APGA

INQUIRY INTO RESIDENTIAL ELECTRIFICATION

Senate Economics References Committee

September 29, 2023

SUPPORTING THE ENERGY TRANSITION

Natural gas provides
34%
of energy delivered to Australian households

<2%
of Australia's total emissions

GAS CONNECTIONS PROVIDE CHOICE, LOWER CONSUMER COSTS, MORE ENERGY RELIABILITY AND CAN BE DECARBONISED WITH RENEWABLE GAS

Up to **15%** fewer CO2 emissions than electrifying gas use in Victoria today

5.2 million residential properties connected to gas networks

165,500 Australians employed full-time in gas supply chain

Up to **50%** gas network emissions reduction possible by 2030

>70% of Victorians are **not** supportive of residential gas bans

WHY AUSTRALIAN ENERGY EXPERTS WANT TO MAINTAIN GAS CONNECTIONS

"I've never been a fan of putting all your energy eggs in one basket. Full electrification isn't a good risk management structure."

Energy Stakeholder Perceptions Audit 2022

"I'm very much in favour of a portfolio of energy sources, I get very nervous when governments just want to back in one horse."

Energy Stakeholder Perceptions Audit 2022

CONTENTS

List of Appendices

List of Attachments

List of Figures

EXECUTIVE SUMMARY

The Australian Pipelines and Gas Association (APGA) welcomes the opportunity to comment on the Economics References Committee's inquiry into residential electrification. APGA encourages the Committee to consider this inquiry as one into residential decarbonisation, rather than residential electrification.

Residential gas use is responsible for around 2% of emissions in Australia and represents one of the most costly and challenging sectors to decarbonise. The gas infrastructure sector can play a major role in supporting least cost decarbonisation of household energy use.

In many circumstances, individual households will face lower decarbonisation costs by using renewable gas to replace their natural gas use rather than electrifying their gas demand. Beyond individual household costs, it is apparent that a future integrated energy system delivering renewable electricity and renewable gas to meet Australia's energy needs is highly likely to be lower cost than a single energy system delivering only electricity.

APGA makes the following points within its submission:

Electrification is not the only option to decarbonise households.
Renewable gas can be used to decarbonise gas supplied to homes rather than replacing it, and doing so would be cost-competitive with electrification.

Pursuing household electrification as the only decarbonisation solution introduces unnecessary social and economic risks.
Restricting households to one decarbonisation option compounds existing socioeconomic inequalities exposes some households to very high costs, impedes economy-wide decarbonisation, and reduces energy system stability –all of which can be avoided if household customers are allowed to choose renewable gas as well as electrification.

Allowing households to choose electrification and renewable gas accelerates the transition.
Australia can secure a more stable, lower cost and more rapidly transitioning energy system by supporting both renewable energy pathways for households and all energy customers.

Renewable electricity can deliver cheaper decarbonisation used elsewhere in the economy
Using Australia's next 177 terawatt hours (TWh) of renewable electricity supply to decarbonise coal-fired generation and light vehicles delivers lower cost decarbonisation – decarbonisation which could occur at the same time as renewable gas starts to decarbonise the gas supply chain.

There is a prevailing narrative that the low cost of renewable electricity generated by solar and wind means energy will be much cheaper in the future. Low-cost variable renewable electricity (VRE) has to be supplied via high-cost electricity infrastructure, firmed by high-cost electricity storage, and used in high-cost electricity appliances. Higher cost (today) renewable gases are transported via low-cost pipeline infrastructure, stored in low-cost gas storage, and used in low-cost gas appliances.

Considering the full cost of each energy system, it is apparent that firm renewable electricity and firm renewable gas can be cost-competitive for household use. This is true today, despite the differing levels of technological maturity between renewable electricity and renewable gas. It is highly likely that, as renewable gas technologies mature, the renewable gas system of the future will be lower cost that the renewable electricity system.

Sitting between upstream natural and renewable gas producers and downstream energy consumers, APGA and its members take into consideration the full energy supply chain as part of determining its policy positions. APGA works constructively with all gas supply chain participants and governments to advocate for and implement expeditious and economical emission reduction in Australian households and industry.

Considering the interconnected nature of the integrated energy system, decisions regarding the electrification of Australian homes cannot be made in a vacuum. An isolated approach to considering residential electrification comes with a significant risk of unintended consequences being felt by households and beyond the scope of the Terms of Reference – including emission increases in households and industry, amplified risk of energy insecurity, and significantly higher costs.

APGA's submission does not put forward a case to diminish residential electrification. On the contrary, the electrification of personal transport has been found to be one of the most economically efficient avenues to rapidly decarbonise the broader economy, with 90 per cent of residential energy cost savings coming from EVs rather than the electrification of gas demand. It is also apparent that residential electric appliances are one of multiple valid pathways toward decarbonising the built environment.

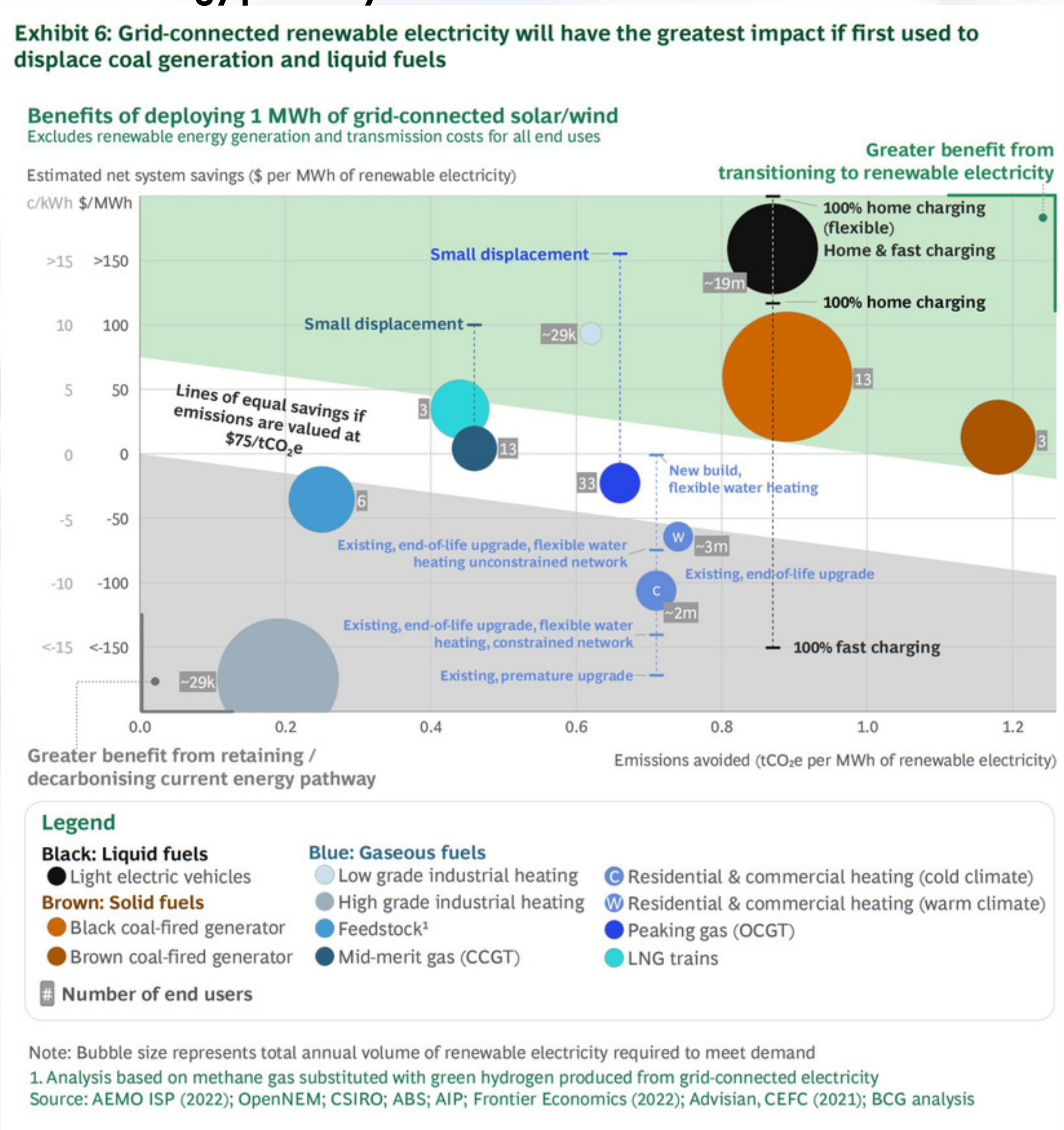
Electrifying households draws upon Australia's pipeline of renewable electricity production projects – a pipeline that already faces infrastructure and storage constraints.

There is a merit order for the uses of energy to which the next wave of renewable electricity should be applied to achieve the greatest emission reduction as early as possible. Recent analysis shows that the next 177 TWh of renewable electricity generation is best targeted towards reduction in coal fired generation and light vehicle fuel use (Figure E1).

APGA highlights to the Inquiry that all forecasts setting out cost savings of electrification rely on future energy costs being much lower than today, often lower than historical levels. While renewable electricity is generated from wind and solar at low-cost, an energy system based on wind and solar is very unlikely to be a low-cost energy system. The renewable electricity system of the future requires unprecedented investment in transmission and storage infrastructure. Australia is only at the very beginning of the investment cycle to deliver this infrastructure and it is apparent that the costs are most likely to be much higher than forecast.

APGA encourages the Committee to consider the evidence to chart a dual pathway to net zero in the home, using electrification and renewable gases, to ensure consumer choice, competition, and energy security for all Australians.

Figure E1 : Grid-connected renewable electricity vs decarbonisation of current energy pathways



Source: BCG, 2023, The role of gas infrastructure in Australia's energy transition

RECOMMENDATIONS

This submission identifies the opportunity to decarbonise households through dual electrification and renewable gas pathways. The social and economic risks of 100 per cent electrification are also considered alongside the added benefits to the Australian economy of dual renewable electricity and renewable gas pathways.

The following recommendations are cross-cutting, supporting the benefits and mitigating the risks of all topics discussed within this consultation. They each address no one aspect – rather, each supports better social, economic and emissions outcomes for households and the Australian economy in general.

Household Electrification

Do not take away customer choice by endorsing electrification as the sole solution to household gas use decarbonisation. Doing so would act in opposition to the best interests of customers, forcing some customers to pay for higher cost options, and in opposition to Australia's national decarbonisation ambition.

Support a GreenPower Accreditation for retail gas bills.
Based on the GreenPower Accreditation program for retail electricity, such a program can build upon existing gas plus carbon offset programs with a requirement for retailers to transition to purchasing 100 per cent renewable gas to cover all GreenPower gas demand over the coming decade.

Nation-wide decarbonisation of households and all gas users

Consider direct policy levers that enable renewable gas to contribute to sector-wide decarbonisation.
There are several policy leaves that governments can apply to unlock the decarbonisation opportunity of renewable gas within the gas supply chain.

- **Establish a Renewable Gas Target.** This target can be modelled on successful renewable electricity initiatives like the Renewable Energy Target (RET). A Renewable Gas Target will stimulate the development of a renewable gas supply which gas retailers could provide to their household and commercial gas customers instead of natural gas.

- **Establish a national Renewable Gas Certification Scheme**. Nation-wide renewable gas certification based on the GreenPower Prototype Renewable Gas Certification Pilot will encourage market-driven solutions, allowing consumers, suppliers, and industries to make decisions based on clear economic signals while achieving decarbonisation goals. The current prohibition for Renewable Gas Certification Pilot certificates to be used for household decarbonisation must be lifted for a successful national scheme.

- **Establish a renewable gas Market-Based Method in NGER.** Given the potential of renewable gases to serve as cost-effective decarbonisation options, lawmakers should prioritise the creation of a robust market-based method under National Greenhouse and Energy Reporting (NGER) similar to that provided for renewable electricity. This would reinforce the market-based decision-making from the National Renewable Gas Certification Scheme through federal emission accounting recognition.

- **Adapt existing policies promoting the adoption of efficient electric appliances to encourage the use of efficient hydrogen-ready appliances.** An increase in gas appliance fleet efficiency reduces emissions immediately while increasing appliance hydrogen readiness reduces the challenge of transitioning to 100 per cent hydrogen in the future. This would signal to the Australian gas appliance manufacturing industry that investment in new high-efficiency hydrogen-ready appliance development is valued.

Prioritise enhancing public awareness regarding the role of gas, including renewable gas, in Australia's energy transition.
This will ensure that the broader population is genuinely informed on their decarbonisation options, helping the Australian public to engage in the transition towards cleaner energy sources.

Prioritise high-impact emission abatement areas
While residential decarbonisation is important, policymakers should also focus on sectors that offer the most significant opportunities for emission reduction, such as transportation, industrial processes, and agriculture. Directing resources to these areas might yield greater emission reduction per dollar spent, thus ensuring a more efficient use of public funds and a lower-cost pathway to net zero.

ABOUT

APGA represents the owners, operators, designers, constructors and service providers of Australia's pipeline infrastructure, connecting natural and renewable gas production to demand centres in cities and other locations across Australia. Offering a wide range of services to gas users, retailers and producers, APGA members ensure the safe and reliable delivery of 28 per cent of the end-use energy consumed in Australia and are at the forefront of Australia's renewable gas industry, helping achieve net-zero as quickly and affordably as possible.

APGA and its members strongly support the Federal Government's net zero by 2050 target and its commitment to reducing emissions by 43 per cent from 2005 levels by 2030.[1] As set out in Gas Vision 2050,[2] APGA sees renewable gases such as hydrogen and biomethane playing a critical role in decarbonising gas use for both wholesale and retail customers. APGA is the largest industry contributor to the Future Fuels CRC,[3] which has over 80 research projects dedicated to leveraging the value of Australia's gas infrastructure to deliver decarbonised energy to homes, businesses, and industry throughout Australia.

To discuss any of the details within this submission further, please contact APGA's National Policy Manager, Jordan McCollum, on +61 422 057 856 or jmccollum@apga.org.au.

[1] APGA, Climate Statement, available at: https://www.apga.org.au/apga-climate-statement
[2] APGA, 2020, Gas Vision 2050, https://www.apga.org.au/sites/default/files/uploaded-content/website-content/gasinnovation_04.pdf
[3] Future Fuels CRC: https://www.futurefuelscrc.com/

INTRODUCTION

Renewable gases such as biomethane and hydrogen can be used by all gas customers. Practically speaking, biomethane can be used by all gas customers today with zero change save the source of gas. Some modifications are needed to use 100 per cent hydrogen. Importantly the scale of these modifications is anticipated to be fewer than those required to electrify Australia. Recent research increasingly demonstrates fewer modifications to households and network infrastructure are required to transition to hydrogen than previously understood. [4,5]

There is no practical barrier to either biomethane or hydrogen. In fact, blended biomethane and hydrogen are being supplied to homes today, decarbonising their gas use while this inquiry unfolds (Appendix 1). This submission will expand upon the analysis which shows that renewable gas is a cost-competitive option to decarbonise gas use in the home, as well as for commercial and industrial customers.

While Australia is a global leader in renewable electricity, it is a laggard in renewable gas. The European Union has hydrogen and biomethane targets that amount to over 20 per cent of total gas use by 2030. [6,7] Denmark has expanded gas supply from biomethane from 10 per cent in January 2020 to 39 per cent in August 2023, and is expected to achieve 70 per cent decarbonisation of gas consumption by 2030 (Appendix 2).

Australia's underperformance in renewable gas industry development is not due to a lack of resources. Australia has access to 2,600 petajoules per annum (PJpa) of biomass feedstock from waste streams, around 500 PJpa of which is well suited to biomethane production. [8] Australia's world-class renewable electricity resource can be applied to green hydrogen production which can be delivered, stored, and used in infrastructure and appliances which cost less than their electricity alternatives. [9] This production potential is compared to around 1,000 PJpa worth of domestic gas consumption in Australia today – a demand level similar to electricity use. [10]

[4] ARENA, 2023, Knowledge Bank Resources for the Australian Hydrogen Centre, accessed September 2023, https://arena.gov.au/knowledge-bank/?keywords=Australian+Hydrogen+Centre
[5] APA Group, 2023, Parmelia Gas Pipeline Hydrogen Conversion Technical Feasibility Study, https://www.apa.com.au/globalassets/our-services/gas-transmission/west-coast-grid/parmelia-gas-pipeline/3419_apa_public-pipeline-conversion_v6.pdf
[6] European Commission, 2023, Hydrogen, accessed September 2023, https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en#:~:text=The%20ambition%20is%20to%20produce,in%20energy%2Dintensive%20industrial%20processes
[7] European Commission, 2023, Biomethane, accessed September 2023, https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en#:~:text=The%20Biomethane%20Industrial%20Partnership%20(BIP,of%20its%20potential%20by%202050
[8] ENEA Consulting and Deloitte Australia, 2021, Australian Bioenergy Roadmap, https://arena.gov.au/assets/2021/11/australia-bioenergy-roadmap-report.pdf
[9] Boston Consulting Group, 2023, The role of gas infrastructure in Australia's energy transition, https://jemena.com.au/documents/reports/the-role-of-gas-infrastrcuture-in-australia-s-ener
[10] DCCEEW, 2022, Australian Energy Update 2022, https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202022%20Energy%20Update%20Report.pdf

INTRODUCTION

Australian households and other gas customers are being let down by the lack of supportive policy for renewable gas. Retailers and wholesale electricity customers can purchase Large Generation Certificates (LGCs) and have these considered in emissions reporting under NGER. Retailers and gas customers do not have this option for renewable gas. A pilot Green Gas Certificate Scheme only commenced in August 2023, and this is still not recognised under NGER.

This lack of supportive policy has coincided with a disparity of fact-based research about forms of renewable energy beyond renewable electricity. Without the facts, the lack of policy support has been understandable.

This submission considers some of the publicly available data in support of decarbonising household and other gas use through renewable gas. APGA makes its recommendations based on this data and seeks policy support for a quicker, cheaper and more secure energy transition for Australian energy consumers.

2 ELECTRIFICATION IS NOT THE ONLY WAY TO DECARBONISE

Electrification is considered by many to be the only option to decarbonise household gas demand. This is not the case. This section highlights that renewable gases are a cost-competitive option for decarbonising gas use in the home. This becomes important from a decarbonisation perspective when electrification in fact increases emissions in the short to medium term, while renewable gas uptake reduces emissions as soon as households are provided the option to use them through supportive government policy.

