €200 million grant allocated to addressing the intermittency challenges associated with reaching 80% renewable energy penetration by 2050 has led to the operation of a 150kW power to gas demonstration plant. The plant uses hydrogen produced from 2MW wind power to be fed into the gas distribution network. Federal departments have also launched an Energy Storage Funding Initiative. The scheme is divided into funding four key groups: electrical storage, material storage, thermal storage and overarching themes • H2V PRODUCT commissioned Nel to build a 100MW electrolyser project (using 40 electrolysers) to produce renewable hydrogen for injection into the natural gas grid in France. The plant cost $370M and will be finished 2020. Should demonstration be successful, there are plans for six other such projects in France.	In new technologies such as injection of hydrogen into the gas network, Innovation in Germany, Japan and China are largely driven by generous research and development (R&D) grants and funding However, what we see in China, Germany and Japan are funding programs that are driven by a long-term vision for the transformative use of hydrogen. They are set with clear guideline and targets by the government.	Effectiveness Equity Institutional feasibility
Hydrogen for export 	Other financial instruments (Direct investment)	A consortium of Japanese energy and infrastructure companies have partnered with Australian government and industry to create a hydrogen energy supply chain by investing A$396 million in Australia's hydrogen production.	The cases for direct investment into hydrogen has been unique to Japan, which has chosen the hydrogen path of energy transition over renewable electric path. The success and commercial application of such investments is yet to be tested. The project has been criticised for its conversion of coal to hydrogen, because the pilot program	Effectiveness

			does not include carbon capture and storage.[54] While it may not have been practical to include CCS on this pilot scale project, deployment at commercial scale will require CCS to deal with the CO_2 emissions associated with the conversion of coal to hydrogen.	
Supply hydrogen fuel cell electric vehicles (FCEVs) 	Goals and Targets	• Japan has ambitions targets 800,000 hydrogen FCEVs by 2030, 900 refuelling stations by 2030. • Similarly, France has announced a EUR 100 M investment, targeting hydrogen use in vehicles and charging infrastructure. • Denmark launched the HyFive project (a partnership between vehicle manufacturers, research institutions, network organisations and government, aimed to promote hydrogen and hydrogen FCEVs in Denmark.[55]	Realistic targets need to be set, with consideration of other market factors which may restrict industries from reaching these goals. Hence, in the case that the technology is not as mature or not yet as cost effective as other technologies, there needs to be additional support from the government in the forms of subsidies or grants to reach specified targets	Effectiveness Efficiency Institutional feasibility
	Financial incentives (funding, grants. subsidies)	• Japan allocated JPY 4.6 billion towards subsidies for the construction of hydrogen fuel station in FY 2013. This led to the successful uptake of 19 refuelling commercially ready stations with a hydrogen supply capacity of 27 kg hydrogen per hour • At Governor Jerry Brown's direction, the state of California is spending more than $2.5 billion in clean energy funds to accelerate the sales of hydrogen and battery vehicles. $900	Direct financial incentives have been effectively in driving investment from the private sector, however the efficiency of investment requires quantitative analysis which outside the scope of this report.	Effectiveness Equity Institutional feasibility

[54] https://www.smh.com.au/business/the-economy/reality-check-on-a-half-billion-dollar-brown-coal-hydrogen-project-20180412-p4z98n.html
[55] https://www.iea.org/publications/freepublications/publication/EnergyPoliciesofIEACountriesDenmark2017Review.pdf

		million earmarked to complete 200 hydrogen stations. There are also fuel incentive and vehicle subsidies for consumers.		Replicability
Supply the chemical manufacturing industry 	Financial incentives (funding, grants. subsidies)	Biogas and biomethane production are sometimes incentivised by reduced interest rates on loans or the provision of a grant to cover a proportion of the investment (e.g. Austria, Sweden).	Direct financial incentives have been effectively in driving investment from the private sector, however the efficiency of investment requires quantitative analysis which outside the scope of this report.	Effectiveness Institutional feasibility
Supply hydrogen fuel cell heating at a residential and commercial level 	Other financial instruments (Private- public partnerships)	Public-private partnerships increase the size of financial and physical resources available for a project and reduces the associated risks and burden associated with exploring a new technology in the private sector. The Fuel Cell and Hydrogen Joint undertaking in the EU is an example of a collaborative project between industry, the scientific community, government authorities and the wider community to research, develop and deploy strategies which would accelerate the uptake of hydrogen technologies	The success of industry partnerships is limited to industry goals complementing government goals. Industry will be driven by financially rewarding goals and failure of the technology to develop could deter industry interest	Effectiveness Efficiency Equity Institutional feasibility Replicability

	Financial incentives (funding, grants. subsidies) [56]	• New York includes all fuel cell systems in their Renewable Portfolio Standard and in the new Clean Energy Standard (released in 2016) and provides a sale and use tax exemption for fuel cell systems and service, and hydrogen gas. The state also has a microgrid program designed to ensure reliable power generation, even during adverse weather events. These programs are helping to fund growing numbers of fuel cells in the state. • The National Innovation Programme (NIP) Hydrogen and Fuel Cell Technology was founded in 2006. Between 2006 and 2016, the Federal Ministry of Transport and Digital Infrastructure and the Federal Ministry for Economic Affairs and Energy have granted funds totalling about EUR 710 million to approximately 750 research and development (R&D) projects. • Japan and South Korea have large expansion targets and investment for the development of fuel-cell plants.	Financial incentives help drive both private investment and speed of innovation by signally a strong political commitment. For example, the grant recipients in Germany for the NIP have, in turn, invested an additional EUR 690 million of their own resources into these projects and raised an additional EUR 20 million in third-party funding. After 10 years of program support, Germany's hydrogen and fuel cell industry standards are at a threshold to commercialise and scale.	Effectiveness Equity Institutional feasibility Replicability

[56] Chun, D., Hong, S., Chung, Y., Woo, C. and Seo, H. (2016). Influencing factors on hydrogen energy R&D projects: An ex-post performance evaluation. Renewable and Sustainable Energy Reviews, 53, pp.1252-1258

3.1. What Australia can learn from the international policy landscape

Where policies that encourage the use of hydrogen are going

While hydrogen production using electrolysis is an established technology, the goal of large-scale cost-effective electrolysis is yet to be achieved. Instead, policies focused on boosting the industry aim to address bridging the technology ‘valley of death’. These policies include

- Financial incentives such as large funding programs directed towards R&D subsidies for investments
- Ambitious goal and targets (for example specifying a percentage of renewable gas to be injected into the gas network)
- Direct investment

Work is also directed towards developing the supply chain and the technologies that allow renewable hydrogen to be transported from production facilities near sources of renewable energy to markets, especially in Asia. This has promoted several pilot projects around the world, which are illustrated in Figure 4 below. The case of hydrogen in Japan is examined in more detail below (Box 1).