This section addresses the following Terms of Reference:
(c) the total upfront cost and longer-term benefits of household electrification and alternative models for funding and implementation;

(d) the marginal cost of abatement for household electrification compared to alternative sectors and options to decarbonise the economy;

(h) solutions to the economic barriers to electrification for low-income households;

2.1 COST-COMPETITIVE DECARBONISATION OPTIONS

While the inquiry is framed around electrification, the Terms of Reference indicate that the intent of the inquiry is to understand options for delivering household gas decarbonisation at the least cost.

Renewable gases and electrification are both cost-competitive options to decarbonise gas use in the home.

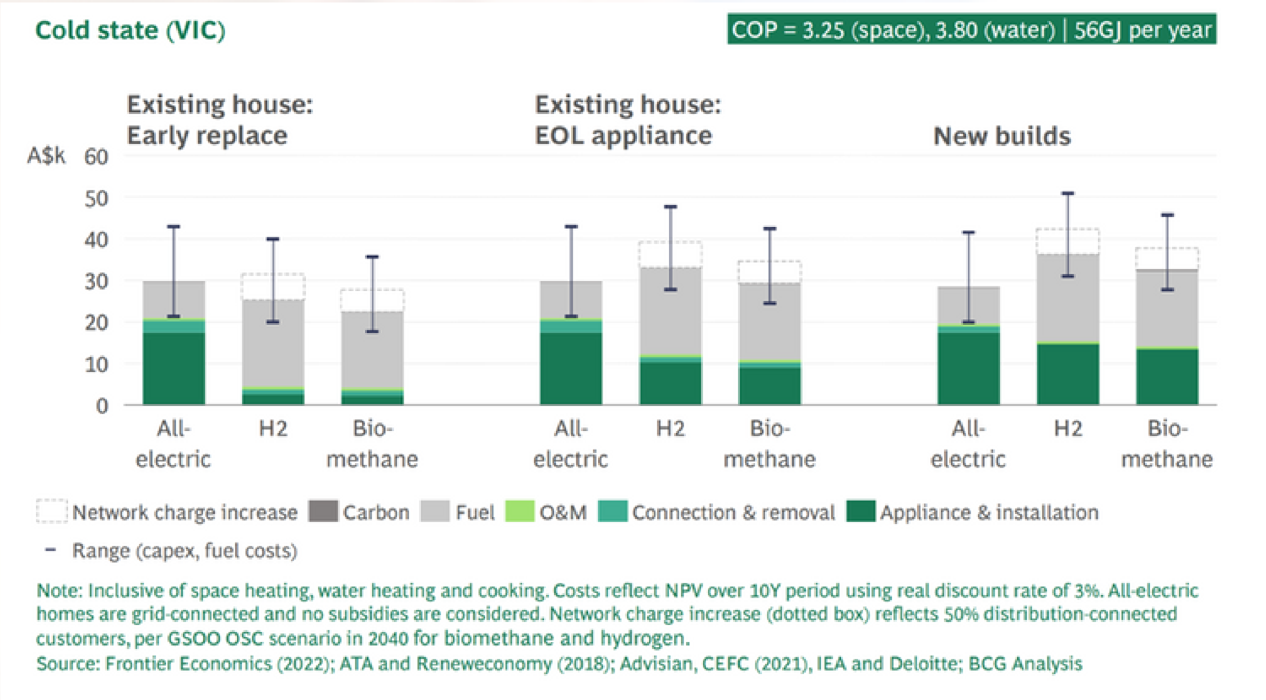
New research published by Boston Consulting Group (BCG) in June 2023 demonstrates the cost competitiveness of renewable gas use in the home.[11] Renewable gases – green hydrogen and biomethane – by definition produce zero Scope 1 carbon dioxide emissions, and better than 99 per cent less carbon dioxide equivalent emissions than natural gas.[12] Renewable gases being cost-competitive for gas use decarbonisation in the home means that household customers have greater choice, greater opportunity, and greater capacity to decarbonise their household gas demand.

Figure 1 considers combined energy and appliance costs for household gas users which decarbonise through electrification, hydrogen or biomethane pathways. Each energy option includes a possible range of cost outcomes for different households considering the range of different potential appliance costs, and the range of different potential energy costs.

[11] BCG, 2023, The role of gas infrastructure in Australia's energy transition.
[12] See the National Greenhouse and Energy Reporting (Measurement) Determination 2008, https://www.legislation.gov.au/Details/F2023C00815

2.1 COST-COMPETITIVE DECARBONISATION OPTIONS

Figure 1: Cost comparison for electricity, green hydrogen and biomethane for residential users in 2040, at different points of appliance replacement



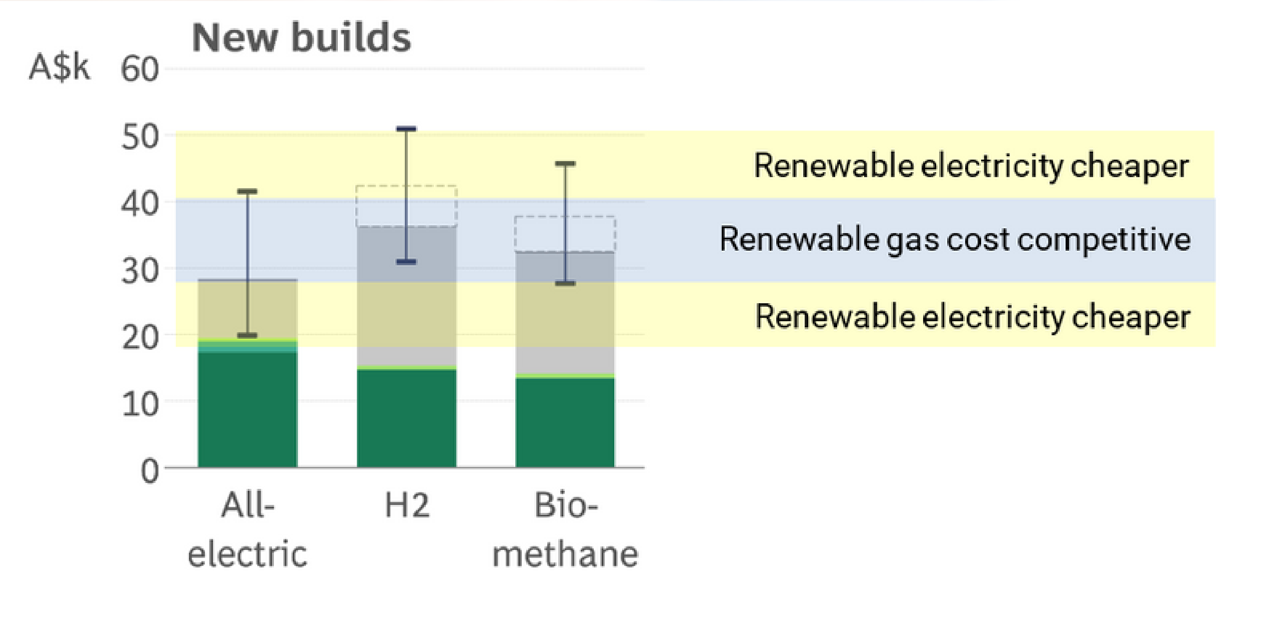
Source: BCG, 2023, The role of gas infrastructure in Australia's energy transition

One observation from the analysis is that the low end of the all-electric cost ranges for Existing house: EOL appliance and New builds are lower than the low value on the hydrogen and biomethane cost ranges. It can be concluded from this observation that it is possible for some homes to achieve lower cost outcomes with the all-electric option. While this is a possible outcome for some households, it provides an incomplete picture of outcomes for all households.

A broader interpretation of this data considers the overlap of the cost ranges for the three household decarbonisation options (Figure 2). While it may be possible for some household energy customers to achieve the lowest all-electric appliance buildout and access the lowest cost electricity, the range indicates that this is not the rule for all households.

2.1 COST-COMPETITIVE DECARBONISATION OPTIONS

Figure 2: Overlap of the cost ranges for new build dwellings



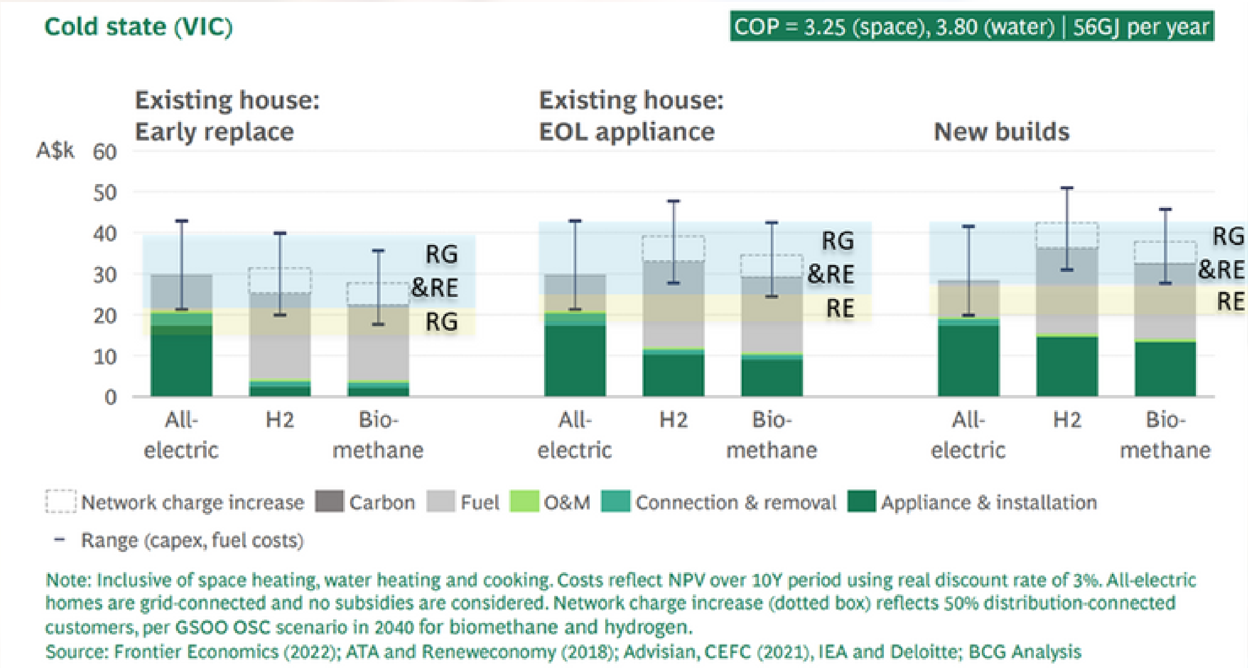
Source: BCG, 2023, The role of gas infrastructure in Australia's energy transition

In reality, households which electrify will experience costs along the range, and some households will experience costs at the top of the electrification cost range. At the same time, households will experience costs across the ranges for hydrogen and biomethane – costs which will be equal to or lower than the electrification cost for many households.

Overlapping combined cost ranges for all-electric, hydrogen and biomethane options indicates that there is a range of household gas customers for which renewable gas and renewable electricity both pose cost competitive gas use decarbonisation options. Further, this indicates that there is a range of household gas customers for which renewable gas is a cheaper option than renewable electricity to decarbonise gas use in their home (Figure 3).

2.1 COST-COMPETITIVE DECARBONISATION OPTIONS

Figure 3: Cost comparison for electricity, green hydrogen and biomethane for residential users in 2040, at different points of appliance replacement with cost competitiveness ranges



Source: BCG, 2023, The role of gas infrastructure in Australia's energy transition with APGA cost competitive range analysis

Beyond creating choice and opportunity for household decarbonisation, renewable gas being cost competitive with renewable electricity helps address many of the challenges of 100 per cent household electrification:

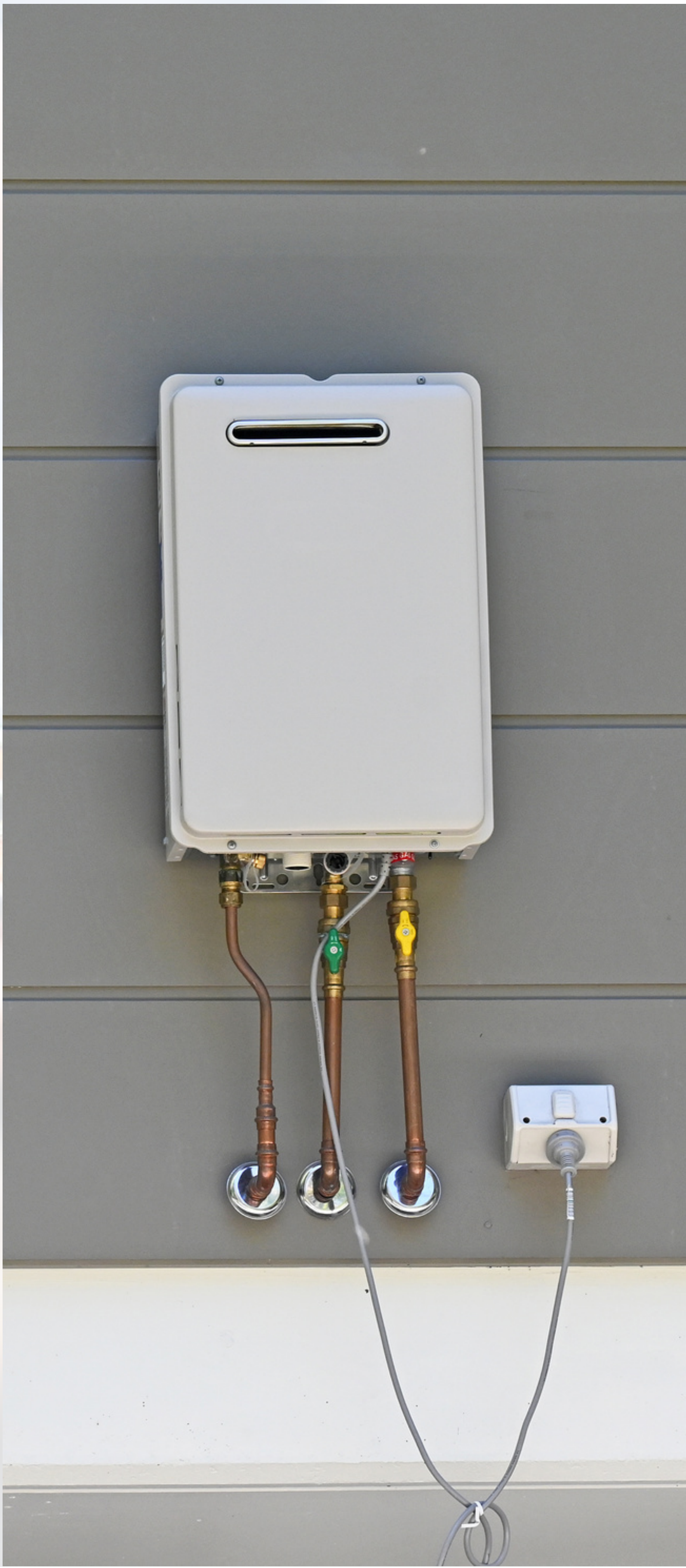
- Low-income households avoid spending tens of thousands of dollars to purchase electric appliances and electricity connection upgrades.
- Renters can choose to contract renewable gas when their landlords do not pay tens of thousands of dollars to replace their gas appliances with electric appliances, avoiding increased rents due to higher appliance costs in the process.
- Apartment complexes can contract renewable gas instead of facing the cost of replacement of central systems and potentially the cost of repurposing valuable real estate within buildings to allow for electric alternatives in extreme cases.
- Where government funding can only subsidise a small portion of more costly electric appliances, expanding funding to high efficiency, hydrogen-ready gas appliances can achieve a greater decarbonisation impact for every government dollar.

2.1 COST-COMPETITIVE DECARBONISATION OPTIONS

This is just the beginning of the benefits of enabling dual household gas use decarbonisation pathways in Australia. Household energy customers deserve access to all cost-competitive energy decarbonisation options, be they electrification or otherwise – renewable gas firmly fits this description while reducing the overall burden of household decarbonisation.

It is worth noting that this analysis has been performed excluding consideration of government appliance subsidies. This is because appliance subsidies are a choice that could be applied to appliances that use either electricity or renewable gas. While this is explored further in Section 3.1 below, undertaking analysis that excludes appliance subsidies produces genuine balanced outcomes to which the application of subsidies can be more accurately considered.

With high-efficiency hydrogen-ready appliances costing less than high-efficiency electric appliances, applying subsidies equally across both can enable more household decarbonisation for every government dollar spent subsidising the hydrogen-ready option.



2.1.1 RENEWABLE GAS COMPETES WITH RENEWABLE ELECTRICITY

Decades of research on low VRE generation costs may raise questions about the validity of the above analysis. However, a clearer understanding emerges when examining the requirements for supplying and utilizing firm renewable energy.

Wholesale production of renewable gas is generally equal or higher cost compared to VRE generation. Once produced, gas and hydrogen pipelines cost less than powerlines when transporting the same quantity of energy over the same distance.[13] These same pipelines can typically be designed to store energy for under $20 per megawatt hour, and in many cases under $10 per megawatt hour – a cost beaten by underground gas storage capable of seasonal storage. Gas and hydrogen appliances also cost much less than electric appliances.[14]

This firm renewable gas supply chain compares favourably to the supply chain required to supply firm renewable electricity based upon VRE generation. Higher cost powerlines and higher cost electricity storage are required to deliver lower cost VRE generation for use in higher-cost electric appliances, but at lower quantities where heat pumps can be used.

It is through these supply chain and appliance differences that it is possible for firm renewable gas and firm renewable electricity to be cost-competitive for use in the home. In addition, all gas and hydrogen pipelines are designed as underground infrastructure under Australian safety standards, minimising impacts on rural landholders and delivering higher reliability outcomes as they are less exposed to extreme weather and bushfire events.

[13] GPA Engineering, 2022, Pipelines vs Powerlines: A Technoeconomic Analysis in the Australian Context available at https://www.apga.org.au/sites/default/files/uploaded-content/field_f_content_file/pipelines_vs_powerlines_-_a_technoeconomic_analysis_in_the_australian_context.pdf
[14] Frontier Economics, 2022, Cost of switching from gas to electric appliances in the home: A report for the Gas Appliance Manufacturer's Association of Australia, https://gamaa.asn.au/wp-content/uploads/2022/07/Frontier-Economics-Report-GAMAA.pdf

2.1.2 WHY AREN'T RENEWABLE GASES USED IN THE HOME TODAY

Renewable gas is used in homes in Australia today. As detailed in Appendix 1, thousands of households around Australia have had their gas combustion emissions reduced through renewable gas demonstration projects delivered by the gas sector. But the larger question remains – why is renewable gas use in the home not more prevalent considering the cost competitiveness of the option?

There is an imbalance in legislation enabling decarbonisation through forms of renewable energy other than electrification. This impedes all gas users, including household users, from using renewable gas to decarbonise gas use.

In the electricity sector, energy retailers and wholesale electricity customers have the option to purchase LGCs or GreenPower electricity certificates and have these certificates considered in emissions reporting under NGER. This option allows provides a direct economic incentive for paying for renewable electricity supply deliverer to customers via existing electricity infrastructure.

Retailers and gas customers do not have the same option to access renewable gas. There is currently no legislative framework to allow renewable gas use to be recognised if it is delivered via existing gas infrastructure – the least cost option for delivering renewable gas. A pilot Green Gas Certificate Scheme only commenced in August 2023, but this is not widely available or recognised under NGER despite certificates also being produced by GreenPower – the same entity recognised for renewable electricity accounting.

The RET's exclusive support for renewable electricity supply was pivotal in driving the growth of renewable electricity, propelling its market share along the innovation diffusion curve to establish a mature market (refer to Appendix 3). If similar support had been extended to renewable gas, Australia might have already developed dual renewable energy pathways. Notably, the RET did promote biogas production for electricity generation, resulting in over 100 Australian facilities currently utilizing biogas for this purpose.

There is no reason for retailers to sell renewable gas to household customers when legislation ignores emissions reduction from using gas delivered via existing infrastructure. This is why households are not being offered retail renewable gas today. Legislation must be changed to enable recognition of decarbonisation through renewable gas use in the home and by all other gas users which contract delivery of renewable gases via existing infrastructure.

2.2 EMISSION IMPACTS OF ELECTRIFICATION AND RENEWABLE GAS

Premature electrification of households, especially in regions reliant on coal for electricity, can contribute to an increase in greenhouse gas emissions in the short-to-medium term. In opposition to the Federal Government's aims to rapidly decarbonise Australia's economy, it is broadly accepted that household electrification will increase greenhouse gas emissions over the short-to-medium term[15,16]. This is due to the aggregated emissions intensity of generators supplying the National Electricity Market (NEM).[17]

This was quantified in a 2021 study by the University of Melbourne for the Future Fuels CRC, which modelled the effect of residential electrification on Victoria's emission reduction plans and found emissions increased by up to 15 per cent.[18] This remains true even when considering the efficiency advantage of heat pumps and induction cooktops, and is in large part due to the state's reliance on brown-coal generation.

The analysis found that natural gas in residential settings will remain the lower-emitting option until 2035, but we acknowledge that the transition has accelerated since the publication of the initial research in 2021. However, Victoria's reliance on brown coal, with an emissions intensity twice as potent as natural gas, will continue for the medium term due to challenges in connecting new renewable generation to the NEM – a fact reinforced by the Victorian Government reaching agreements to financially support the operation of Loy Yang A and Yallourn brown coal generators until 2035 and 2028 respectively.

While transitioning to renewable energy sources is essential for a sustainable future, rushing to electrify households using a majority coal-fired grid fails to achieve emission reductions. Instead, a measured approach that incorporates natural and renewable gases and acknowledges their lower emissions is vital.

Electrification of gas use in the home will reduce emissions in all cases – one day. But it is not in the short-to-medium term. The University of Melbourne's findings underscore the importance of this nuance in the energy transition.

---

[15] Climate Council, 2022, Switch and save: how gas is costing households, https://www.climatecouncil.org.au/wp-content/uploads/2022/10/CC_MVSA0323-CC-Report-Switch-and-Save-Gas-vs-Electricity_V6-FA-Screen-Single.pdf
[16] Wood T quoted in Baxendale R, Andrews Government gas ban to increase emissions, The Australian, https://www.theaustralian.com.au/nation/andrews-governments-gas-ban-to-increase-emissions/news-story/bd58cee775a7b5f74a070fb16a39461c
[17] Clean Energy Regulator, 2023, Emissions and Energy Reporting System release 2022-23, https://www.cleanenergyregulator.gov.au/OSR/EERS/eers-current-release
[18] Future Fuels CRC, 2021, Integrated Electricity and Gas Systems Studies: Electrification of Heating, https://www.futurefuelscrc.com/wp-content/uploads/FF-CRC-Integrated-Electricity-and-Gas-Systems-Studies-Electrification-of-Heating-for-public-release.pdf

2.2.2 REDUCING EMISSIONS THROUGH RENEWABLE GAS

Today, the 166 PJ per annum of residential gas use accounts for around 17 per cent of total domestic direct gas consumption and less than two per cent of Australia's total emissions. Despite this, residential gas use has been a specific target for recent government decarbonisation strategies, especially in Victoria and the ACT. These have been undertaken without considering the decarbonisation potential of gas use itself, and that gas networks have decarbonisation pathways.

Most studies setting out the long-term emission benefits of residential electrification do not assume any direct decarbonisation of gas. However, gas networks can, should and are evolving in alignment with decarbonisation efforts, most notably by enabling renewable gas uptake by their customers. This focus on renewable gases is because they are considered to produce zero carbon dioxide emissions when combusted, and better than 99 per cent less carbon dioxide equivalent emissions compared to natural gas.[19]

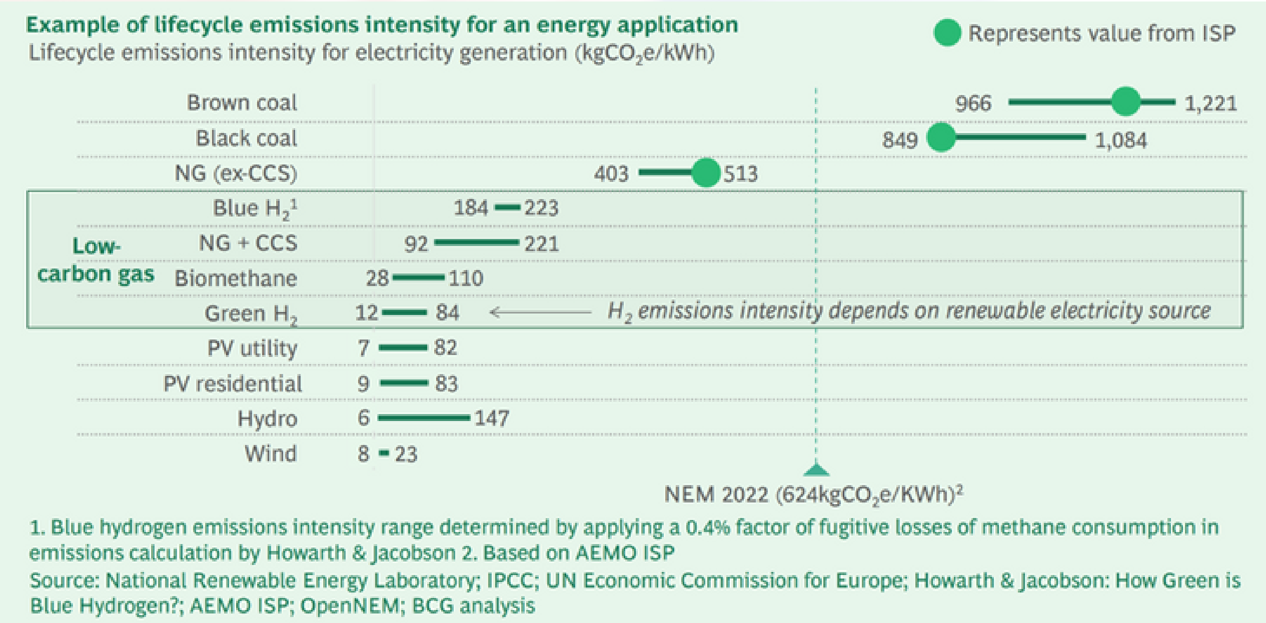
Beyond Scope 1 emissions of combustion, green hydrogen and biomethane also have equivalent lifecycle emissions to common forms of renewable electricity (Figure 4).

The analysis by BCG found lifecycle emissions of renewable gases range between 12 to 110 kgCO2e per kilowatt hour compared to renewable electricity ranging from 6 to 147 kgCO2e per kilowatt hour. This is why using renewable gas alongside electrification has been found to be able to reduce emissions from domestic gas by 16 to 50 per cent by 2030,[20] taking advantage of the existing gas network transmission and distribution infrastructure to do so.

[19] See the National Greenhouse and Energy Reporting (Measurement) Determination 2008, https://www.legislation.gov.au/Details/F2023C00815
[20] ENEA, 2022, 2030 Emission Reduction Opportunities for Gas Networks, final report prepared for Energy Networks Australia, https://www.energynetworks.com.au/miscellaneous/2030-emission-reduction-opportunities-for-gas-networks-by-enea-consulting-2022

2.2.2 REDUCING EMISSIONS THROUGH RENEWABLE GAS

Figure 4 : Consuming low-carbon gases results in similar lifecycle emissions as renewable electricity



Source: BCG, 2023, The role of gas infrastructure in Australia's energy transition

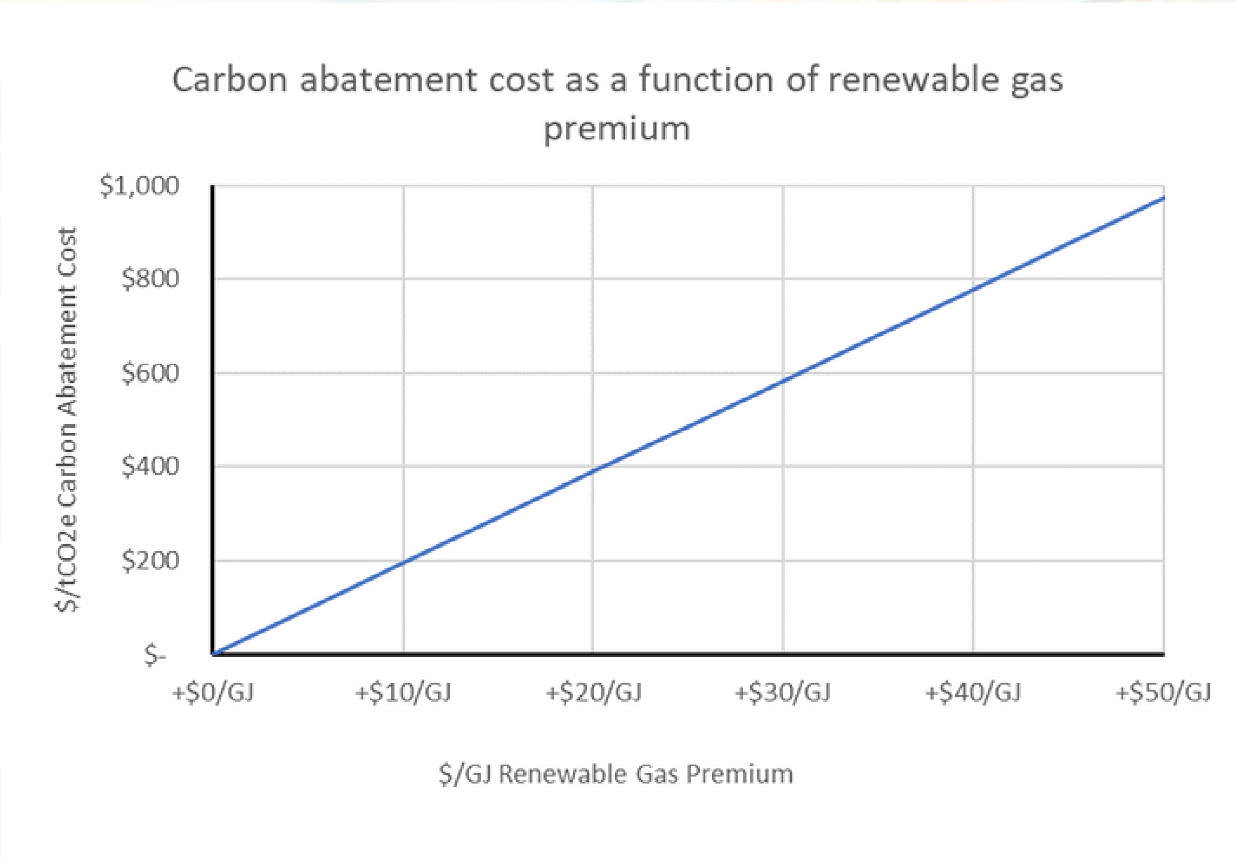
2.2.3 RENEWABLE GAS COST OF ABATEMENT

The most immediately available renewable gas which could decarbonise homes today is biomethane. Biomethane requires no change in infrastructure or appliances, nor does low level hydrogen blending. Abatement cost for renewable gases which can be used in existing appliances is simply a factor of how much more renewable gas costs compared to natural gas.

Using one gigajoule of renewable gas in place of one gigajoule of natural gas reduces emissions by 51.4 kilograms of carbon dioxide. This means that every dollar per gigajoule of biomethane premium equates to $19.46 per tonne CO2 equivalent carbon abatement cost. From this relationship, the carbon abatement cost relationship seen in Figure 5 can be produced.

Figure 5 is a useful tool for comparing household electrification costs of abatement to their renewable gas alternatives. The theoretical production capacity of renewable gases which can be considered in this way accounts for enough supply to decarbonise half of all direct gas use in Australia, residential or otherwise.

Figure 5: Carbon abatement cost as a function of renewable gas premium



Source: APGA analysis of NGER Measurement Determination data

3 SOCIAL AND ECONOMIC RISKS OF AN ELECTRIFICATION-ONLY PATHWAY

Achieving 100 per cent electrification of households is extremely challenging. The upfront cost to customers; the risks to low-income Australians; the practical challenge of non-like-for-like appliance replacement; the space issue in high-density living; and the customer choice challenge – these are all broadly recognised. What isn't always identified alongside these is the risk of higher network costs forcing commercial and industrial gas customers off the gas and the increasing decarbonisation burden this and households add to the challenge of achieving secure 82 per cent renewable electricity in Australia.

None of these risks have to be accepted if renewable gas is an option to decarbonise gas use in the home.

APGA may not be best placed to articulate each of these risks fully. However, we do understand a solution that can mitigate each of these risks. This inquiry should serve as a platform to convene thought leaders and experts—those who understand the challenges and those who can offer innovative solutions.

This collaboration could pave the way for strategies that extend beyond attempting to completely electrify household energy.

This section addresses the following Terms of Reference:

(b) the macro-barriers to increasing the uptake of home electrification;

(f) the impacts and opportunities of household electrification for domestic energy security, household energy independence and for balance of international trade;

(g) the impacts of household electrification on reducing household energy spending and energy inflation as a component of the consumer price index;

(h) solutions to the economic barriers to electrification for low-income households;

(i) the effectiveness of existing Australian Federal, state and local government initiatives to promote and provide market incentives for household electrification;

3.1 SOCIAL RISKS OF 100 PER CENT HOUSEHOLD ELECTRIFICATION

Many of the social risks of mandating 100 per cent household electrification are well documented.[21] Efficient electric appliances are costly, as is installing them in existing homes, particularly in high-density residential settings. This costliness is most challenging for low-income households, including renters which either don't have the choice to change or are forced to bear the cost of appliances through increased rents.

These costs risk amplifying existing social inequalities. They risk low-income households having to choose between heating and eating. It also restricts rental markets for low-income families through increased rents, in turn exacerbating the risk of homelessness. The upfront cost of electrification risks deepening social inequality at a time of acute cost-of-living pressures.

This is especially the case where households could have achieved lower upfront and overall energy costs through renewable gas uptake.
The potential hazard is made worse by the last user challenge of energy network abandonment. As more users leave gas networks, those who remain will likely incur greater costs as fewer people pay for the same infrastructure.

Through 100 per cent electrification policies, households that cannot afford or are physically incapable of electrifying are most likely to carry the 'last user' cost network burden. To date, no state or federal government has planned to mitigate the consequences of this looming additional cost for households.

Others are much better placed to further elaborate on the significant social costs and implications of 100 per cent household electrification. Instead, this submission will focus on how to mitigate these risks. While some suggest appliance subsidies as a salve, there is another option – renewable gas.

---

[21] Grattan Institute, 2023, Getting off gas: Why, how, and who should pay?, https://grattan.edu.au/wp-content/uploads/2023/06/Getting-off-gas-why-how-and-who-should-pay.pdf; also see Frontier Economics, 2022, Cost of switching from gas to electric appliances in the home; ACT Government, 2023, Developing an ACT Integrated Energy Plan, https://hdp-au-prod-app-act-yoursay-files.s3.ap-southeast-2.amazonaws.com/1216/9138/6293/Integrated_Energy_Plan_Position_Paper_ACCESS_FA2.pdf , Chandrashekeran S, de Bruyn J, Bryant D and Sullivan D, 2023, Enabling electrification: Addressing the barriers to moving off gas faced by lower-income households, Brotherhood of St Lawrence, https://library.bsl.org.au/bsljspui/bitstream/1/13361/2/BSL_LCC_Enabling_electrification_2023v2.pdf

3.1.1 RENEWABLE GAS MITIGATES SOCIAL RISK OF 100% ELECTRIFICATION

Almost all social risks of 100 per cent electrification are mitigated by allowing gas customers the option to choose between electrification and renewable gas decarbonisation options. This is due to the simplicity of using renewable gases in gas and hydrogen appliances:

- A significant proportion of anticipated renewable gas supply can be used in existing gas appliances; and
- Conversion to new hydrogen appliances where necessary entails lower upfront cost and complexity than installing equivalent electric appliances.[22]

This means that renewable gases can be used at no or lower upfront appliance cost compared to electrification, and with lower complexity where conversion is required.

This immediately removes or significantly reduces the following social risks:
- The upfront economic hurdle for low-income homeowners.
- The increased rental cost risk for low-income renters.
- The access to appliance conversion risk for all Australians who rent.
- The upfront cost, space, and complexity risk for Australian high-density households
- The risk of last network user costs for all Australians.

[22] Frontier Economics, 2022, Cost of switching from gas to electric appliances in the home. https://gamaa.asn.au/wp-content/uploads/2022/07/Frontier-Economics-Report-GAMAA.pdf

3.1.1.1 APPLIANCE SUBSIDIES

Where the combined appliance and energy cost of renewable gas use is equal to or less than electrification, the ability to pay less upfront reduces the economic hurdle of decarbonisation. But it does not always remove it.