Box 1 - Japan’s hydrogen-society roadmap

The Japanese Ministry of Economy, Trade and Industry (METI) has ambitious plans to transform its energy system based on hydrogen. There are three prongs to this energy transition, which can be summarised as:

1. Hydrogen for power generation
2. Hydrogen for transport with hydrogen fuel cell electric vehicles and refuelling infrastructure
3. Worldwide hydrogen supply chain

The Japanese Government has set the 2020 Tokyo Olympics as a tipping point for the hydrogen industry, announcing that just as the 1964 Tokyo Olympics left a legacy of high-speed trains, they will make the hydrogen society a legacy of the 2020 Olympics.

The Government has invested over $US1.2 billion on research and development, subsidies, government incentives and industry targets. Japan’s dependence on fuel imports for its hydrogen-society remain the biggest roadblock to its success. The creation of a global hydrogen supply chain will require the buy-in from other countries such as Australia, and the economic case for liquid hydrogen export is not yet proven.

The hydrogen strategy was only released Dec 2017. Japanese government and industry recognise achieving a hydrogen society will be a 30-year journey, with a broad range of technical and commercial barriers to overcome.

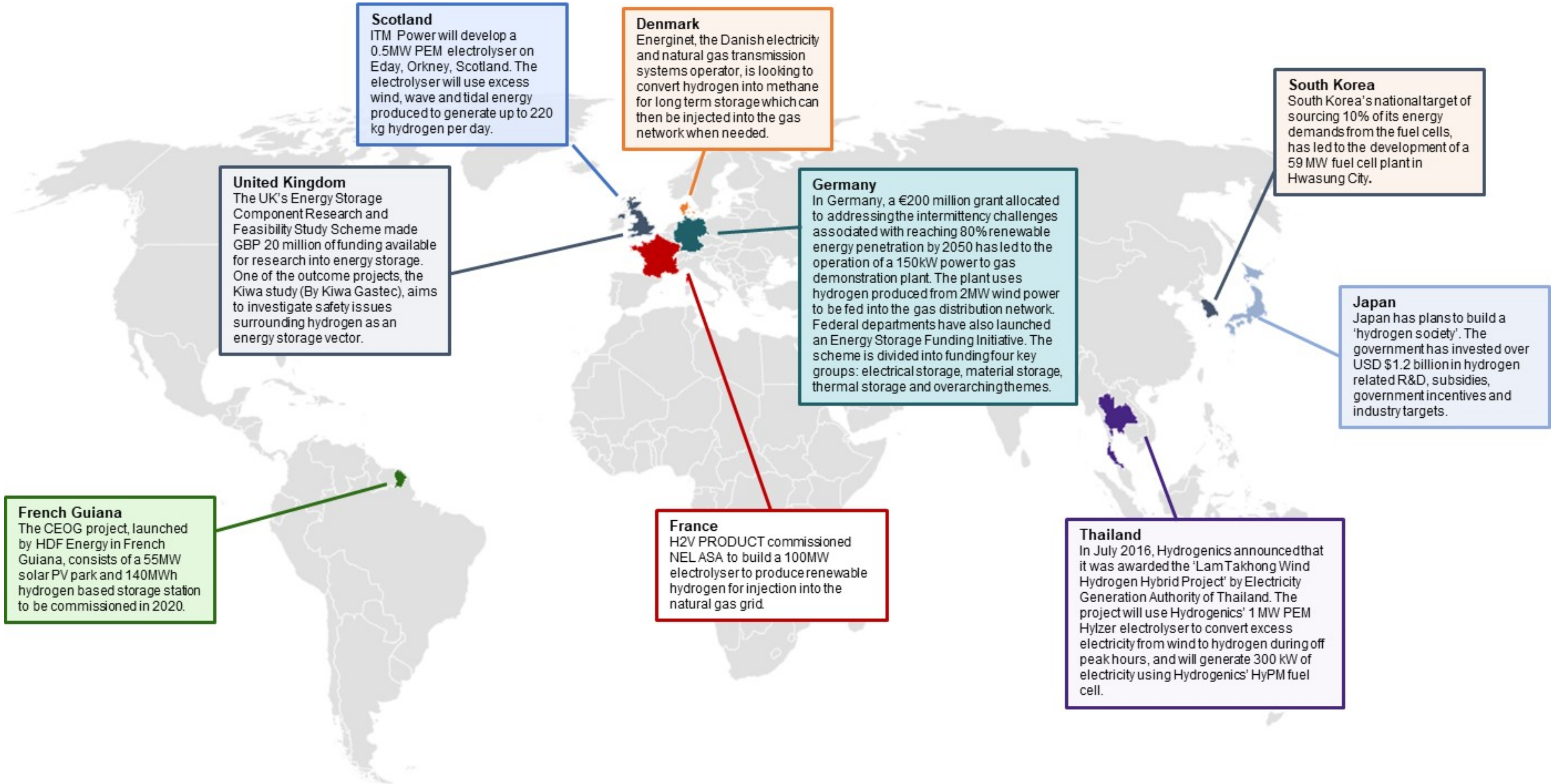

Figure 4: International hydrogen project map

Where policies that encourage the use of biogas are going

The production of biogas and biomethane from organic biomass and residues is a well-established process. Encouraging fuel-switching from natural gas to these renewably produced alternatives offers a relatively clear route to the decarbonisation of heating.

There are more than 300 biogas facilities injecting renewable gas into natural gas grids across Europe. They supply the order of 50 PJ of renewable gas to European gas users in 2015. From our survey, we see that biogas integration into the gas infrastructure in Europe has been driven by policy levers such as ambitious carbon reduction goals, integrated policies for renewable energy, renewable heating targets (which are often attached to feed-in-tariffs) and a cohesive technical standard.

Biogas upgrading is promoted in Europe with minor activity seen elsewhere (USA and South Korea), where policies have encouraged the development of biogas facilities and upgrading plants primarily using feed in tariffs to the electricity grid or gas network. In some cases, feed in tariffs are not seen as sufficiently attractive to promote the upgrading of biogas and biogas is being used for space heating near the production facility. Consequently, some jurisdictions have been scaling back feed-in tariffs in favour of other support mechanisms.