Appliance subsidies could be used to completely remove economic costs or renewable gas readiness for less than the cost of electrification subsidies – framed differently, more decarbonisation can be enabled for every government dollar put towards subsidising high-efficiency hydrogen-ready appliances.

3.1.2. CUSTOMER CHOICE

The household decarbonisation debate focuses on economically efficient choices to reduce emissions. However, it's essential to acknowledge that human decision-making can be influenced by a myriad of factors, not always adhering strictly to rational economic principles.

Research reveals that a significant proportion of Australians, in particular Australians from diverse cultural backgrounds, prefer to use gas. [23]

It presents a challenging and unfortunate scenario if 100 per cent electrification is perceived as the sole solution for household decarbonisation. The risks associated with customer choice in decarbonisation efforts are mitigated when consumers have the alternative to opt for renewable gas.

[23] APGA, 2023, Media Release: Victorians welcome new gas supply to unlock a net-zero renewable future, Frontier Economics, 2022, Cost of switching from gas to electric appliances in the home.

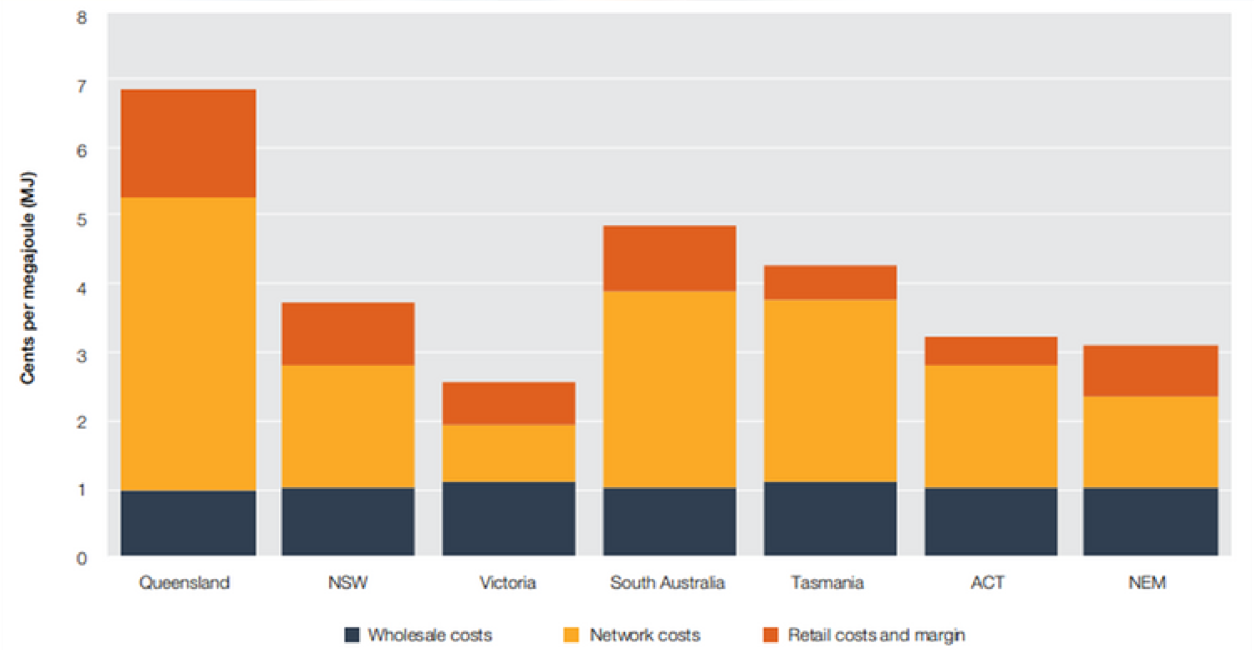
3.2 RISK OF COSTLIER COMMERCIAL AND INDUSTRIAL DECARBONISATION

Any decision to restrict Australian households from gas connections will also have broader implications for businesses and commercial users who depend heavily on the gas network. This dependency covers both the immediate supply of gas, and the broader principle of economies of scale.

When a system or service, like the gas network, loses a significant portion of its user base (in this case, all households), the costs and efficiency of maintaining that system can increase for the remaining users until it become untenable. Australian governments appear to largely expect that gas networks will continue to operate as they do today, supplying commercial and industrial users for equivalent cost. But unless urgent steps are taken to ensure the long-term viability of these networks, commercial decisions may precipitate the early decommissioning of gas infrastructure assets.

Gas networks can likely support the loss of some household customers without substantial impact. Gas bill breakdown data published by the Australian Energy Regulator indicates that network costs account for around 40 per cent of residential gas bills nationally (Figure 6).[24] This percentage increases – for households and other network customers – as the residential share decreases.

Figure 6. Composition of residential gas bills



Note: Data are estimates at 2017. Average residential customer prices excluding GST (real $2018–19).
Source: Oakley Greenwood, Gas price trends review 2017, March 2018.

Source: AER, 2022, Chapter 6: Retail energy markets, State of the Energy Market 2022

[24] Australian Energy Regulator, 2022, Chapter 6: Retail energy markets, State of the Energy Market 2022, APGA, 2023, Media Release: Victorians welcome new gas supply to unlock a net-zero renewable future, Frontier Economics, 2022, Cost of switching from gas to electric appliances in the home.

3.2 RISK OF COSTLIER COMMERCIAL AND INDUSTRIAL DECARBONISATION

This will have far-reaching effects across the broader Australian economy. The domestic-enabled economic activity of gas as an energy source was approximately $470 billion in 2019-20, with the gas supply chain directly underpinning more than 46,800 businesses and 165,500 full-time equivalent jobs.[25]

For businesses that are geographically spread across metropolitan areas, and where electric alternatives are not viable or cost-effective, a reliable gas supply is a necessity. If the gas networks were to be decommissioned due to reduced viability, these businesses could be compelled to consider relocating their operations to regions where they can secure more reliable and cost-effective energy solutions – or, alternatively, to cease trading. These economic impacts, coupled with the potential for carbon leakage, have already begun to be felt.

The discussion around residential electrification is often set within the larger narrative of decarbonising energy infrastructure. Rather than focusing solely on electrifying energy use, global governments and organisations are becoming cognisant that there can be no least-cost pathway toward the decarbonisation of households and businesses without embracing renewable gases.[26] These carbon-neutral gases provide a viable and sustainable way to utilise the existing gas infrastructure while meeting environmental objectives.

[25] Australian Economic Advocacy Solutions, 2022, Economic and Employment Contribution of the Australian Gas Industry Supply Chain: 2020-21, Australian Economic Advocacy Solutions, 2022, Economic and Employment Contribution of the Australian Gas Industry Supply Chain: 2020-21
[26] International Energy Agency, 2022, World Energy Outlook 2022, https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf; International Renewable Energy Agency, 2022, World Energy Transitions Outlook 2022: 1.5C pathway, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Mar/IRENA_World_Energy_Transitions_Outlook_2022.pdf?rev=6ff451981b0948c6894546661c6658a1 ; International Renewable Energy Agency, 2022, Expert insight: Renewables and Green Gas: The Only Viable Antidote to High Fossil Fuel Prices, https://www.irena.org/News/expertinsights/2022/Feb/Renewables-and-green-gas

3.2 RISK OF COSTLIER COMMERCIAL AND INDUSTRIAL DECARBONISATION

While the idea of restricting gas connections to Australian households may seem like a step towards decarbonisation, it's essential to consider the broader implications on commercial sectors and the economy. A more nuanced approach would be to transition to renewable gases, leveraging existing infrastructure and ensuring a sustainable and reliable energy supply for both households and businesses.

Retaining household gas demand for renewable gases would have the additional benefits of preserving the economies of scale, maintaining the viability of the gas network for commercial entities. Additionally, businesses linked directly to the gas industry, from installation to maintenance, would be poised to benefit from a transition to these greener gases, ensuring job security and spurring further innovation in the sector.

As discussed in Section 4.2, a transition to renewable gases can help maintain energy security for Australian businesses. The energy mix, robust due to its diversity today, can maintain this robustness while reducing carbon intensity with the inclusion of biomethane and green hydrogen. Instead of becoming dependent on electricity or energy imports, Australia could continue to have a balanced, secure energy portfolio based on its own energy supply chains.

3.3 RISK OF A LESS STABLE RENEWABLE ENERGY SYSTEM

Australia's electricity system faces a monumental challenge to decarbonise.

Ambitious federal targets of 82 per cent renewable electricity by 2030 face headwinds of transmission buildout delays coupled with massive and already prolonged electricity storage buildout as well as a steadily deteriorating electricity system beyond limits set by AEMO. With high-emitting coal-fired generation as the backstop, failure is not an option.

This is all before we add 100 per cent of household gas demand to Australia's electricity system. All of the work required to achieve 82 per cent renewable electricity in the existing electricity system is amplified by adding household gas use to the challenge. Further, success in achieving 82 per cent renewable electricity is put at genuine risk if 100 per cent household electrification starts to force other gas customers onto the electricity system as well (see Section 3.2 above). Add electric vehicles (EVs) and the challenge amplifies again.

There is another option. Allowing households to decarbonise through renewable gas uptake reduces the immediate burden of household electrification on the electricity system. This further reduces the risk of other gas customers being forced onto the electricity system through higher gas infrastructure costs. A strong domestic hydrogen sector can even reduce EV demand on the grid by supporting hydrogen electric vehicles.

Unnecessarily pursuing 100 per cent household electrification risks further undermining grid stability unnecessarily. This in turn risks undermining the energy transition. All can be avoided by providing customers with the choice to use renewable gas in the home.

3.3.1 THE ELECTRICITY GRID STABILITY CHALLENGE

The National Electricity Market (NEM) faces the most significant transformation since its inception nearly 25 years ago. As highlighted in the Australian Energy Market Operator's 2023 Electricity Statement of Opportunities[27], up to 62 per cent of the coal fleet is anticipated to be shuttered before 2033. This signals the need for imminent and substantial investment in the energy sector to ensure system's reliability and the necessity of considering the implications of pushing for widespread residential electrification without adequate preparation.

[27] AEMO, 2023, 2023 Electricity Statement of Opportunities, https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2023/2023-electricity-statement-of-opportunities.pdf?la=en

3.3.1 THE ELECTRICITY GRID STABILITY CHALLENGE

The reliability standard measures the percentage of total energy consumption not served due to a shortage of capacity or energy. Exceeding this standard indicates the potential for power outages, in both households and industry, underscoring the urgency of addressing the predicted reliability gaps.

The ESOO assessment regarding the reliability of energy supply in the coming decade anticipates reliability gaps as soon as the 2023-24 summer in Victoria and South Australia. These states, New South Wales and Queensland are expected to breach reliability standards throughout the following decade by a significantly higher degree than previously forecast.

There are a multitude of reasons behind these projection findings, but observable delays and cost blowouts in the delivery of new energy projects are significant contributors. This includes delays to major projects such as the Snowy Hydro 2.0, and challenging electricity transmission projects like HumeLink and VNI West. These projects are necessary to deliver renewable electricity to the grid.

The reliability outlook also now factors in increased generator unplanned outage rates, refined weather data, and higher energy consumption forecasts driven by the electrification of households and businesses. As Australia moves towards a greater reliance on electricity the need for a stable, reliable dual-fuel energy system becomes more pressing. As AEMO outlines, electrification efforts will increase electricity demand at times where it will be difficult to meet that demand, and if the grid is unprepared or lacks sufficient renewable sources, this could lead to electricity shortages. These scenarios not only have economic implications but also endanger public health and welfare.

Government initiatives to promote electrification – from consumer adoption of electric vehicles to the well-intentioned but short-sighted policies to transition from residential gas heating to electric heat pumps – are also driving electricity consumption upward before renewable sources are integrated into the NEM. This has forced state governments to make arrangements to extend the lives of increasingly unreliable and higher-emitting coal-fired generators at major taxpayer cost to ensure the NEM remains dependable.

As the grid shifts away from baseload and towards variable electricity, the intermittency imposed on the NEM poses greater challenges. As ESOO notes, there are higher forecast occurrences of low wind and high demand conditions in regions like Victoria during peak periods. Without adequate storage solutions, this will contribute to reliability risks.

3.3.2 CHALLENGE OF THE VICTORIAN GRID

As the state with the highest proportion of residential gas use, it is worth considering the Victorian context and the challenges it faces in electrification.

Natural gas accounts for 23 per cent of all energy consumed in Victoria, while 34 per cent is accounted for by coal, and 6 per cent from renewables.

It is notable that the state will ban new gas network connections from 1 January 2024. At the same time, it has committed to increasing its long-term reliance on coal-fired generation by signing deals to ensure Loy Yang A and Yallourn power plants keep burning coal. This is in spite of the fact that the brown coal burnt at Loy Yang A and Yallourn is more than twice as emissions-intensive as natural gas.

Recent analysis by energy consultancy EnergyQuest has found that accelerating the electrification of all gas use will significantly worsen Victoria's already concerning reliability outlook (Figure 7).[28]

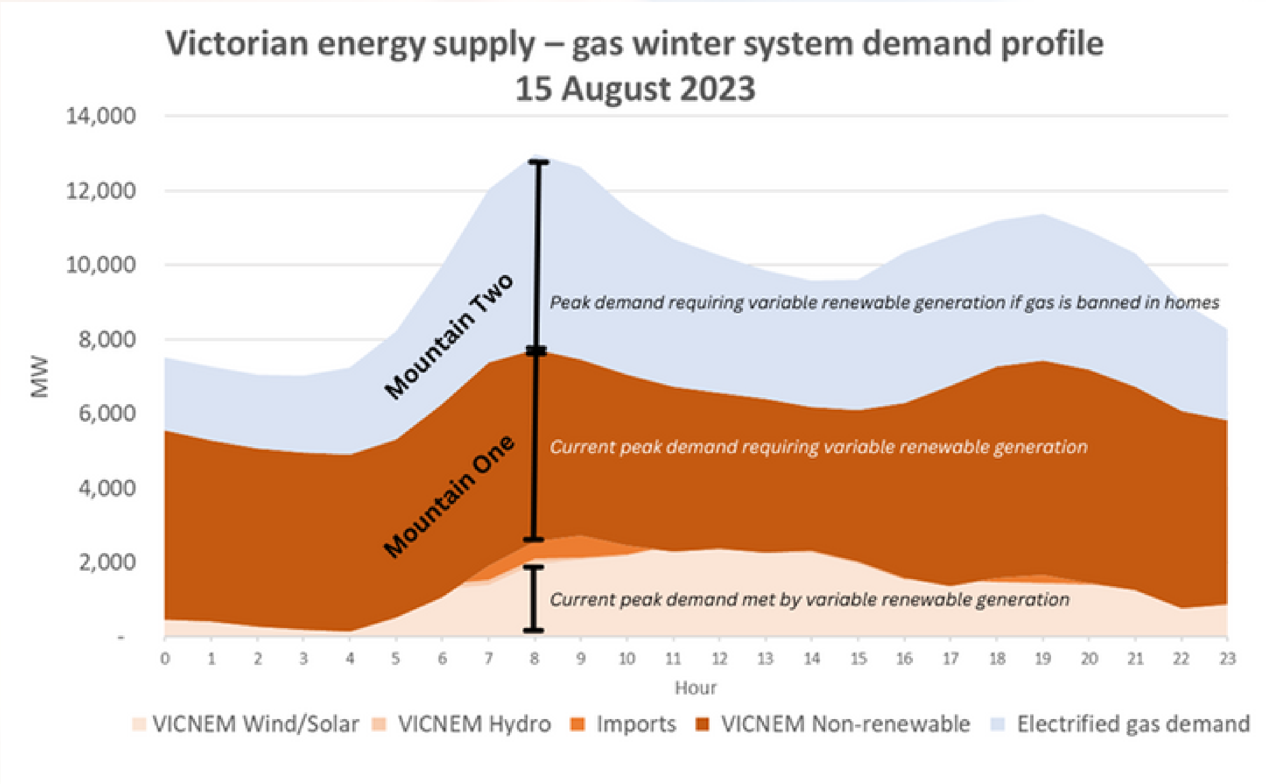
AEMO also acknowledges this in the 2023 ESOO, stating the projected electrification of traditional gas loads, particularly heating loads in Victoria, increases forecast consumption and maximum demands in winter.[29]

Throughout the 2023 winter, this analysis found that to replace coal-fired generation during peak periods to meet current demand, Victoria would require 233 per cent more renewable output than is currently available.
If the Victorian Government were to press further and shift all gas demand to renewable electricity, output would need to rise by a further 206 per cent to ensure electricity supply remained reliable – even if assuming a 71 per cent electric appliance efficiency benefit.

In total, EnergyQuest found replacing non-renewable generation and total gas use with renewables would require 539 per cent more output than has been observed during peak demand periods this winter. The analysis does not include the major uplift in electricity demand that will be required for charging EVs.

[28] EnergyQuest, 2023, Victorian peak demand analysis, https://www.apga.org.au/sites/default/files/uploaded-content/website-content/energyquest_-_victorian_peak_demand_analysis_report_august_2023.pdf
[29] AEMO, 2023, 2023 Electricity Statement of Opportunities, AEMO, 2023, 2023 Electricity Statement of Opportunities.

Figure 7. Victorian energy supply - gas winter system demand profile, 20 June 2023



Source: EnergyQuest, 2023, Victorian peak demand analysis

Maintaining residential gas connections offers an effective counterbalance in this scenario.

By promoting renewable gases for heating and cooking while prioritising electricity as the most economically efficient decarbonisation avenue for residential transport, it's possible to mitigate the potential demand surges on the electricity network. Residential gas connections both act as a direct energy source and reduce immediate demand on the central grid, thereby lowering risk of network reliability events.

[28] EnergyQuest, 2023, Victorian peak demand analysis, https://www.apga.org.au/sites/default/files/uploaded-content/website-content/energyquest_-_victorian_peak_demand_analysis_report_august_2023.pdf
[29] AEMO, 2023, 2023 Electricity Statement of Opportunities, AEMO, 2023, 2023 Electricity Statement of Opportunities.

4 ECONOMIC BENEFITS OF DUAL DECARBONISATION PATHWAYS

Providing dual renewable electricity and renewable gas decarbonisation pathways for all energy customers allows the market to deliver least cost decarbonisation outcomes for each individual customer – household and otherwise. Australia has the opportunity to pick up the pace of its energy transition by decarbonising dual energy pathways in parallel with one another, applying different skillsets and supply chains to each sector while not wasting tens of billions of dollars' worth of renewable energy capable gas infrastructure.