Attention is being paid to the technical and regulatory requirements for biogas including sustainable origins and the demands for gas quality for both injection into pipelines and end use applications. For example, the European Commission has issued several directives which standardise the injection of natural gas into pipelines (Directive 2009/73/EC) and promote the use of renewable sources (Renewable Energy Directive 2009/28/EC). The Renewable Energy Directive establishes in Article 17,18, 19 and Annex V Sustainability, criteria for biofuels and bioliquids.[57] These criteria control the source of biomass (e.g. no biomass from nature protection areas), require a minimum greenhouse gas emissions saving of 60% compared to a fossil fuels, and provide a methodology to calculate the greenhouse gas emissions involved in the biofuel production pathway.

Case studies for renewable gas

Energetics' review of international incentives for the biogas and hydrogen industry reveals two primary drivers. Countries with both ambitious carbon reduction targets and a higher reliance on natural gas for energy are leading proponents of decarbonisation of the gas network. For example:

- Germany aims to cut greenhouse gas emissions by 40% by 2020, and up to 95% by 2050. Because it has a large natural gas consumption, renewable energy targets and focus on decarbonising heating have led to biogas contributing 12% to the natural gas grid. In 2015, Germany was the European leader with a biogas production of 329 PJ and a share of 50% of total biogas production in Europe in 2015.[58] It has by a large margin, been the largest developer of biogas upgrade plants in Europe[59]
- Almost 50%of final energy consumed in the UK goes towards space and water heating in homes which is currently supplied by natural gas. Adaptation of its existing gas network with blending with lower carbon gas, and an eventual transition to a completely hydrogen

[57] "Optimal use of biogas from waste streams: An assessment of the potential of biogas from digestion in the EU beyond 2020", European Commission, December 2016
[58] https://doi.org/10.1016/j.renene.2018.03.006
[59] https://www.oxfordenergy.org/wpcms/wp-content/uploads/2017/06/Biogas-A-significant-contribution-to-decarbonising-gas-markets.pdf

network is both considered in its decarbonisation pathway.[60] Because UK has an advanced natural gas grid infrastructure and it currently heats 85% of homes, decarbonisation of the gas network was preferred as consumers are already familiar with the existing network.

Supportive policy settings can lead to an increase in biogas projects that feed into the gas grid. In the last 5 years, France has gone from 0 to 59 projects with a further 290 on the waitlist to commence injection into the grid.

We also found that East Asian countries that rely on fossil fuel imports are looking to hydrogen as a long-term fuel import. Japanese policy makers have proposed an energy roadmap for a 'hydrogen economy' and set the 2020 Tokyo Olympics as a major milestone for its delivery. The new government in South Korea has ambitious goals for reducing emissions and sees hydrogen as part of the solution.

Other nations are using policy levers to support the development of renewable gas networks, and they can offer some guidance to Australian policy makers who wish to see Australia pursue the same national objectives. In the final section of this report we build on the existing domestic policy landscape, informed by the global landscape, to propose a set of measures to support the development of a renewable gas industry.

[60] https://www.ofgem.gov.uk/system/files/docs/2016/11/ofgem_future_insights_programme_-_the_decarbonisation_of_heat.pdf

4. Low-emissions gas vision for policy makers

This final section of the report explores a potential policy landscape to support the renewable gas network. The discussion is initially framed in terms of the six categories of policy incentives observed in Table 6, before branching out to discuss some specific, high priority initiatives.

In proposing polices to support the creation of a renewable gas network, Energetics took a technology neutral position. This means that the potential measures discussed below do one of two things:

- Seek to address areas where the existing policy landscape in Australia unfairly omits consideration of renewable gas and renewable gas networks
- Highlights where there is active discrimination against renewable gas and gas networks.

It is up to others to propose measures that actively favour renewable gas over competing routes to decarbonisation.

Table 7: Mapping the broad policy incentives to Australia

Addressing a policy gap	Why this is important
Broad policy incentive: integration of low emissions gas policies into renewable energy incentives	
Australia's renewable energy policies are heavily slanted towards low carbon electricity. However, the major national policy, the RET, is approaching the end of its life, and neither major political party has specifically proposed its extension. The ALP's proposal for 50% renewable electricity does not yet discuss specific policy levers, but its focus is only on renewable electricity. The Safeguard Mechanism remains the major instrument for driving the decarbonisation of Australia and should be available to support renewable gas. For this reason, we propose **a CFI method for injecting renewable gas into the existing gas transmission and distribution infrastructure be developed**.	This initiative has the potential to fund investment in the renewable gas network without placing an additional financial burden on Australia beyond what was already required to meet its existing international emissions reduction commitments.
Several state governments have initiatives around hydrogen. They appear to have a bias towards export although domestic use of hydrogen is not ruled out. Using the existing gas infrastructure to distribute hydrogen provides a route to developing hydrogen production at scale without needing to address the storage of hydrogen or liquefaction/processing for export. We therefore suggest that where **state governments have expressed their support for renewable hydrogen production, that they prioritise the development of a domestic market before focusing on the export of hydrogen.**	Australian states have extensive renewable energy resources (i.e. wind and solar) which are often close to gas pipelines. Supporting renewable hydrogen production for domestic use as an intermediate step on the path to a viable export hydrogen industry, reduces the risk to the nation as it avoids the need investment in costly export