Doing so can also deliver a more secure energy system, both from international price shocks and instability within either system. There is no downside for customers in allowing households to decarbonise through dual renewable energy pathways.

This section addresses the following Terms of Reference:

(f) the impacts and opportunities of household electrification for domestic energy security, household energy independence and for balance of international trade;

(h) solutions to the economic barriers to electrification for low-income households;

(k) any other matters.

[28] EnergyQuest, 2023, Victorian peak demand analysis, https://www.apga.org.au/sites/default/files/uploaded-content/website-content/energyquest_-_victorian_peak_demand_analysis_report_august_2023.pdf
[29] AEMO, 2023, 2023 Electricity Statement of Opportunities, AEMO, 2023, 2023 Electricity Statement of Opportunities.

4.1 RAPID DECARBONISATION FOR AUSTRALIA

4.1.1 BEST USE CASES FOR RENEWABLE GAS AND RENEWABLE ELECTRICITY

When considering the decarbonisation opportunities of renewable gases, recent government positions have largely centred on 'reserving' renewable gas supplies for 'high value' uses, namely industrial. In some respects, this is due to the perceived high cost and low availability of both renewable gases as a product, the high cost or feasibility of electrifying industrial uses, and the perceived value of electrification.

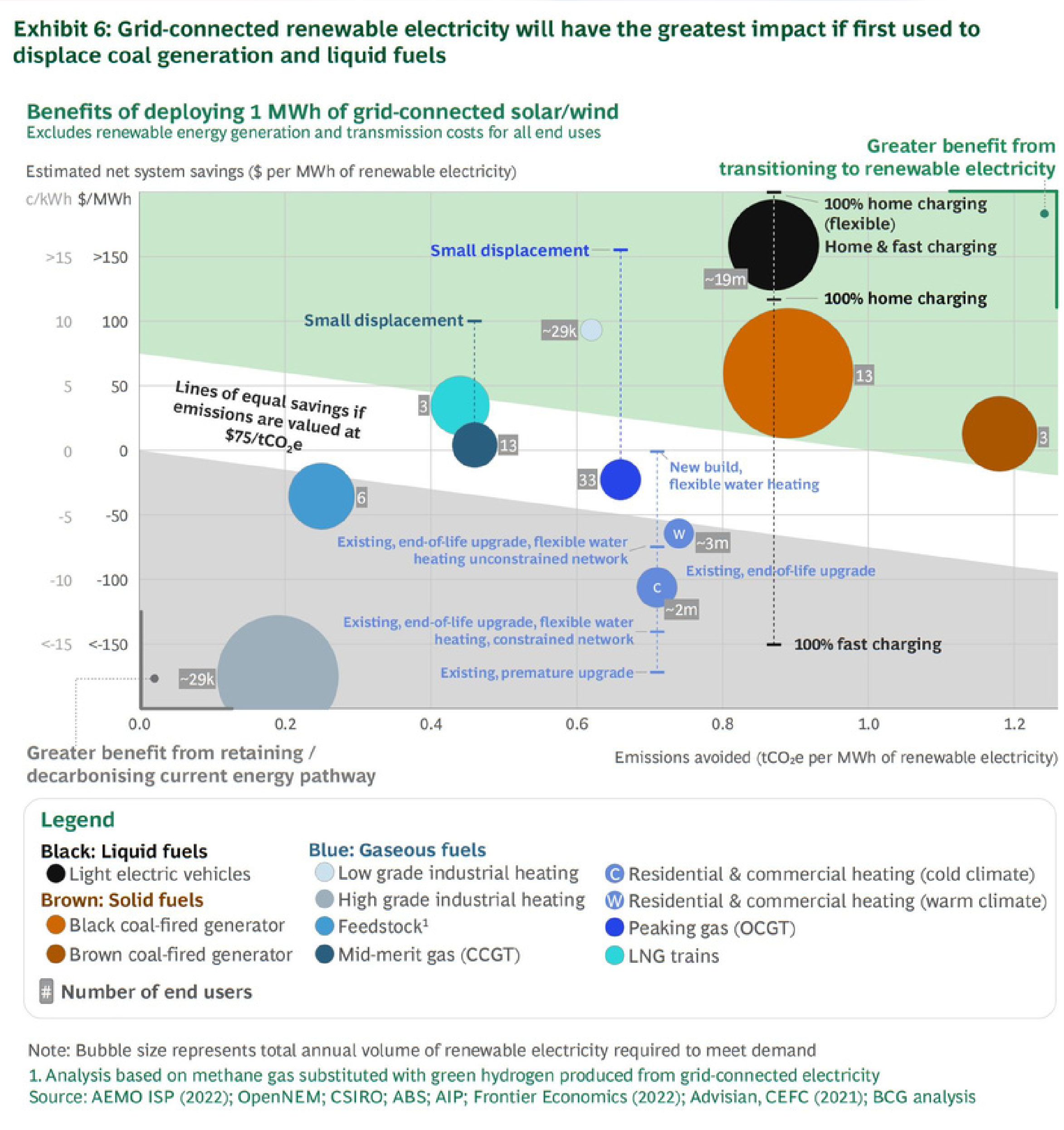
Once a like-for-like analysis is performed, we see the true cost of electrifying households is very high. The same is true for much of commercial and industrial gas demand.

The capital directed towards electrifying residences could instead be channelled into sectors where the potential for emission reductions is both higher and more cost-effective. Coal-fired generation, transportation and agriculture all account for a significant proportion of emissions – and as shown by a recent BCG report, cost less to reduce than electrifying homes.

Figure 8 shows that while some aspects of the economy via renewable electricity are cost-effective, there are cost-competitive and cheaper options for other aspects of the economy. By allocating disproportionate funds to residential electrification, governments and investors continue to neglect more impactful emission-reducing opportunities elsewhere.

4.1.1 BEST USE CASES FOR RENEWABLE GAS AND RENEWABLE ELECTRICITY

Figure 8: Grid-connected renewable electricity vs decarbonisation of current energy pathways



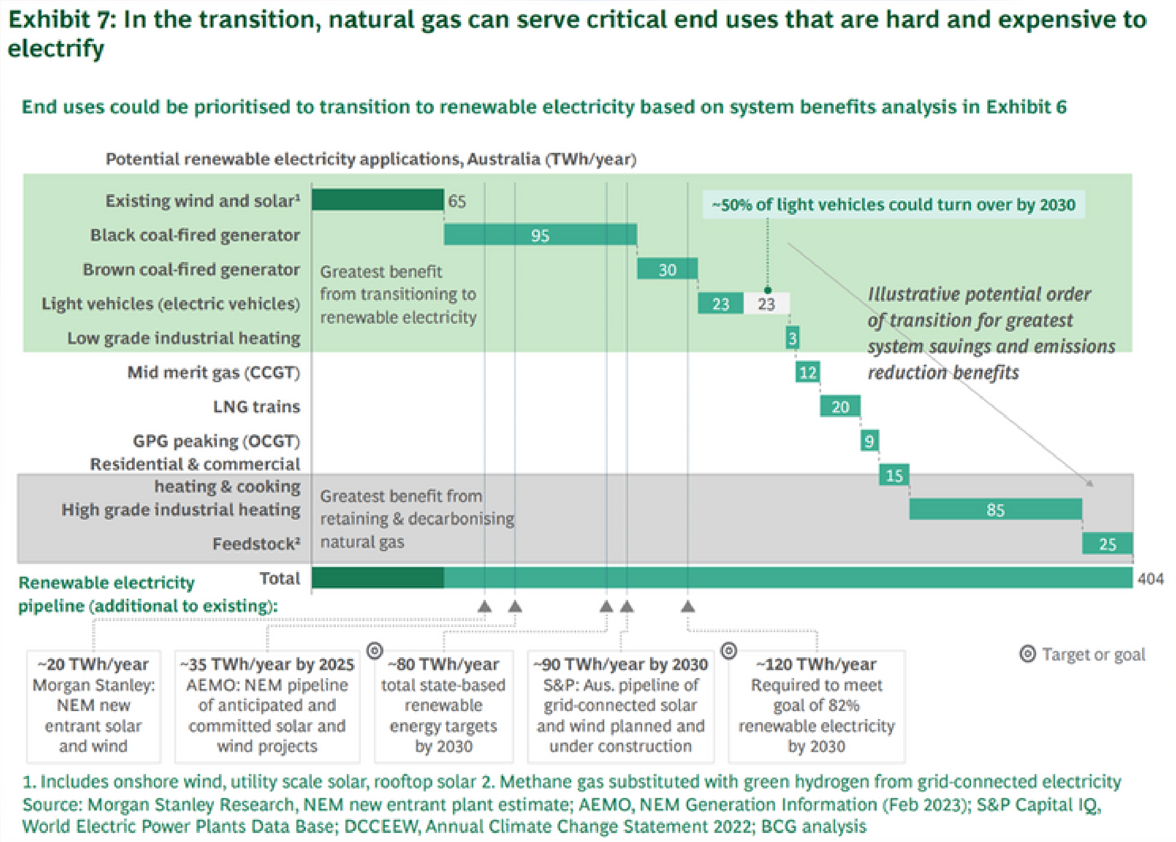
Source: BCG, 2023, The role of gas infrastructure in Australia's energy transition

This data can be built upon to consider a merit order for applying scarce renewable electricity resources to the sectors as seen in Figure 9. This figure shows that the most cost-effective decarbonisation comes from applying the next 174TWh of renewable electricity to the decarbonisation of coal-fired generation and light vehicle use before applying this energy to any other sector.

Furthermore, the next 166TWh of renewable electricity decarbonisation could be achieved through other forms of renewable energy for equal or lesser cost.

4.1.1 BEST USE CASES FOR RENEWABLE GAS AND RENEWABLE ELECTRICITY

Figure 9: Decarbonisation by renewable electricity priority stack



Source: BCG, 2023, The role of gas infrastructure in Australia's energy transition

This analysis indicates that there is a quicker and lower cost way to decarbonise all sectors considered within the analysis compared to full electrification.

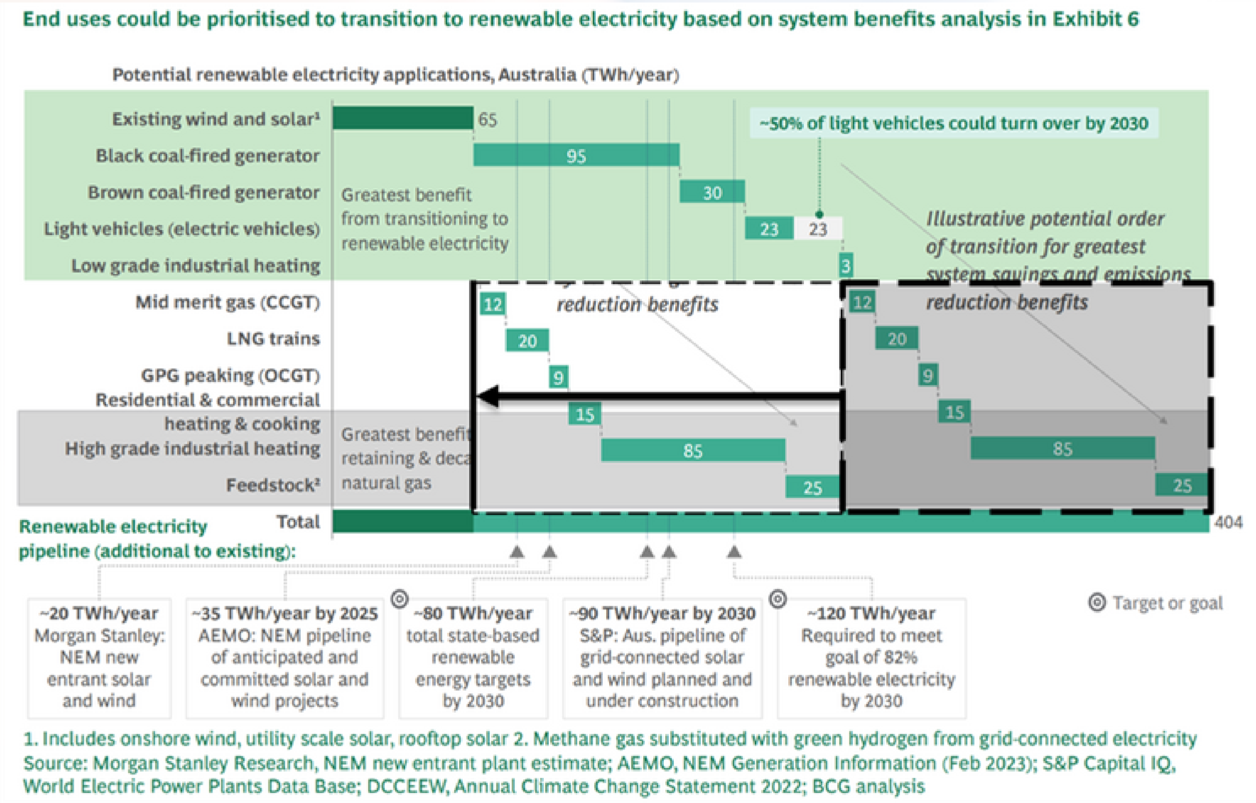
As seen in Figure 10, the latter portion of decarbonisation could be pursued in parallel with the first 177 TWh of electrification by applying renewable gas and other renewable fuels instead of electrification. Importantly, the white and grey backgrounds indicate that this wouldn't only be quicker but would be achievable at equal or lesser cost to full electrification.

Residential and commercial heating and cooking sit on the boundary of the cost-competitive and lower-cost portions of the decarbonisation priority stack.

Pursuing parallel renewable electricity and renewable gas decarbonisation can double the pace of decarbonisation while reducing costs. Pursuing 100 per cent electrification of households acts in opposition to this end.

4.1.1 BEST USE CASES FOR RENEWABLE GAS AND RENEWABLE ELECTRICITY

Figure 10: APGA analysis of accelerating decarbonisation considering the renewable electricity priority stack



Source: APGA analysis of BCG, 2023, The role of gas infrastructure in Australia's energy transition

4.2 INCREASED DOMESTIC ENERGY SECURITY

The value of renewable gas extends beyond cost-effective decarbonisation of gas consumers. National energy security can be improved through the deployment of parallel and complimentary renewable gas and renewable electricity supply chains. Improvements include but are not limited to:

- Improved vehicle fuel supply chain security of supply
- Improved electricity supply chain security of supply
- Improved gas supply chain security of supply

4.2.1 VEHICLE FUEL SUPPLY CHAIN SECURITY

Australia's greatest national energy security risk is in its liquid fuel supply chain. Predominantly supplied from overseas, Australian energy security is at the whims of international producers. A return to nationally produced vehicle fuels in particular would go a long way towards addressing Australian exposure to this energy security risk.

A robust renewable gas supply chain, and in particular, a robust hydrogen supply chain, can support domestic supply of decarbonises vehicle fuel. By pursuing this opportunity alongside residential, commercial and industrial hydrogen uptake, economies of scale can be leveraged in hydrogen production and infrastructure investments. An example of this is the opportunity to develop hydrogen pipelines along Australia's major highways between major demand centres.

Rather than developing bespoke hydrogen supply for industry, residential and vehicle customers, lower-cost hydrogen can be produced and transported via larger production facilities and larger pipelines along highways. Doing so would achieve economies of scale in energy production, transport and storage while securing domestic supply for each energy customer segment. Australian energy security stands to markedly improve by decoupling vehicle fuel demand from international markets via a transition to a hydrogen vehicle fleet.

4.2.2 ELECTRICITY SUPPLY CHAIN SECURITY

The development of a robust renewable gas supply chain can support the grid in much the same way as natural gas does today. Firm dispatchable renewable generation can be provided through renewable gas power generation, allowing the electricity sector access to low-cost biomethane and hydrogen pipeline energy storage. This low-cost energy storage can also be accessed through electrolysis demand response reducing grid load in times of need.

Grid load can further be reduced by simply supplying potential electricity customers with renewable gas instead, allowing for combined renewable electricity and renewable gas system optimisation. Also, grid constraints can be avoided altogether with VRE upstream of grid constraints able to be turned into hydrogen and used either directly or to generate firm dispatchable renewable electricity closer to demand centres.

By providing alternative energy storage, transport and firm generation solutions, renewable gas supply chains reduce national reliance on international lithium, copper, and other precious metal supply chains, as well as potentially constrained electric appliance supply chains. In doing so, renewable gases diversify the options for energy generation in Australia, improving national energy security.

4.2.3 GAS SUPPLY CHAIN SECURITY

Decades of state and federal legislation impeding investment in gas production have influenced the Australian gas market towards becoming short in supply[30]. This has increased gas prices and opened the country to potentially needing to import Liquified Natural Gas (LNG). This would make Australia dependent on other gas-producing nations for its energy supply, reducing energy security.

Prompt support for an Australian renewable gas market can deliver increased production into the gas supply chain. As natural gas supply further reduces, replacing supply with domestically produced renewable gases ensures that national energy security is maintained at the same time as renewable electricity is used to reduce our reliance on coal-fired generation.

[30] APGA, 2023, Submission: Reliability and supply adequacy framework for the east coast gas market, https://www.apga.org.au/sites/default/files/uploaded-content/field_f_content_file/230721_apga_submission_-_dcceew_stage_2_supply_adequacy.pdf

5 APPENDICES

APPENDIX 1: RENEWABLE GASES ARE ALREADY DECARBONISING AUSTRALIA

The first renewable gas programs are underway in Australia, with lower-carbon blends already being transported through domestic gas networks to properties in South Australia, Western Australia and New South Wales, while further projects are under development in Victoria and Queensland.

One such project is the Malabar Biomethane Injection Plant, a collaboration between Jemena and Sydney Water with funding from ARENA.[31] This pioneering venture is converting biogas from organic waste at the Malabar Water Resource Recovery Facility into biomethane for the gas network. This waste recovery facility is one of several in NSW, turning wastewater's organic waste into biogas. Jemena, owning the NSW gas network, has identified enough biomethane within range of its assets to make Sydney’s residential gas use carbon neutral.

Another innovative project, Australian Gas Infrastructure Group’s Hydrogen Park SA (HyP SA), is Australia's maiden initiative producing renewable hydrogen gas.[32] With the South Australian Government's backing, providing a $4.9 million grant towards the total $14.5 million cost,[33] the HyP SA project aligns with the state's ambitions of capitalising on its abundant renewable resources to be a global leader in renewable hydrogen and achieve net-zero emissions by 2050. Since beginning production in May 2021 and expanding in 2023, HyP SA has provided a 5 per cent renewable gas blend to over 4000 customers in southern Adelaide, covering residents, businesses, and educational institutions.

Additionally, hydrogen is supplied to industries via tube trailers, and now provides green fuel for Adelaide’s first two hydrogen buses. Expansion plans are underway, targeting a 10 per cent hydrogen blend in regions like Gladstone,[34] and Albury and Wodonga.[35]

---

[31] Australian Renewable Energy Agency, 2023, Malabar Biomethane Injection Project, accessed 28 September 2023, https://arena.gov.au/projects/malabar-biomethane-injection-project/ Jemena, 2023, Malabar Biomethane Injection Plant, accessed 28 September 2023, https://jemena.com.au/about/innovation/renewable-gas/key-projects/malabar-biomethane-project
[32] Australian Gas Infrastructure Group, 2023, Hydrogen Park South Australia, accessed 28 September 2023, https://www.agig.com.au/hydrogen-park-south-australia
[33] Department of Energy and Mining, 2023, Australian Gas Networks – HypSA, accessed 28 September 2023, https://www.energymining.sa.gov.au/industry/modern-energy/hydrogen-in-south-australia/hydrogen-projects-in-south-australia/australian-gas-networks-hypsa
[34] AGIG, 2023, HyP Gladstone, accessed 28 September 2023, https://www.agig.com.au/hydrogen-park-gladstone
[35] AGIG, 2023, HyP Murray Valley, accessed 28 September 2023, https://www.agig.com.au/hydrogen-park-murray-valley

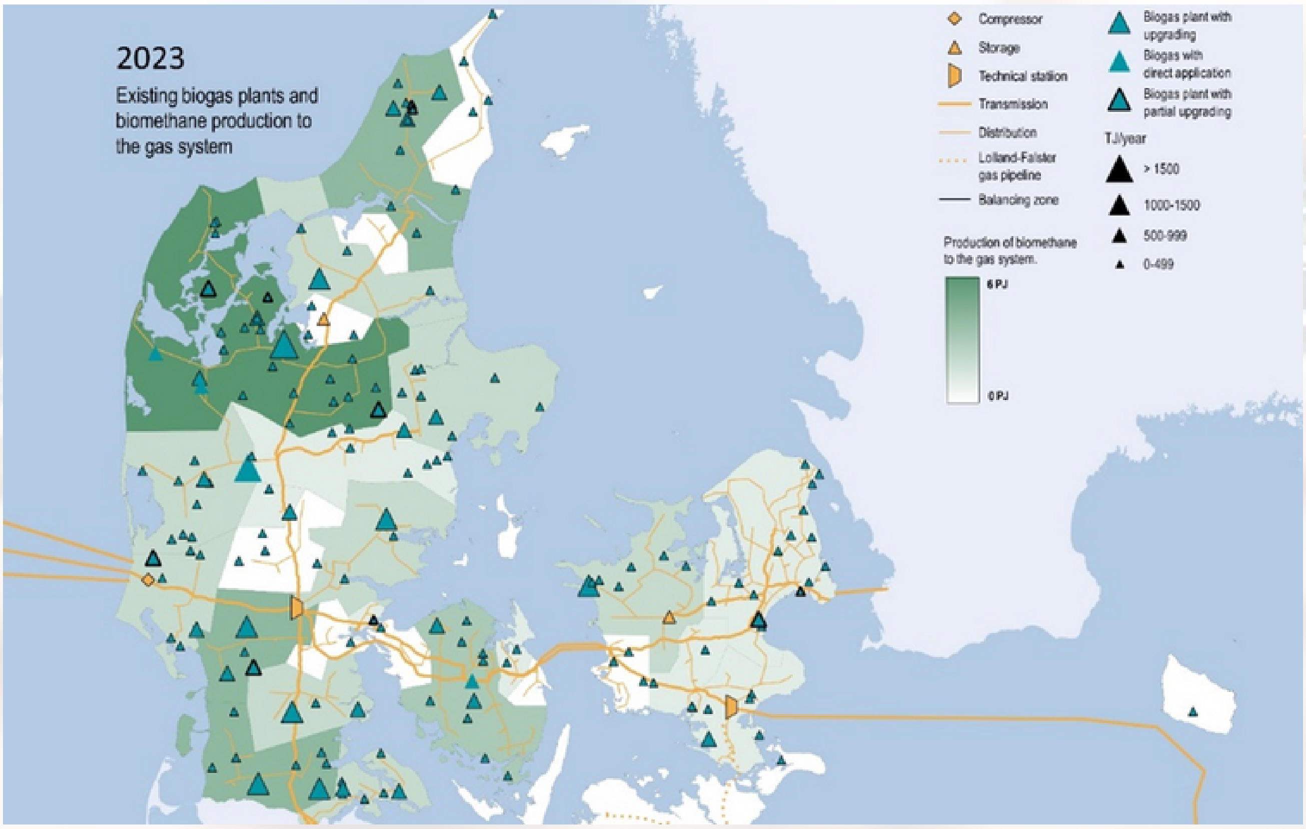
APPENDIX 2: RENEWABLE GASES IN OTHER JURISDICTIONS

Europe already harnesses biomethane extensively, for industrial/commercial and residential use as it is directly injected into the natural gas grid. The European Green Deal's REPowerEU program aims to cease European reliance on natural gas from Russia by 2030, with steep targets designed to send a strong price signal to investors and producers. [36]

Under the REPower EU program, the European Commission has proposed to produce 35 billion cubic metres (approx. 1230 PJ) of biomethane by 2030. [37]

- In France, Engie SA is targeting 36 PJ of biomethane production pa by 2030. [38]
- Denmark has expanded gas supply from biomethane from 10 per cent in January 2020 to 39 per cent in August 2023 [39], and is expected to achieve 70 per cent decarbonisation of its gas infrastructure assets by 2030.

Figure A1. Existing biogas plants and biomethane production to the gas system.



[36] European Commission, 2023, REPowerEU Program, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en
[37] European Commission, 2023, Biomethane, https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomethane_en
[38] Engie SA, 2023, Accelerating our sustainable growth, https://www.engie.com/en/group/our-vision/our-strategy
[39] Energinet, 2023, Biomethane, https://en.energinet.dk/gas/biomethane/

APPENDIX 2: RENEWABLE GASES IN OTHER JURISDICTIONS

The REPowerEU program also provides strong green hydrogen production targets, produce 10 million tonnes of renewable hydrogen and import 10 million tonnes by 2030.

In 2021, France announced a fairly ambitious target of 6.5 gigawatts (GW) of green hydrogen electrolysers by 2030. To date, the French government has invested in an overall potential capacity of around 1 GW by 2026. [40]

The UK has an even larger target, of up to 10 GW of low-carbon hydrogen production by 2030, with at least 5 GW of this being green hydrogen produced using electrolysers. [41] It is also currently consulting on whether to strategically support blending of up to 20 per cent hydrogen by volume into existing gas distribution networks. [42]

In 2023, Germany doubled its green hydrogen electrolyser capacity target from 5GW to 10GW by 2030. [43]

[40] Government of France, 2023, Industry: towards a new hydrogen strategy for France, https://www.economie.gouv.fr/industrie-nouvelle-strategie-hydrogene-pour-la-france
[41] Government of the United Kingdon, 2021, UK Hydrogen Strategy, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1175494/UK-Hydrogen-Strategy_web.pdf
[42] Government of the United Kingdom, 2023, Hydrogen blending into GB gas distribution networks, https://www.gov.uk/government/consultations/hydrogen-blending-into-gb-gas-distribution-networks
[43] Government of Germany, 2023, National Hydrogen Strategy Update, https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/national-hydrogen-strategy-update.pdf?__blob=publicationFile&v=3

APPENDIX 3: DIFFUSION OF INNOVATION AND RENEWABLE GASES

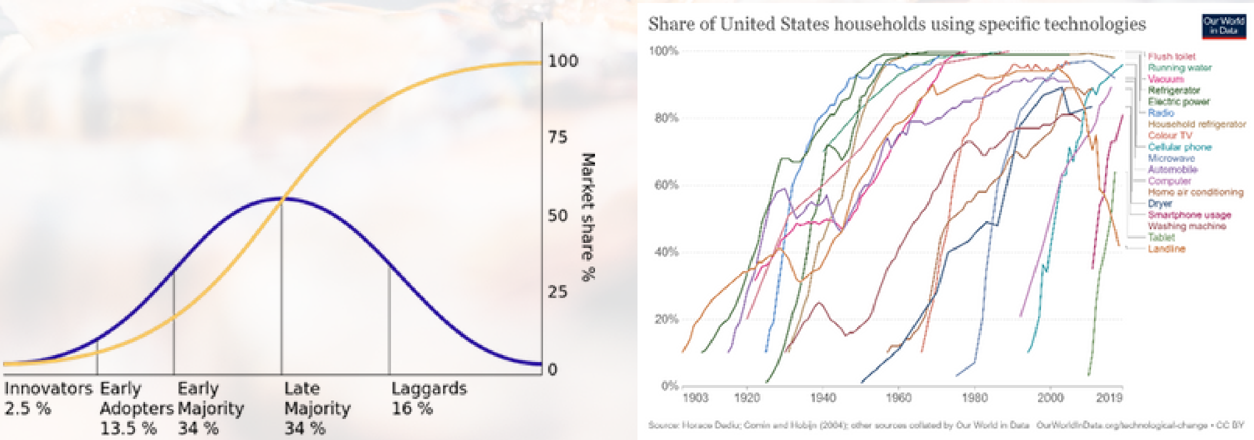
Originally appeared in The Australian Pipeliner, May 2023 [44]

As advocates for the transition to renewable gases, we often talk about the ability to reach net zero gas in Australia by 2050. But what does reaching net zero gas actually mean?

Having come leaps and bounds in researching the production, transport, storage and utilisation of renewable gases like hydrogen and biomethane, we know that we have the tools necessary to achieve a net zero gas system domestically in Australia. However, the path ahead of us is still a little less clear. Luckily, renewable gases aren't the first new technology to embark on a gradual takeover of an existing market. Thanks to the experience of the motor vehicle, the internet, smartphones and even renewable electricity before them, the pathway of renewable gases to transition Australia's gas supply chain to net zero gas isn't as murky as one may think.

Like new technologies past, renewable gases are anticipated to follow what is referred to as Diffusion of Innovation Theory. The Theory observes that most new technologies will follow, at least approximately, a normal distribution s-curve when taking over an incumbent market – referred to as the Diffusion of Innovation Curve.

Figure A2. Diffusion of Innovation curve and Diffusion of Innovation curve examples



[44] McCollum J, 2023, Why a renewable gas target is critical to gas use decarbonisation, The Australian Pipeliner 197, https://www.pipeliner.com.au/why-a-renewable-gas-target-is-critical-to-gas-use-decarbonisation

APPENDIX 3: DIFFUSION OF INNOVATION AND RENEWABLE GASES

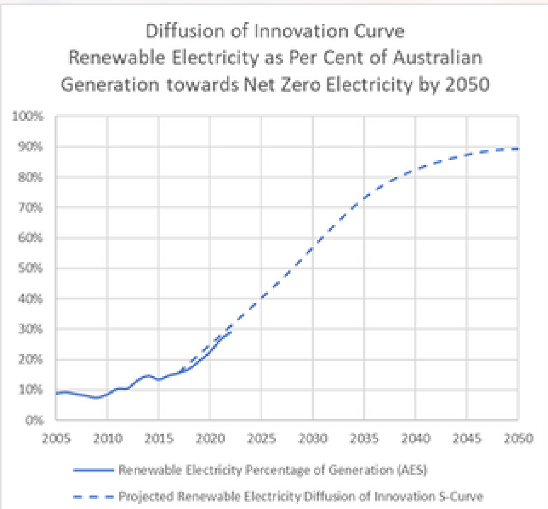
Approximations of the Diffusion of Innovation Curve have been seen across most new technologies that have developed across the past century. This is also true of the Australian renewable electricity industry. With 20% adoption by 2020 under the Renewable Energy Target (RET), this positions the renewable electricity industry on the curve to achieve net zero for the existing electricity market by 2050 (Fig 3).

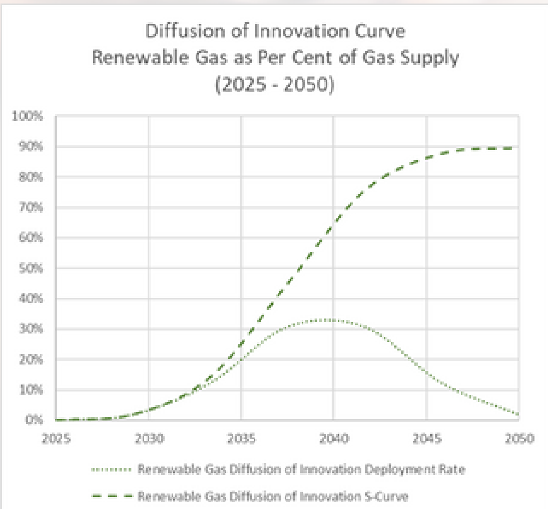
Whether by accident or design, targeting 20% uptake played a significant role in putting renewable electricity firmly on the trajectory to full market takeover. The 20% mark is well above the combined Innovators (first 2.5% of uptake) and Early Adopters (next 13.5% of uptake). By ensuring uptake enters the Early Majority portion of the Diffusion of Innovation Curve, the RET ensured that renewable electricity uptake would continue even after the target had been met.

Renewable gas advocates can take advantage of this knowledge to plan out the renewable gas Diffusion of Innovation Curve required to achieve net zero gas by 2050. As per the electricity sector, targeting 90% renewable gas production by 2050 will be considered equivalent to achieving net zero, and 2025 can be considered as a reasonable point in time to start targeted renewable gas development.

The application of a Diffusion of Innovation Curve between 2025 and 2050 can be seen in Figure A3. By following this renewable gas uptake trajectory, rather than a straight line or some other form of trajectory, Diffusion of Innovation Theory suggests Australia should deliver net zero gas by 2050.

Figure A3. Diffusion of Innovation curves for renewable electricity and renewable gas





APPENDIX 3: DIFFUSION OF INNOVATION AND RENEWABLE GASES

Now that we know that this is the trajectory that the renewable gas industry must meet to achieve net zero gas by 2050, the question that remains is – how do we get on this trajectory? While we know that the renewable gas industry will develop in line with the Diffusion of Innovation Curve, what is not certain is the timeframe in which this will unfold.

This is why a Renewable Gas Target is so critical to gas use decarbonisation in Australia. A Renewable Gas Target of 3.5% by 2030 and 20% by 2035 can ensure that renewable gas deployment develops beyond the Innovators and Early Adopters phases of the Diffusion of Innovation Curve prior to 2035. By doing so, renewable gas deployment will be on a trajectory that aligns with net zero gas by 2050.

By observing how new technologies diffuse into existing markets and how the RET ensured that this occurred in a timely manner for renewable electricity, we have the opportunity to ensure that renewable gas deployment doesn't just follow the Diffusion of Innovation Curve, but that a Renewable Gas Target is set that aligns with achieving net zero gas by 2050 in Australia.

ATTACHMENT 1: BOSTON CONSULTING GROUP, 2023, THE ROLE OF GAS INFRASTRUCTURE IN THE ENERGY TRANSITION

BOSTON
CONSULTING
GROUP

THE ROLE OF GAS INFRASTRUCTURE IN AUSTRALIA'S ENERGY TRANSITION

JUNE 2023

Context

This is a summary article on the role of Australia's domestic gas infrastructure in the energy transition. It has been commissioned by APA Group, Australian Gas Infrastructure Group, and Jemena. These are the three largest investors in Australia's gas pipeline transport infrastructure, and each has a publicly stated commitment to achieving net zero emissions.

This article considers the potential role of gas infrastructure - in Australia - in the transition to and in a net zero future, with a focus on transport infrastructure: pipelines, transmission and distribution. It describes the role over three loosely defined timeframes:

- The current state
- The 'transition phase' through which the energy system moves towards net zero
- The net zero future

This article should be read as a description of the potential role gas infrastructure could play in Australia, with a focus on supporting the transition of the Australian energy system as a whole in a least cost and most robust manner. The article does not address specific state-based emissions targets.

The article should not be read as a forecast of the role gas infrastructure will play, which is subject to a broader range of drivers, including policy decisions at all government levels. The article highlights broad actions required to realise the potential role but does not prescribe specific corporate or government policy actions.

This article includes a desktop review of several other papers written on the role of gas in the energy transition by a broad range of contributors, including industry, government bodies and advocacy groups. Reference to those papers should not be read as endorsement of their findings.

While the three commissioning organisations have been able to provide feedback on drafts of this article, the BCG team assigned to the project retained full control over the content. The conclusions presented in this article are the views of that BCG project team.

Disclaimer

Summary

Natural gas – and the gas infrastructure that stores and transports it – is a cornerstone of Australia's energy system today, representing 27% of primary energy. It is used by nearly all types of energy customers: ~71% by industry; ~15% by grid-connected electricity generation; and ~14% by homes, businesses, and other small user groups (e.g. agriculture, forestry, fishing). However, natural gas production, transport, and combustion accounts for 22% of Australia's energy-related emissions, and its use will need to be reduced to meet net zero ambitions, either by replacing natural gas with low-carbon gases or displacing gas by electrifying end uses supported by renewable electricity.

Natural gas will continue to play an important, but reducing (by volume), role during the energy transition phase. Various reports across a range of scenarios estimate that domestic consumption of natural gas will reduce to between 40% and 90% of current levels by 2040. The nature and extent of its use will be determined by how rapidly Australia develops renewable energy sources and how quickly customers electrify their use of energy. **Some customers have an economic case to electrify their usage – e.g. industrial low-grade heating, some light vehicles and new-build homes. For existing gas-using homes, the economic choice appears to be highly dependent on individual circumstances.** Customer choice may also be influenced by practicality, individual preference and amenity.

Renewable electricity is the primary technology to provide low emissions energy, along with other renewable energy sources. It can be deployed to displace fossil-generation or to electrify various end-uses, yielding different emissions reduction and system cost outcomes. **Beyond those customers who choose to electrify, a 'renewify first, maintain customer choice' sequence (prioritising the displacement of fossil primary energy sources – in particular coal for electricity generation – with renewable sources and electrification of transport), ahead of an electrification sequence (changing the end-use energy vector from gas to electricity) will reduce emissions sooner and with lower total system cost.**

During the 'transition phase', natural gas can support the 'renewify first' sequence by serving applications that are hard or expensive (peaking applications in particular) for the system to electrify. These applications include high-grade industrial heat, industrial feedstock, peak power generation and space heating in households – especially those in cold climates. Retaining natural gas for these applications will make the transition more robust and help manage the impact of potential disorderly exit of coal-fired generation, or unexpected delays to development of renewable electricity, transmission and storage projects.