Addressing a policy gap	Why this is important
	facilities and does not rely on an export market for Australian hydrogen.
Broad policy incentive: targets	
Australia has several key targets linked to its emissions reduction aspirations, however they focus almost exclusively on renewable electricity. These include the goal of a 26% to 28% reduction in emissions, the RET and the various state-based renewable energy targets. And while not adopted, the national energy guarantee (NEG) proposed a 26% emissions reduction target for electricity. To address the omission of renewable gas, a full cost benefit analysis on the role of renewable gas (biogas or hydrogen) for the nation should be conducted as a first step. This national ‘business case’ would in turn help drive investment and innovation and serve as the basis for a clear government narrative on how the gas will be integrated, with timelines, trajectories and targets. Furthermore, in many countries, strong decarbonisation targets along with carbon prices, have improved the economics of biomethane injection and developing hydrogen for storage. **Australia should take the steps towards understanding and articulating the value of renewable gas to the nation and establishing a near term aspirational target for renewable gas injected into the gas networks by 2030.**	The impact will depend upon the size of the target. For instance, a target of 10% renewable gas (or 130PJ on 2016 figures) will reduce Australia’s emissions by 6.8 Mt CO_2-e or 7% of the gap to be closed if Australia is to achieve its Paris target. It will effectively offset all emissions associated with the use of gas by the residential sector. The net cost to the economy depends upon the price of natural gas, the price of renewable gas (which becomes a question of the rate of commercialisation) and any price on carbon.
Broad policy incentive: technical standard setting and guidance	
EU countries have supported the injection of biogas into the gas networks through the establishment of biomethane standards. Following this lead and informed by existing documentation, **Australia should develop a national standard for the injection of biogas into the existing gas transmission and distribution infrastructure** and establish regulatory controls over the sources of renewable biogas production.	Early establishment of technical standards removes potential barriers to the widespread adoption of renewable gas projects.
The National Hydrogen Roadmap identified several gaps in current standards related to hydrogen used as a fuel to displace natural gas. **Australia should develop a health, safety, design and metering standard for hydrogen injection into the natural gas network**.	Early action to address the gaps highlighted by the CSIRO will remove potential barriers to renewable hydrogen.

Addressing a policy gap	Why this is important
Broad policy incentive: Financial incentives (funds, grants, subsidies)	
We see that other nations have used public funds to support renewable gas. In Australia, the CEFC and ARENA already fund carbon transition projects, and several have addressed the renewable gas network. For instance, ARENA has supported Australian Gas Infrastructure Group's Hydrogen Park SA project[61] and ATCO Clean Energy Innovation Hub[62]. Of more interest is the limited understanding in Australia of the potential of the renewable gas network. ARENA's study into renewable alternatives to natural gas[33] did not discuss renewable gas, leaving readers with the impression that the only alternative to using natural gas was to convert industrial heaters to biomass or other heating technologies. We therefore recommend that **ARENA look more closely at the opportunities and costs of a renewable gas network.**	The assessment of the potential market for renewable gas is a necessary first step before any reassessment of ARENA's or the CEFC's funding priorities.
Broad policy incentive: Feed in tariffs	
Australia has been moving away from feed-in-tariffs as a support mechanism. **We do not recommend that feed-in-tariffs be applied to renewable gas at this stage**.	
Broad policy incentive: Other financial instruments	
Australia has demonstrated through the expansion of renewable power generation, a willingness to invest in low emissions technologies. The rise of funding instruments such as green bonds, corporate power purchase agreements and environmental upgrade agreements also demonstrates flexibility in the means of funding.	

[61] https://www.australiangasnetworks.com.au/our-business/about-us/media-releases/australian-first-hydrogen-pilot-plant-to-be-built-in-adelaide
[62] https://yourgas.com.au/energy-future/clean-energy-innovation-hub/

Table 8: Features of good policies

Policy	Would a new policy address a barrier to the development of a renewable gas network?	Would a new policy build on the existing policy suite?	Is the proposed policy easy to understand?	Can the proposed policy be shown to deliver a benefit to Australia?
A CFI method for injecting renewable gas into the existing gas transmission and distribution infrastructure be developed	It provides an incentive to distribute low emissions gas using the gas networks.	It will be a new method in the suite of existing CFI methods.	The gas industry could easily demonstrate how genuine abatement results from this CFI method.	Australia's emissions are reduced by 0.75 Mt $CO_{2\text{-}e}$ for each % of natural gas that is displaced by zero emissions gas.
State governments commit to support renewable hydrogen production for domestic use before focusing on the export of hydrogen	This would help create a domestic market by providing a source of renewable hydrogen.	Several state governments have proposed a range of hydrogen projects or strategies.	It would build on existing renewable gas initiatives.	It would provide a new source of gas for the east coast; take advantage of Australia’s extensive solar resources and support other initiatives to export renewable energy.
Australia should establish a near term aspirational target for renewable gas injected into the gas networks by 2030	Provided the national business case can be made in favour of renewable gas, a target would galvanise investment and innovation.	Targets have been used to drive investment in renewable electricity (the RET).	The RET provides a precedent.	
Australia should develop a national standard for biogas injection into the existing gas transmission and distribution infrastructure	The absence of appropriate technical standards introduces regulatory risk when new renewable gas projects are proposed.	Australia has a robust system of standards.	Australia has a robust system of standards.	Removing regulatory risk will reduce the cost of any new renewable gas projects.

Policy	Would a new policy address a barrier to the development of a renewable gas network?	Would a new policy build on the existing policy suite?	Is the proposed policy easy to understand?	Can the proposed policy be shown to deliver a benefit to Australia?
Australia should develop a health, safety, design and metering standard for hydrogen injection into the natural gas network	The absence of appropriate technical standards introduces regulatory risk when new renewable gas projects are proposed.	Australia has a robust system of standards.	Australia has a robust system of standards.	Removing regulatory risk will reduce the cost of any new renewable gas projects.
ARENA consider supporting a study directly focused on the “renewable gas network”	Other ARENA studies have looked at hydrogen for export and at biomass to displace natural gas in industrial applications. Reports by ARENA have note specifically looked at the market for low emissions gas in Australia and the business case for investments in renewable gas for domestic use.	ARENA have funded many studies.		It would show how the low emissions gas injected into the existing gas networks helps address Australia’s emissions and the shortfall of low cost gas on the east coast.

4.1. Recommendations

Based on our review of Australia's existing policy framework and evaluation of the international policies for renewable gases, we found that Australia has the renewable resources to decarbonise the gas networks. Similar to European countries like UK and Germany, Australia has an extensive gas network that can be repurposed and refuelled to supply low-emissions residential and commercial gas heating.

Unlike Japan and Korea, we have ample renewable energy potential that can be harnessed in the form of hydrogen or biogas which can supply some of Australia's energy needs or serve as inter-seasonal storage.

However, a comparison of renewable gas with renewable electricity shows that the key missing elements are national targets that will drive investment, and mechanisms that allow renewable gas project developers to participate in Australia's renewable energy markets.

We therefore see actions to address these gaps as having priority, and the logical next steps are:

1. Establish a near term aspirational target for cost-effective renewable gas injection into the gas networks by 2030.
2. Undertake a cost-benefit analysis of renewable gas for domestic consumption and emissions abatement, looking beyond the levelised cost of renewable gas production. Development of such analysis would constitute an important first step towards setting an appropriate national target for renewable gas in our domestic gas networks.
3. Approach the Department of the Environment and Energy with a proposal to develop the CFI method for injecting renewable gas into existing gas transmission and distribution infrastructure. The successful development of the method will facilitate participation in the Australia's renewable energy markets.

Appendix A International policies and programs

Policies which incentivise the use of hydrogen

Policy response	Operational	Assessment	Outcomes and long-term benefits
CONNECTICUT: DEEP's Fuel Cell Program provides incentive funding through the Connecticut Green Bank's On-Site Distributed Generation Program, the Microgrid Grant and Loan Program, and the Low and Zero Emissions Renewable Energy Credit Program (LREC/ZREC).[63]	In effect	Fuel cells and hydrogen are a key industry sector in Connecticut and the state's support for stationary fuel cells is strong. Several major fuel cell manufacturers are in the state and more than 600 companies are part of the fuel cell and hydrogen supply chain.	Conservatively, at least 35 MW of fuel cells now operate in the state and another 20 MW are planned. A 63.3 MW fuel cell installation has been approved by Connecticut's Siting Council. This would be the world's largest fuel cell power park, surpassing a 59MW fuel cell installation in South Korea. In 2017, a public hydrogen fuelling station opened in Hartford, one of 12 initial northeast U.S. hydrogen stations under development by Toyota and Air Liquide. CTTransit, a bus system that is a division of that state's Department of Transportation, began operating demonstration hydrogen fuel cell electric buses in 2007 and now operates one hydrogen fuel cell electric bus in daily revenue service.
NEW YORK: Reforming the Energy Vision (REV) strategy, New York's Clean Energy Standard, sales and use tax exemption, NY Prize microgrid program, and NYSERDA's fuel cell R&D program for New York companies.	In effect	New York includes all fuel cell systems in their Renewable Portfolio Standard and in the new Clean Energy Standard (released in 2016) and provides a sale and use tax exemption for fuel cell systems and service, and hydrogen gas. The state also has a microgrid program designed to ensure reliable power generation, even during adverse weather events. These	In 2017, a public hydrogen fuelling station opened in the Bronx, one of 12 initial northeast U.S. hydrogen stations under development by Toyota and Air Liquide.

[63] https://www.energy.gov/sites/prod/files/2016/11/f34/fcto_state_of_states_2016_0.pdf

Policy response	Operational	Assessment	Outcomes and long-term benefits
		programs are helping to fund growing numbers of fuel cells in the state.	
GERMANY: The National Innovation Programme (NIP) Hydrogen and Fuel Cell Technology was founded in 2006. Between 2006 and 2016, the Federal Ministry of Transport and Digital Infrastructure and the Federal Ministry for Economic Affairs and Energy have granted funds totalling about EUR 710 million to approximately 750 research and development (R&D) projects.	In effect, extended to 2026.	The NIP encompasses a range of application areas – hydrogen production, transportation sector applications, building heating and power applications, industry heat and power applications, as well as specialized markets. It also funded several cross-cutting projects that span the five areas of application. Overall, approximately 240 industrial companies have received NIP funding, including 90 small and medium-sized enterprises as well as 50 research and educational institutions and public-sector bodies.	The grant recipients, in turn, have invested an additional EUR 690 million of their own resources into these projects and raised an additional EUR 20 million in third-party funding.[64] After 10 years of program support, Germany's hydrogen and fuel cell industry standards are at a threshold to commercialize and scale.
SOUTH KOREA: has a large expansion target for hydrogen with incentive programs for the power industry, building industry and transport industry since 2011. In 2015, the South Korean government provided USD $554 million for further expansion of fuel cell plants. In 2018, they announced an investment of about USD $2.33 billion to build a hydrogen fuel cell industry ecosystem	In effect since 2011	South Korea will have the largest share of the stationary fuel cell market and success of their initiatives will depend on consumer uptake. Subsidies are currently in place to reduce the cost of businesses and residences installing fuel cells. The scheme is a public-private partnership and supports Korean car makers' aims to have the capacity to manufacture more than 200,000 FCEVs a year by 2020. This is projected to be more than 13% of the global market for FCEVs	In 2014, the world's largest fuel cell plant opened in Hwasung City, on the northwest coast. The 5.1-acre facility consists of 21 2.8 MW hydrogen fuel cells supplied by FuelCell Energy, of Danbury, Connecticut. The 59 MW fuel cell park is owned and operated by POSCO Energy, Korea's largest independent power producer.[65]

[64] https://www.now-gmbh.de/content/1-aktuelles/1-presse/20180126-bericht-evaluierung-nip-1/now_nip-evaluation-summary_web.pdf
[65] https://www.powermag.com/worlds-largest-fuel-cell-plant-opens-in-south-korea/

Policy response	Operational	Assessment	Outcomes and long-term benefits
EU: In 2016, the Hydrogen Mobility Europe Initiative launched a six-year Hydrogen Mobility Europe 2 (H2ME 2) project across Europe to promote the deployment of hydrogen refuelling infrastructure and passenger and commercial hydrogen FCEVs. This is the first EU-wide Guarantees of Origin scheme for green and low-carbon hydrogen. As well, the Alternative Fuels Infrastructure (AFI) Directive requires evaluation of national policy frameworks.	In effect	This includes the deployment of 1,230 hydrogen FCEVs and the addition of twenty hydrogen refuelling stations to the existing European network	To be released This ongoing activity will identify EU Member States that plan to include hydrogen
JAPAN: METI has renewed its Hydrogen Society Roadmap with three key components: residential fuel cells, hydrogen fuel cell electric vehicles (FCEVs) and its refuelling infrastructure; global carbon-free hydrogen supply chain. Japanese government has spent over $US1.2 billion on hydrogen and fuel cell activities since the launch of its hydrogen society roadmap in grants for R&D, hydrogen FCEVs subsidies, grants for demos, grants for renewable hydrogen demos, subsidies for hydrogen FCEVs refuelling infrastructure and stationary fuel cells.	Updated 2016 reaffirmed and in effect.	High system costs for home fuel cells and increasing competition from rooftop PV and energy storage have slowed down uptake of residential fuel cell. Of four producers for residential fuel cells, only two remain. Automakers have not met their targets for hydrogen FCEVs and refuelling points due to challenges in reducing vehicle costs and deploying the necessary refuelling infrastructure Oil and chemical companies did take up subsidized refuelling infrastructure. Key challenge is Japan does not have nationwide natural gas pipeline and storage	220,000 residential fuel cells, as of July 2017. The goal of 1.4 million units by 2020 is unlikely to be achieved 2,200 hydrogen FCEVs as of June 2017. The goal of 800,000 hydrogen FCEVs and 900 refuelling stations by 2030 is still achievable. Currently there are 25 projects directed towards the hydrogen supply-chain. Japan set ambitious goals for the development of the hydrogen supply chain, but unless the rest of the world joins in Japan's vision, large scale supply chain is unlikely to be achieved in the long run.