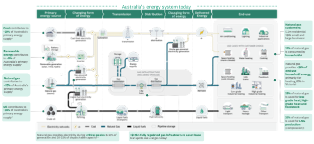
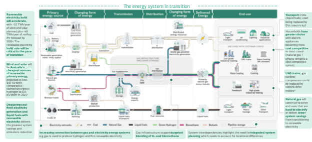
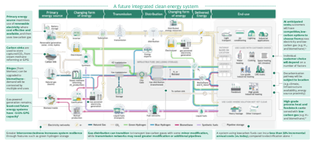
During the 'transition phase', existing gas infrastructure could be used to continue the development of low-carbon gases. Low-carbon gases are likely to be needed in a net zero future, for industrial use at a minimum. Preserving the gas infrastructure preserves an option for their wider use.

In a net zero future, low-carbon gases could provide competitive solutions at a total-cost level for customers – including some existing gas-using households – if supply costs reduce as anticipated, network charges are managed, and sufficient supply becomes available.

Some reports indicate that **an integrated clean energy system, combining low-carbon gas networks and expanded electric networks, could be the least cost approach to net zero**. **However, the specific least cost approach is likely to differ by location based on regional- and network-level considerations**.

The potential role of gas infrastructure in the transition and net zero timeframes will not happen automatically. Stakeholders in the energy sector would need to avoid near-term natural gas supply shortfalls, minimise fugitive methane emissions, define adequate and equitable cost recovery for regulated assets, integrate energy system planning at a granular level (across electricity and gas), and move low-carbon gas supply down the cost curve.

Exhibit 1: The role of gas and gas infrastructure in the energy transition (infographics in appendix)

	1. TODAY	2. TRANSITION	3. NET ZERO
THE ROLE OF GASEOUS FUELS	**Natural gas is a pillar of the energy system** 27% of primary domestic energy 34% of household energy 5-10% grid-connected electricity generation (NEM+SWIS)	**Natural gas has a reducing but critical role** Serves hard/expensive to electrify applications Maintains peaking applications, such as gas-powered generation (critical to an orderly electricity system transition) Provides low-carbon gas as sources start to build	**Low-carbon gas could be competitive for some existing gas customers, at anticipated prices** Essential for some hard-to-electrify industrial applications Competitive option for some households and available for potential new customers (e.g. fuel cell heavy transport)
THE ROLE OF GAS TRANSPORT INFRASTRUCTURE	**Gas infrastructure plays a critical role supplying energy to over 5m industrial, commercial, and residential customers** Transmission network supports distribution and industrial customers Distribution network supports homes, businesses and industrial customers	**Gas infrastructure continues to serve customers, while demonstrating low-carbon gases** Develops and demonstrates physical and economic feasibility of low-carbon gas (blending and 100% streams)	**Low-carbon gas networks form part of an integrated clean energy system** Transports low-carbon gas to end users domestically, and potentially for export Role likely to differ by region and network, based on a range of factors
	 **View Appendix 1**	 **View Appendix 2**	 **View Appendix 3**

1 Natural gas and its infrastructure form a pillar of today's energy system, but the role of natural gas needs to change for a net zero future

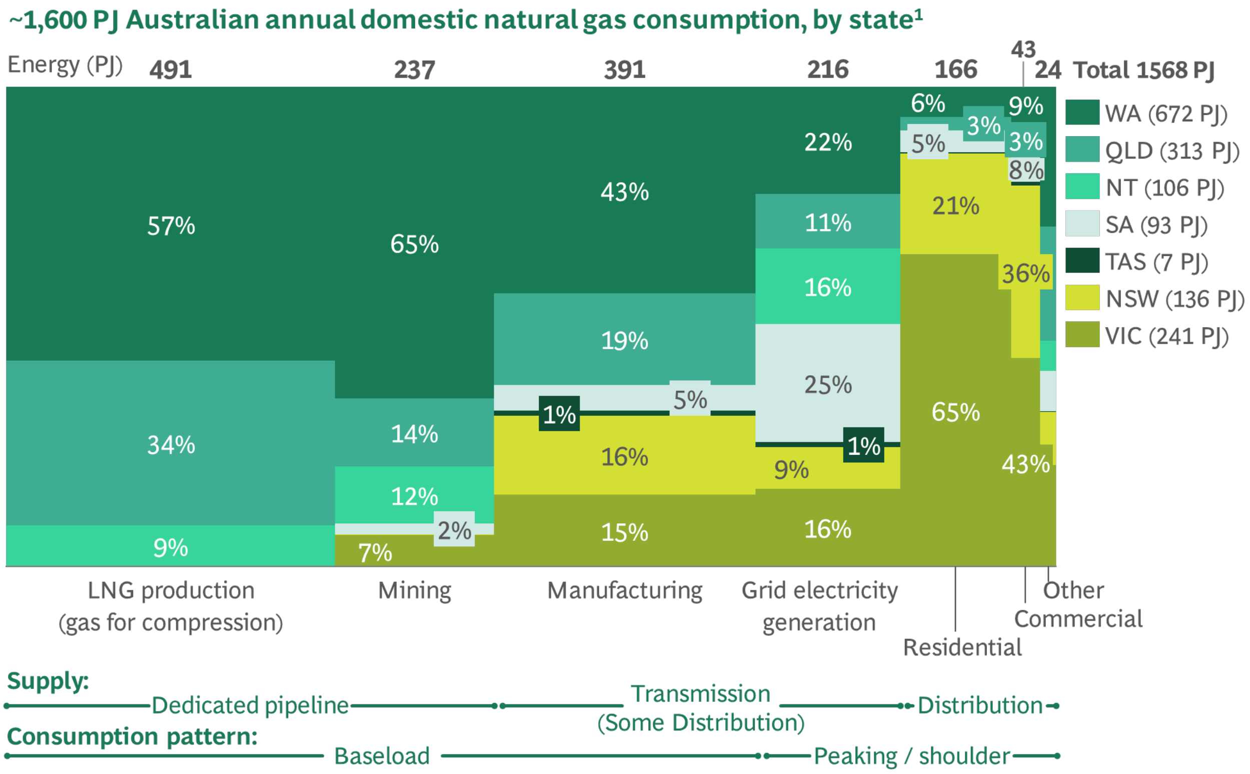
Natural gas is one of 3 pillars of Australia's energy system It provides 27% (1600PJ) of domestic primary energy and is used by nearly all customer groups, both directly and via its contribution to electricity generation. While residential and commercial users are the smallest group by energy use, over 5 million households and business are connected to the gas distribution network. Notwithstanding its importance, natural gas is a fossil fuel that contributes 22% of Australia's energy-related emissions (18% of total emissions), and its use must be decarbonised if Australia is to meet its net zero ambitions.

→ See Appendix 1

Natural gas is one of three pillars of Australia's energy system and contributes 27% of total domestic energy use (1600PJ of 5600PJ). The other two pillars are liquid fuels and coal, which contribute 37% and 28% of domestic energy respectively. Renewable electricity provides around 4% of domestic primary energy today and is playing an increasingly prominent role.

Natural gas plays a material role in the stability and resilience of the energy system. It is used by nearly all energy customer groups: ~71% of natural gas is used by industry; ~15% for grid-connected electricity generation; and ~13% for residential and commercial heating. While residential and commercial is the smallest group by energy use, over 5 million households and businesses are connected to the gas distribution network. 65% of residential natural gas is used in Victoria.

Exhibit 2: Natural gas is used by a range of customers for electricity generation, mining, industrial, commercial, residential use, and for export



1. Natural gas exports and imports excluded

Source: Australian Energy Statistics, Table F, Table J (2022); APPEA Key Statistics (2022); AEMO GSOO 2021; AEMO WA GSOO 2020; BCG analysis

Natural gas has particularly useful characteristics for the range of energy end-uses it currently serves. It is reliable and responsive, has a lower cost per unit energy and lower capital cost than its historical alternatives, and is the only available technology for some end uses.

However, natural gas represents ~22% of Australia's domestic energy-related emissions.[1] Alternatives to natural gas are becoming available:

- Electric technologies are becoming more widely available, such as heat pumps, battery storage, induction cooking, more efficient (e.g. heat pumps are in the order of 4x more efficient than natural gas appliances) and increasingly cost-competitive[2]
- Low-carbon gases could displace natural gas to decarbonise some end uses (see BOX 1)

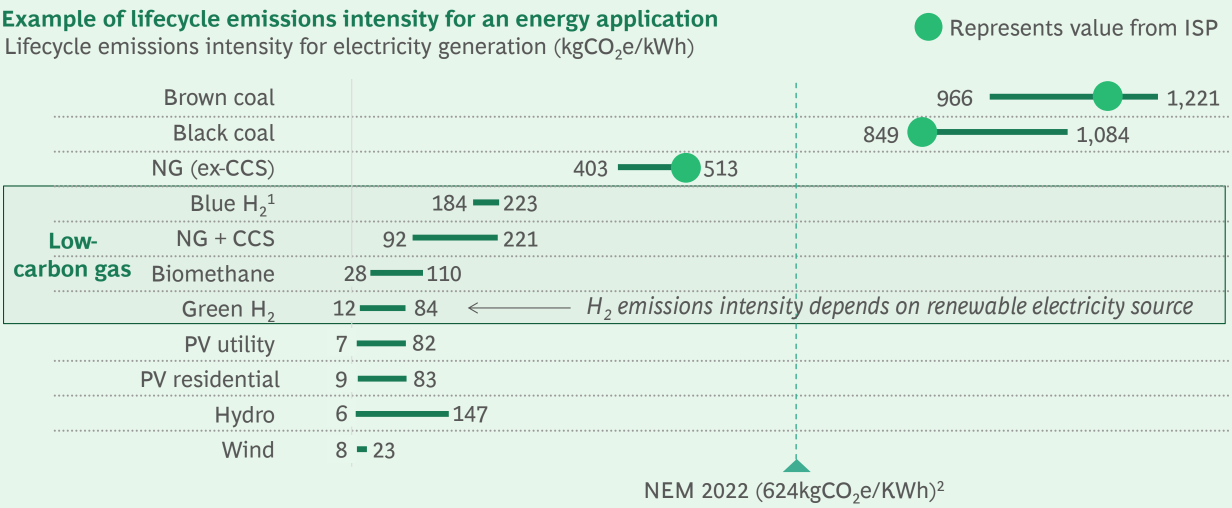
BOX 1: WHAT IS LOW-CARBON GAS?

The combustion of natural gas creates emissions (predominantly CO_2), and additional methane fugitive emissions (losses or leaks) are released along the supply chain. Emissions from natural gas are greater than from renewable energy, but lower than from combusting coal or liquid fuels.

Alternative gases can transport energy with fewer lifecycle carbon emissions (e.g. from raw materials, manufacturing, energy production, conversion, transport and use) than natural gas. Low-carbon gases include:

- Biomethane, derived from biomass feedstock
- Natural gas with carbon capture and storage (CCS)
- Green hydrogen, derived from electrolysis using renewable electricity
- Blue hydrogen, derived from steam methane reforming (SMR) with CCS
- Synthetic methane, synthesised from green hydrogen and direct-capture carbon dioxide

Exhibit 3: Combusting low-carbon gases results in similar emissions levels as electricity production



1. Blue hydrogen emissions intensity range determined by applying a 0.4% factor of fugitive losses of methane consumption in emissions calculation by Howarth & Jacobson 2. Based on AEMO ISP
Source: National Renewable Energy Laboratory; IPCC; UN Economic Commission for Europe; Howarth & Jacobson: How Green is Blue Hydrogen?; AEMO ISP; OpenNEM; BCG analysis

---

[1] DCCEEW, Australian Energy Statistics, IEA methane tracker, IPCC, BCG analysis

[2] IRENA, Australian Equipment Energy Efficiency Committee

2 Natural gas will continue to play an important, but reducing, role during the transition phase

During the transition phase, natural gas and its existing infrastructure will play a reducing but critical role and support hard- and expensive-to-electrify applications. These applications lack alternatives (chemical feedstock and high-grade heat) or are peaking in nature (gas-powered generation and household space heating - especially in cold climates). The nature and extent of the role of natural gas will be determined by how fast renewable energy (including low-carbon gases) is built and customers electrify. The choice to electrify is highly individual for each customer. Beyond customer choice, emissions will be reduced sooner and at lower cost in a 'renewify first, maintain customer choice' sequence, in which renewable electricity is prioritised to decarbonise the grid and electrify light transport. This approach will also be more robust to risks in the electricity transition and preserves optionality. In the transition phase, gas infrastructure could be used to demonstrate low-carbon gases, such as hydrogen and biomethane, as blends of these gases require little change to existing gas infrastructure.

Natural gas will play a role in the energy transition, with varying views on the nature and extent of that role. Across a number of studies, 2040 domestic consumption of natural gas ranges from 40-90% of 2020 levels.[3]

The pace at which Australia develops renewable energy sources (**including low-carbon gases**)**, and the rate at which customers electrify, will influence the nature and extent of the role that natural gas and gas infrastructure play in the transition.** Exhibit 4 illustrates three potential sequences.

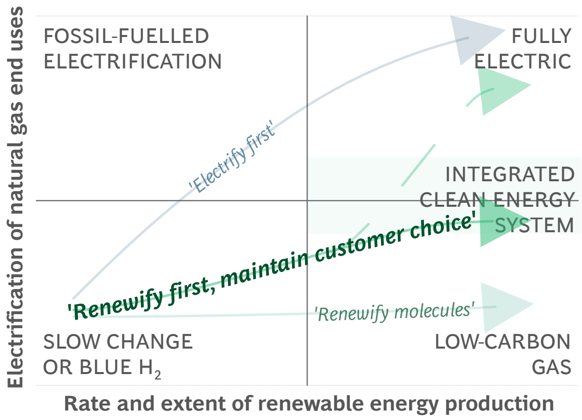
In '**electrify first'**, natural gas end-use is rapidly replaced with electricity. The higher demand for grid electricity would today be met with largely fossil-based electricity and in the future renewable electricity.

In **'renewify first, maintain customer choice',** fossil-based energy sources are replaced by renewable energy first to decarbonise the grid. Some customers choose to electrify their usage, in part driven by the economics. Depending on the emergence of low-carbon gases as a competitive solution, remaining customers might either draw low-carbon gases from the gas grid or electrify.

The **'renewify molecules'** represents a pathway in which illustrate a pathway in which rapid development of renewable gases allows customers to choose to use low-carbon gases in the same way they do today.

A critical difference between the 'electrify first' and 'renewify first' pathways is how they respond to delays to the development of renewable electricity and storage, or a disorderly transition. **'Renewify first' mitigates these risks** because existing electricity supply shifts to firmed renewables as demand for electricity increases, and low-carbon gases are developed to decarbonise applications that are not electrified.

Exhibit 4: The rate of renewable deployment and extent of electrification will determine the role of gas and gas infrastructure in the energy transition



Source: BCG analysis

[3] BCG analysed scenarios from Net Zero Australia (2023), AEMO GSOO (2023), Frontier Economics (2020), and Investor Group on Climate Change (2022)

The economics of electrification for customers is highly individual

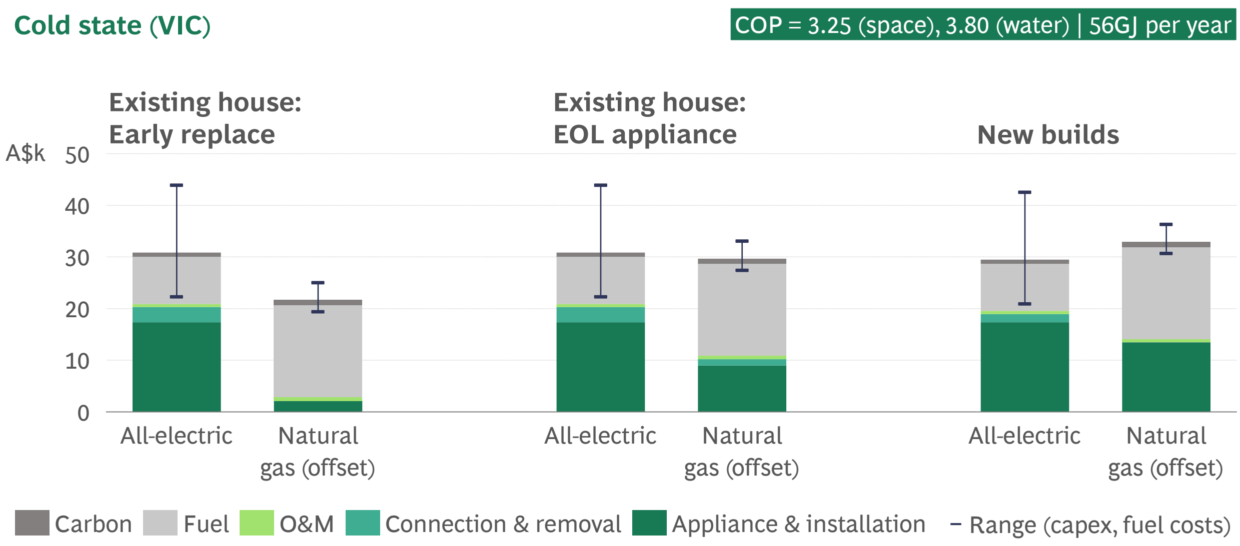
From a customer perspective, it could be economical for some end uses (e.g. low-grade industrial heating, some light vehicles) to switch to renewable electricity. For other customers, electrification is not technically feasible or economical for their end-uses, such as high-grade (>150C) industrial heat and chemical production (e.g. using natural gas for ammonia feedstock).

The economics of electrification for residential customers is contested in existing literature and the choice for households is highly individual. Location, appliance configuration, preference and other factors influence the most cost-effective solution, and customers may make decisions based on practicality, individual preference and amenity. Households will generally save energy and reduce bills because of the efficiency of heat pumps (also known as reverse-cycle air conditioners), though these energy savings are partially offset by the higher unit (per kWh) cost of electricity. However, the higher cost of new electric appliances and their installation, costs to upgrade power connections (if needed), and the cost of remediating gas connections, can mean it is cheaper to remain on natural gas if fuel savings do not recoup the capital cost over time.

For residential customers, Exhibit 5a shows an estimate of the relative costs (before subsidies) today of switching to electric appliances in the home compared to staying on natural gas appliances in Victoria for an average household consumption. It compares existing houses (where appliances are replaced early, or where they are at the end of life) with new builds (with new appliances).