Policy response	Operational	Assessment	Outcomes and long-term benefits
		facility to facilitate transport and storage of hydrogen. Therefore, it is focused on importing large quantities of hydrogen from overseas to reduce dependence on fossil fuels	
DENMARK: committed up to 50% of its electricity supply to be sourced from wind by 2020, and to be fossil fuel free by 2050. Gas Storage Denmark – part of Energinet, the Danish electricity and natural gas transmission systems operator, is specifically targeting hydrogen as a mean to meet this goal.	In effect	This includes the conversion of hydrogen into methane for long term storage and seasonal shifting. Methane can then be injected into the gas network when needed.	European Joint Technology Initiative have signed an agreement to establish one of Europe's largest plants to produce hydrogen using wind power. The project is budgeted at EUR 15 million and has received €2.6 million in support from the Danish ForskEL program administered by the Danish TSO Energinet.dk, as well as EUR 8 million from the EU's Fuel Cells and Hydrogen Joint Undertaking.
UK Energy Storage competitions, focused on grid-scale storage, with total grant funding of up to GBP 9 million. 1. Energy Storage Technology Demonstration Competition: to develop and demonstrate grid-scale storage technologies. 2. Energy Storage Component Research and Feasibility Study Competition: for component-level research and system-level feasibility studies for development and integration of grid-scale storage.	Completed	Small projects have been awarded for the delivery of feasibility studies for hydrogen.	ITM Power, in partnership with AEG Power solutions - GBP 508,000 to develop a new alkaline membrane electrolyser for use in a reversible fuel cell. 0.5 MW electrolyser to demonstrate the use of blended hydrogen in the UK gas grid
GERMANY: The Federal Ministries for Economic Affairs and Energy (BMWI) and Environment, Nature Conservation and Nuclear Safety (BMU), and of Education and	Ad hoc R&D grants in effect.	The programme funds have been allocated, with the most amount of funding to date allocated to hydrogen and Power to Gas (P2G), compressed air energy storage (CAES),	Operation of 150 kW P2G demonstration plant producing green hydrogen to be injected into the gas network.

Policy response	Operational	Assessment	Outcomes and long-term benefits
Research (BMBF) launched an Energy Storage Funding Initiative in 2010 and which started making grants available in 2012. It allocated EUR 200 million available for research projects. The Initiative is focused on tackling the intermittency challenges that Germany faces in reaching its goal of 80% renewable penetration by 2050. In 2016, Germany's National Hydrogen and Fuel Cell Technology Innovation Program recently announced it would provide Siemens and RWTH Aachen with €12 million to support research into next-generation fuel cells		renewable energy integration and geological-focused storage solutions. Projects covered to date began in 2012-13 and will be completed at the latest by 2017, with the earliest due to be completed by the end of 2014.	Green hydrogen production from 2 MW wind power to be fed into gas distribution network, grid operation by Ontras Gastransport GmbH.
UK: Department of Business, Energy and Industrial Strategy (BEIS) has invested £25m in developing a supply chain for hydrogen in the UK. Hydrogen will be produced through steam reforming of methane.	In effect May 2018	Additional studies are underway examining how much hydrogen can be added to the existing gas network without affecting its operation. Although it is still unclear how these pathways will unfold, a combination of options is likely to occur; for example, 100% hydrogen could be used in local hydrogen grids, biomethane plants can supply the existing natural gas grid and hydrogen can also be added as a blend at safe levels to the existing network.	By 2050, it is proposed that 28% of the UK's heat could be provided by hydrogen. Overall the gas demand in the UK will rise, estimated at 130% of the 2016 levels, with 55% supplied by hydrogen. Cluster projects include for developments in Leeds, which is assessing 100% hydrogen and the Liverpool-Manchester area, which is investigating a hydrogen-methane blend. Hydrogen gas pipeline infrastructure could be established in the UK by 2030.
FRANCE: ADEME announced USD $156 million investment to encourage deployment of hydrogen industry, mobility and energy.	Starting 2019	The fund is earmarked for:	New initiative, yet to be tested.

Policy response	Operational	Assessment	Outcomes and long-term benefits
Target areas include heavy vehicles, commercial fleets and charging infrastructure.[66]		• Creation of a decarbonised industrial sector, with objective of 10% decarbonized hydrogen by 2023 • Development for zero emissions solutions for roads, rail, river etc transport with deployment on the horizon for 2023 of 5000 light utility vehicles, 200 heavy vehicles and 100 hydrogen stations to refuel vehicles with locally produced hydrogen. • Increase in integration and storage capacity for renewable energies • Establishing a hydrogen certification scheme by 2020 and ensuring that the regulation of greenhouse gases will classify hydrogen according to its mode of production • Putting in place regulations on safety and risk prevention, including a specific regulatory framework for hydrogen distribution stations by mid-2018	
UK: A new £23 million fund to accelerate the take up of hydrogen vehicles and roll out more cutting-edge infrastructure has been announced by the government today.	In effect March 2017	Hydrogen fuel providers will be able to bid for funding in partnership with organisations that produce hydrogen vehicles to help build high-tech infrastructure, including fuel stations. The funding will boost the creation of hydrogen fuel	A number of fuelling stations have been introduced in the UK but not enough to boost consumer confidence.

[66] http://https//www.ecologique-solidaire.gouv.fr/plan-hydrogene-outil-davenir-transition-energetique

Policy response	Operational	Assessment	Outcomes and long-term benefits
		infrastructure and uptake of hydrogen-powered vehicles.	
CALIFORNIA: At Governor Jerry Brown's direction, the state is spending more than $2.5 billion in clean energy funds to accelerate the sales of hydrogen and battery vehicles. $900 million earmarked to complete 200 hydrogen stations. There are also fuel incentive and vehicle subsidies for consumers.	In effect	Uptake has been slow due to competition from electric vehicles and the 14000 public charging stations in California.	As of March 2018, there were 3800 hydrogen powered sedans in California and 31 hydrogen filling points (each costing at least $2.5 million) The projected testing the demand for hydrogen FCEVs given ample subsidies.
CHINA: over $US100 million for research and development of large-scale hydrogen production, hydrogen powered cars and fuel cells. The 13th National Five-Year Plan identifies "new energy vehicles" as one of six emerging technologies that will receive particular attention. The plan states that there will be a total of 5 million 'new energy' vehicles across the country by the end of the five-year plan[67]	In effect	The government has outlined plans to encourage the development of hydrogen energy and hydrogen FCEVs, but the national and local policies aren't specific or strong enough to give the industry clear guidance and greater confidence. Several Chinese firms and provinces have announced ambitious plans to produce fuel cells and FCEVs. China plans to have the capacity to produce about 170,000 FCEVs annually.	Statistics published by the Society of Automotive Engineers of China last year suggest that there will be about 1 million hydrogen FCEVs on the nation's roads by 2030. To support the rise of such vehicles, China has 12 hydrogen fuelling stations in operation, and 19 more are under construction across the country. Eventually, the number will exceed 100. Zhangjiakou, Hebei, will be a hydrogen energy demonstration city as host to the 2022 Winter Olympic Games.
USA: there are four main incentives for hydrogen, mostly focused on fuel cell. Alternative fuel tax exemption, low and zero emission public transportation research	In effect	There are a range of support options available for the development of hydrogen fuel cells in the US, but where there is active development, it is driven by state initiatives (as illustrated by	For a good overview of all hydrogen developments see the US Department of Energy's 2016 review.[68]

[67] http://www.chinadaily.com.cn/a/201806/05/WS5b15ddf4a31001b82571e211_2.html
[68] https://www.energy.gov/sites/prod/files/2016/11/f34/fcto_state_of_states_2016_0.pdf

Policy response	Operational	Assessment	Outcomes and long-term benefits
demonstration, and deployment funding, Improved energy technology loans, and Alternative fuel and advanced vehicle technology research and demonstration bonds.		the examples of California initiatives given above). US states have a coalition of governors committed to ‘zero-emission vehicle states’ and hydrogen FCEVs are more mature in these states than in non-zero-emission states.	
BRAZIL: is the only Latin American member of the International Partnership for Hydrogen and Fuel Cells in the Economy and has several tax incentives for hydrogen FCEVs. The National Bank for Social Economic Development (BNDES) also offers a few financing incentives for hydrogen fuel cells.[69]	Ongoing ad hoc R&D incentives	15 universities, 8 research centres, 4 fuel cell companies and 7 investors are currently involved in hydrogen and fuel cell technologies in Brazil. All projects are still in the design prototype phase.	3 hydrogen bus fleets were funded and established in 2005 which concluded in 2016.

[69] https://www.iphe.net/brazil

Policies which incentivise the use of biogas

Policy response	Operational	Assessment	Outcomes and long-term benefits
FRANCE: direct subsidies ("Waste Fund" managed by ADEME) for biogas production investments: the budget was at EUR 26 million in 2011, increased sharply since 2007; feed in tariffs for biomethane injection into the grid, prepared by an ordinance in November 2011; feed in tariff for electricity generated from biogas (including biomethane) A Heat Fund is implemented to support heat use.	2011	From an industrial perspective, cost reductions are necessary and have become conceivable because of innovation and the optimisation of technologies and operating practices. The study shows that a 30% reduction in production costs is achievable within the next five to ten years	As of 2017, 35 sites injected biomethane into the gas grid, supplying the equivalent of 315 GWh of annual production. This represents 0.05% of France's natural gas consumption; 297 additional projects were on the waiting list to be connected to the gas grid, corresponding to an additional injection capacity of 6.5 TWh/year, i.e. 2% of France's natural gas consumption[70] Developing the regulatory framework to maximise France's potential by facilitating the exploitation of resources located at a significant distance from gas grids by structuring dedicated mechanisms and creating the regulatory conditions needed for greater quantities of gas to be injected during the summer months
LUXEMBOURG: Green electricity regulation published provides feed-in tariffs for biomethane injection into the gas grid if the first injection takes place between 2014 and 2017. Feed in tariffs are valid for 15 years.[71]	In effect		As of 2015[72] 3 biomethane plants that do not feed into the grid.
DENMARK: has ambitious targets to supply the existing gas grid with 100% green gas by 2035. The Danish Energy agreement (12 March 2012) provides support for upgrading	In effect	The calculations are based on assessments for potential that were produced by Aarhus University and compared to projections for gas consumption in Denmark. The calculations	Biogas production has increased by nearly 50% in 2016/2017 compared to 2015.

[70] http://www.enea-consulting.com/wp-content/uploads/2018/04/ENEA-2017-10-biomethane-france-2017-en.pdf
[71] http://european-biogas.eu/2014/08/18/luxembourg-increase-fit-renewables/
[72] https://www.sciencedirect.com/science/article/pii/S096014811830301X

Policy response	Operational	Assessment	Outcomes and long-term benefits
biogas and feeding into the existing natural gas grid. The agreement is supported by subsidy schemes for upgrading, feed in tariffs for grid injection, as well as use of gas for heating, transport and industrial purposes. There are political thoughts on issuing purchase of obligation for Danish heating plants.		show that, with the right framework conditions, there is potential for green gas (methane) to cover Denmark's expected gas consumption of 72 PJ in 2035. The potential of 72 PJ is based on a continued rise in use of manure and waste, an efficiency improvement of biogas production and a 50% utilisation of straw resources. Aarhus University points out that a utilisation of the gas grid's potentials for electricity storage through methanation could boost the potential to 100 PJ.	As of 2017, there are 19 biomethane plants and 16 gas filing stations for biomethane. Biomethane represent 10% of the gas in the natural gas grid. It is possible for Denmark to be the first country in Europe to be free of natural gas.
UK: Biomethane is recognised under the Renewable Heat Incentive (world's first long term financial support program for renewable heat). Anaerobic digestion plant operators will be able to claim a restored tariff of 5.4 p/kWh (2017) of renewable heat generated for their Tier 1 biomethane (first 40,000 MWh injected into the grid per year) and once their plant is commissioned they will receive a guaranteed tariff level for 20 years.[73]	Renewable heat incentive in effect since 2011	UK provides a good example of how government policy can stimulate rapid growth in biomethane upgrading. In 2011, there was just one biomethane plant in the country. The introduction of Carbon Price support from 2013, as well as feed-in tariff per kWh of biomethane injected into the grid under the Renewable Heat initiative, resulted in 20-30 new plants per year coming online between 2014-2016.[74] In 2017, 85 plants producing biomethane were operational[75].	Green gas industry is now forecasting that as many as 40 plants may be built over the next 2 years as a result of restored tariff levels. Generating up to an additional 2 TWh of renewable heat per year.[76]

[73] http://www.biosurf.eu/wordpress/wp-content/uploads/2015/06/BIOSURF_Roadmap-for-UK_REA-RM-additions-GH.pdf
[74] https://www.oxfordenergy.org/wpcms/wp-content/uploads/2017/06/Biogas-A-significant-contribution-to-decarbonising-gas-markets.pdf
[75] http://task37.ieabioenergy.com/country-reports.html
[76] https://www.renewableenergymagazine.com/biogas/new-tariffs-give-uk-green-gas-industry-20180514

Policy response	Operational	Assessment	Outcomes and long-term benefits
IRELAND: Green Gas Certification Scheme project which is co-funded by the Department of Communications, Climate Action and Environment, Department of Jobs, Enterprise and Innovation as well as GNI and the Renewable Gas Forum of Ireland was launched in April 2017 and aims to develop a comprehensive methodology for a certification scheme that facilitates biomethane trading for both renewable heat and transport markets. It is anticipated that such certification and independent traceability of Guarantees of Origin and sustainability criteria will be mandated in the updated RED as well as demonstrating compliance with EU and national targets	To be launched	To be assessed Ireland's gas network Ireland (owns and operates over 13,500 km of transmission and distribution gas pipelines in Ireland) identified 'hub and pod model' as a model with the most potential to maximise mobilisation of biomethane in Ireland.[77]	To be assessed
NETHERLANDS has implemented the SDE+ scheme which supports biogas related heat production and biomethane production and offers premium tariff for biomethane.	In effect	The main driver for the development of renewable energy and therefore also for biogas and biomethane is the NREAP. For 2020 there is a target set to produce 24 PJ from biomethane.	13 biomethane plants in operation and one of the forerunners of the market for biogas and biomethane.
POLAND introduced new energy regulations that awarded brown certificates to producers injecting biomethane into natural gas grid, with the same value as green certificates	Not in effect.	Not in effect	Not in effect

[77] http://www.ieabioenergy.com/wp-content/uploads/2018/04/green_gas_web_end.pdf

Policy response	Operational	Assessment	Outcomes and long-term benefits
(EUR 67 per MWh). Grid operators must now enable grid connection for biomethane producers and then buy the biomethane.			
GERMANY: by a large margin, has led the development of biogas, supported by a feed-in tariff system, and other legislation strongly supporting its development.[78] Under the German Renewable energy Act 2017 (EEG 2017), instead of a state determined feed in tariff, all renewable energy sources are now subject to an auction scheme to introduce market-based incentives. The Biofuel Sustainability Ordinance offers both a quota system and tax exemption for biomethane.	In effect since 2009	Under the EEG 2017, 150 MW of electricity from biomass power plants will be available for auction. Under the new act, biogas installations producing less than 150 kW will be exempt from auctions and will continue to benefit from feed in tariffs.	Currently 197 biogas upgrading plants are in operation compared to 10 in 2016. 9.4 TWh of biomethane is injected into the grid for heat, mobility, raw material export. There are about 120 biogas refilling stations in operation.[79] The target of 6 billion m^3 biomethane production by 2020 and 10 billion m^3 by 2030 injection in the national gas grid have been met.
UK: reviewing the pricing regulation for biomethane injection	In effect	Under current regulations, consumers' gas bills are based on calorific value (or energy content) of gas in the local network. The calorific value of biomethane is lower than natural gas and to ensure fair billing, producers must add propane to enrich the gas before injection. This raises the cost of production by 30% and increases the biomethane carbon footprint.	The National Grid is investigating alternative billing methods, to avoid the need for propane addition.

[78] http://task40.ieabioenergy.com/wp-content/uploads/2013/09/t40-t37-biomethane-2014.pdf
[79] http://www.biosurf.eu/wordpress/wp-content/uploads/2015/06/5.-Hofmann.pdf

Policy response	Operational	Assessment	Outcomes and long-term benefits
SWEDEN: strongly supported biogas, but with a particular focus on upgrading to biomethane for use in the transport sector.[80] Exemption from carbon tax, government directive on procurement of environmentally friendly cars, 5 years exemption from vehicle tax and 40% reduction in the amount of fringe benefit in the income tax for environmentally friendly cars.	In effect	Sweden has always been active in developing renewable fuels and has pioneered work in the deployment of biogas upgrading technologies during the last two decades. The Swedish example is the most successful regarding the integration of biogas in the transport sector.	According to the Swedish Gas Centre, in 2015 there were 61 plants in operation that upgraded biogas to biomethane, seven of which are connected to the public grid.
AUSTRIA: Energy Strategy Austria envisages biogas to contribute to the renewable energy target by delivering electricity or biofuel. Both investment grants and feed in tariffs are available as part of the Green Electricity Act.	In effect since 2001	The first option is the addition of 20% biomethane to natural gas to reach 200,000 cars by 2020. The second option is increasing the amount of biogas produced to 10% of gas demand, which corresponds to 8 TWh in Austria.	In 2016, there were 13 plants that upgrade biogas to biomethane. approximately 10,000 natural gas vehicles and 172 compressed natural gas filling stations, 3 of which are located at biogas upgrading plants. As of 2018, amendments to the Green Electricity Act will mean stricter rules are applied to the efficiency of biogas plants and raw materials.
ITALY: the government signed in a decree that allows biomethane injection into the grid and its use as a transport fuel. A premium tariff is offered for biomethane.	In effect	Greater extent of expansion in biogas operations for electricity generation compared to grid injection.	No biomethane projects commissioned so far.
CHINA: biomethane is included in the 13th Five-Year Plan (2016-2020) which indicates support for commercial utilisation as vehicle fuel and for grid injection.	In effect	China's dependence on imported natural gas makes biomethane upgrade of interest to policy makers, but so far it is still focused on exploring production and development.[81]	The first biomethane upgrading plant was set up in 2017 in the province of Shangdong.[82]

[80] ibid
[81] https://doi.org/10.1016/j.cjche.2015.12.025
[82] https://www.envitec-biogas.com/fileadmin/media/pdf_downloads/subpage_references/fact_sheets/fact_sheeet_Minhe_EN.pdf

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