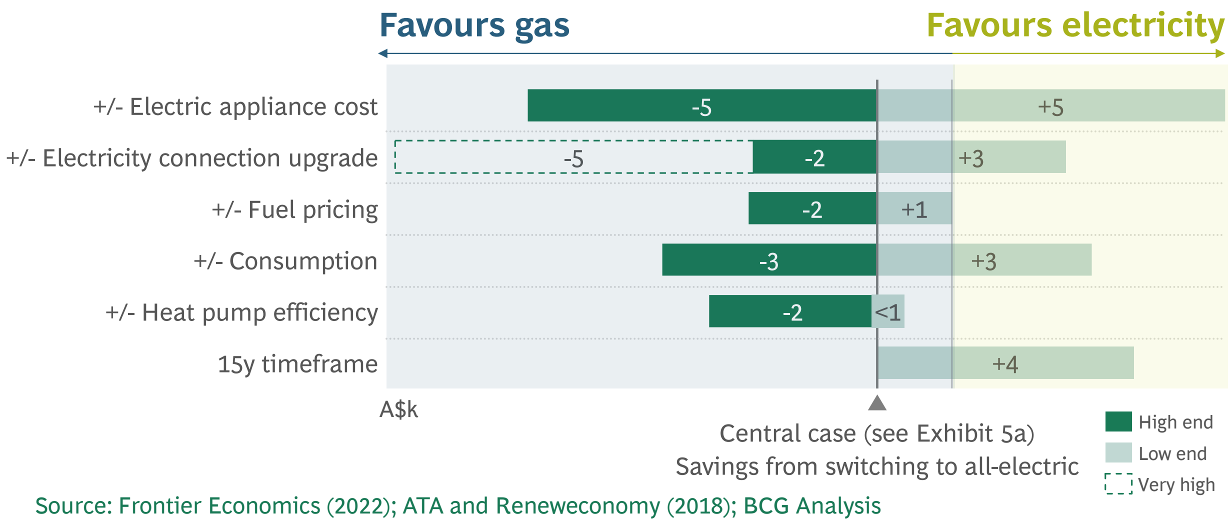
- **For existing homes with assets at end of life**, in the central case it would be marginally lower cost over 10 years to remain on natural gas than to switch to electric appliances, even if emissions are offset. The higher appliance costs, costs of removing existing appliances, upgrading the electricity connection (if needed), and disconnecting and abolishing the existing natural gas connection outweigh the accumulated savings. The conclusion depends directly on the extent and value of appliance purchase, installation, and remediation costs, which are specific to each household (Exhibit 5b).
- **For new builds**, in the central case it would be lower cost to electrify as gas appliance removal and disconnection costs are not applicable.

Exhibit 5a: Natural gas and electricity cost comparison (excl. subsidies) for residential users today



Note: Inclusive of space heating, water heating and cooking. Costs reflect NPV over 10Y period using real discount rate of 3%. All-electric homes are grid-connected and no subsidies are considered.
Source: Frontier Economics (2022); ATA and Reneweconomy (2018); BCG Analysis

Exhibit 5b: Relative total cost of ownership and savings from switching to all-electric (VIC)



Source: Frontier Economics (2022); ATA and Reneweconomy (2018); BCG Analysis

Beyond customer choice, a 'renewify first' sequence will reduce emissions sooner and at a lower system cost

Renewable electricity is a key technology to provide low emissions energy. It can be deployed in a number of ways: renewifying the primary energy source for grid electricity (i.e. displacing coal and gas-powered generation) or supporting electrification of direct uses of fossil fuels. Each application yields different emission reductions and imposes different costs on the system.

Exhibit 6 and Box 2 describe the emissions and cost impact of deploying 1 MWh of grid-connected renewable electricity for different applications. To avoid the most emissions and minimise system costs, renewable electricity could be prioritised (starting from the green area at top right and moving diagonally down through the white area in the middle of Exhibit 6). The priority applications for renewable electricity are to displace coal generation and liquid fuels used in light vehicles and low-grade industrial heating.

Electrification of residential gas applications is prioritised lower due to their impact on system cost, in particular where they coincide with electricity demand peaks

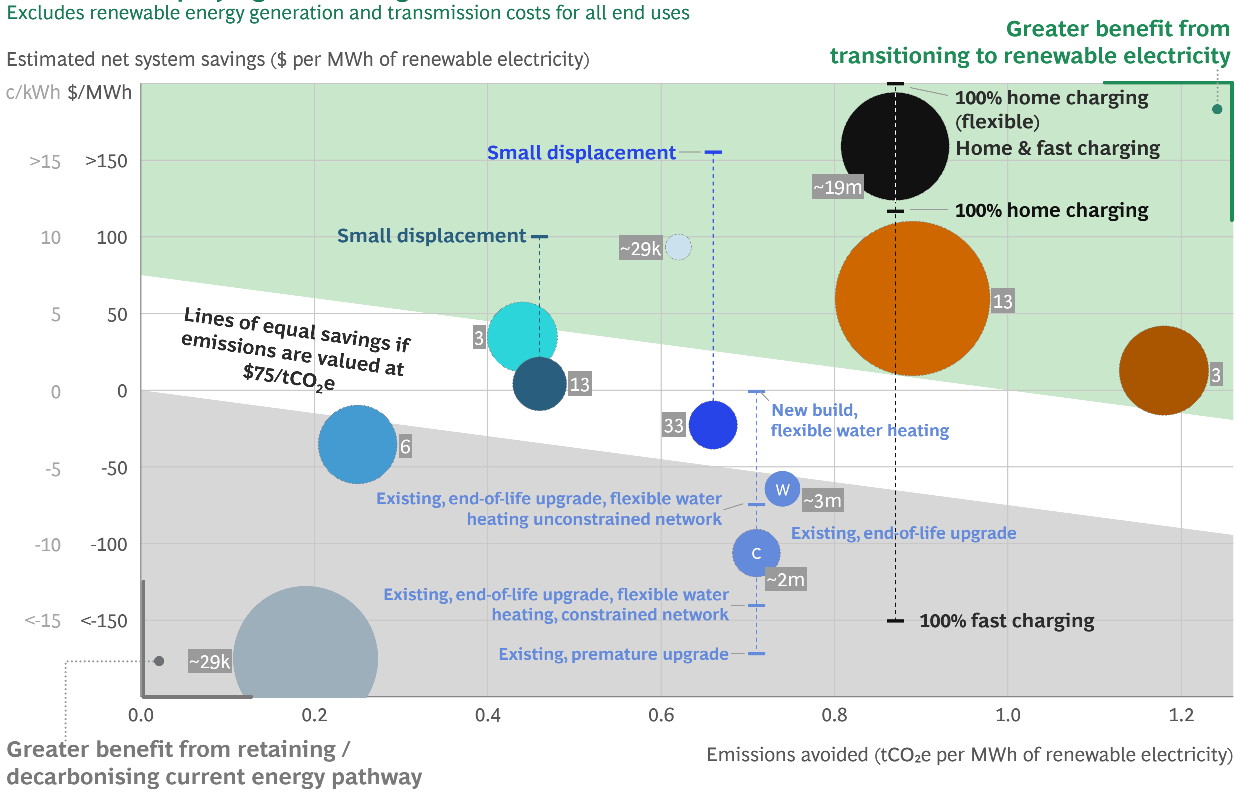
Electrifying end uses such as high-grade industrial heating, industrial feedstock (via green hydrogen produced from renewable electricity), residential and commercial heating (in particular in cold climates) and peaking gas-powered generation (in the grey and white areas of Exhibit 6) would have a higher cost for the system and avoid fewer emissions.

In the case of residential and commercial use, this is driven in part by the shape of demand: natural gas demand spikes in cold weather and in the evenings. In cold climates this would lead to an increase of peak electricity demand: system investment in network expansion could be needed and profile shaping would be needed (Box 2).

Exhibit 6: Grid-connected renewable electricity will have the greatest impact if first used to displace coal generation and liquid fuels

Benefits of deploying 1 MWh of grid-connected solar/wind

Excludes renewable energy generation and transmission costs for all end uses



Legend

Black: Liquid fuels
- Light electric vehicles

Brown: Solid fuels
- Black coal-fired generator
- Brown coal-fired generator

Blue: Gaseous fuels
- Low grade industrial heating
- High grade industrial heating
- Feedstock[1]
- Mid-merit gas (CCGT)
- C Residential & commercial heating (cold climate)
- W Residential & commercial heating (warm climate)
- Peaking gas (OCGT)
- LNG trains

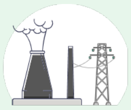
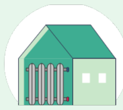
\# Number of end users

Note: Bubble size represents total annual volume of renewable electricity required to meet demand

1. Analysis based on methane gas substituted with green hydrogen produced from grid-connected electricity

Source: AEMO ISP (2022); OpenNEM; CSIRO; ABS; AIP; Frontier Economics (2022); Advisian, CEFC (2021); BCG analysis

BOX 2: WHAT DOES IT TAKE TO GET VALUE FROM 1 MWH OF RENEWABLE ELECTRICITY?

	 Displace coal-fired generation	 Electrify light vehicles	 Electrify residential usage
Emissions reduction	0.8 – 1.2 tCO_2e/MWh	0.9 tCO_2e/MWh	0.7 tCO_2e/MWh
Cost savings	✓ Coal supply ✓ Coal plant variable opex	✓ Fuel ✓ Fuel distribution ✓ Lower vehicle opex	✓ Gas supply ✓ Gas transmission and distribution variable opex ✓ Gas transmission infra-structure from new sources ✓ Lower appliance opex
Additional costs		✗ Consumption profile matching ✗ Electricity distribution network upgrades ✗ Incremental capital cost of electric vehicle ✗ Public EV charging infrastructure	✗ Consumption profile matching (hot water treated as controllable) ✗ Electricity distribution network upgrades ✗ Incremental capital cost of equipment

For all applications, the cost of supplying the MWh is excluded for comparison

Compared to displacing coal-fired generation with 1 MWh of renewable electricity, electrifying a house's appliances and bringing 1 MWh to the home includes additional costs to:

- Match the profile of variable renewable electricity generation (when it is sunny and windy) to the profile of consumption (when people are heating their homes)
- Transport the electricity (with potential upgrades to the electricity distribution network)
- Buy new electric equipment (e.g. a heat pump), currently at higher capital cost [4]

These additional costs are why bubbles are in the grey area of Exhibit 6. While electrifying light vehicles does incur additional costs, charging could be more flexible – if the vehicle is charged when overall (or local) electricity demand is low, it provides a benefit by balancing the system.

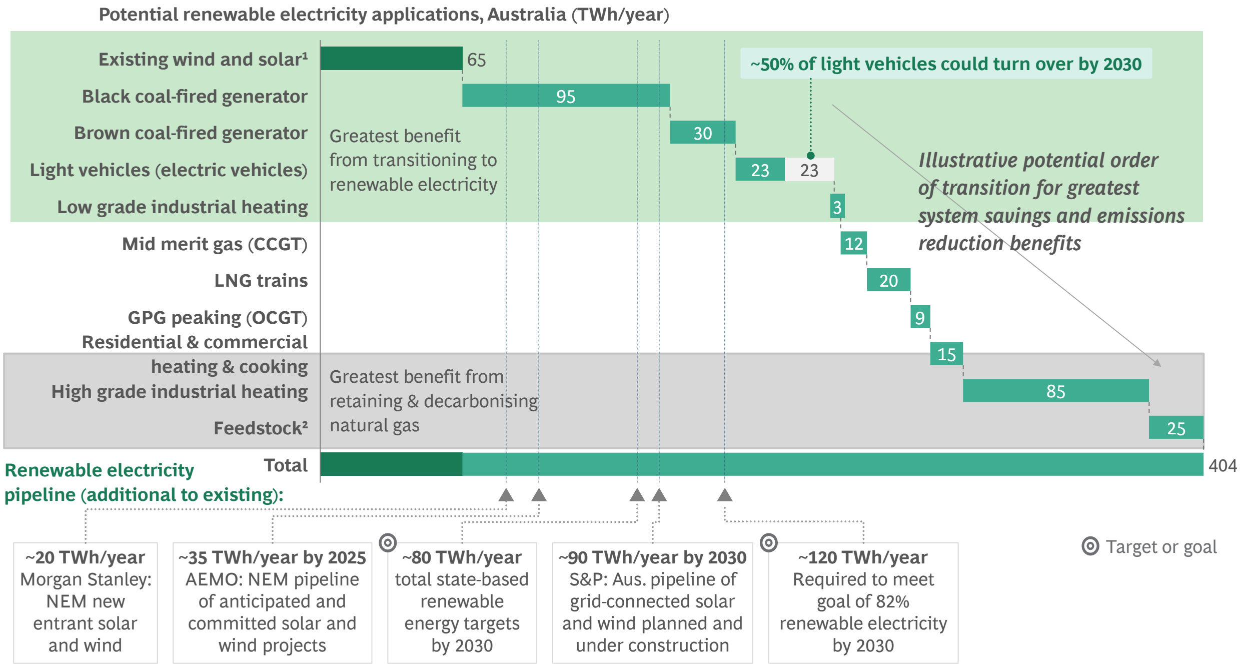
[4] This system analysis and total cost of ownership analysis is based on electrification with the use of heat pumps. Customers may choose to electrify with lower efficiency appliances

The renewable electricity pipeline does not yet have capacity to renewify all potential applications

Exhibit 7 shows the expected pipeline of renewable generation compared to the renewable generation required to transition a range of potential applications to renewable electricity. If the 82% renewable electricity ambition by 2030 were met, and if new renewable generation is prioritised in the sequence described in Exhibit 7, only coal generation would be displaced.

Exhibit 7: In the transition, natural gas can serve critical end uses that are hard and expensive to electrify

End uses could be prioritised to transition to renewable electricity based on system benefits analysis in Exhibit 6



1. Includes onshore wind, utility scale solar, rooftop solar 2. Methane gas substituted with green hydrogen from grid-connected electricity
Source: Morgan Stanley Research, NEM new entrant plant estimate; AEMO, NEM Generation Information (Feb 2023); S&P Capital IQ, World Electric Power Plants Data Base; DCCEEW, Annual Climate Change Statement 2022; BCG analysis

In this prioritisation, natural gas plays a complementary role to renewable electricity

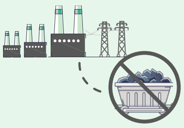
While renewable electricity is prioritised to end uses in the top right of Exhibit 6, natural gas can continue to support the end uses that are lower priority to electrify because they are hard or expensive to electrify. These are the end uses in the bottom left corner of Exhibit 6.

By doing this, natural gas will make the transition more robust

By avoiding additional strain on the electricity system at peak times and providing peak electricity generation, these applications of natural gas make the transition of the electricity system more robust. In other words, if the transition does not proceed as planned (e.g. renewable electricity and storage is delayed, or through the disorderly exit of coal), gas would pick up the slack. Gas-powered generation is a good backstop because it is dispatchable (unlike variable renewable electricity), can ramp up quickly (unlike legacy coal plants), and has access to storage in the gas infrastructure system.

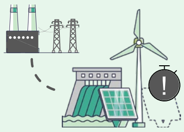
BOX 3: A CRITICAL ROLE FOR GAS IN AN ORDERLY TRANSITION

While renewables will eventually dominate electricity generation, gas-powered generation has a critical role to play. Analysis in AEMO's GSOO shows that:



+100PJ

Gas for gas-powered generation is required if there is a **disorderly coal exit**



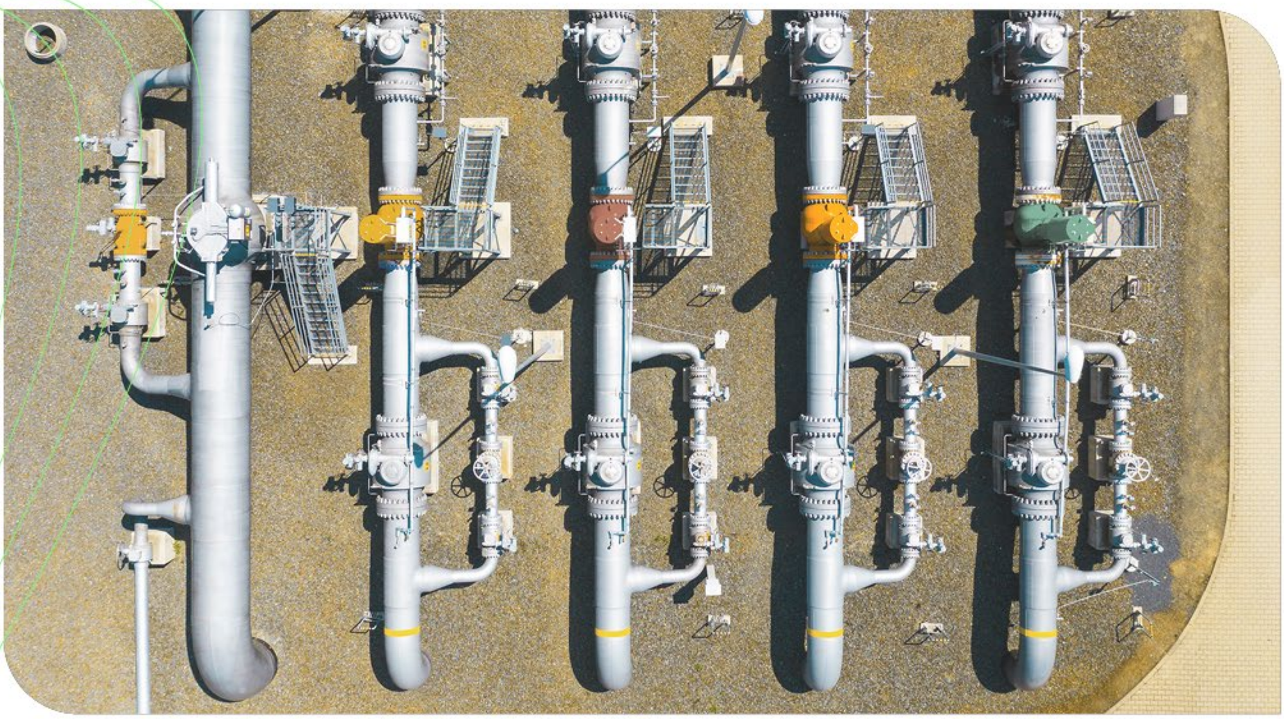
+30-40 PJ

Gas for gas-powered generation is required 2023-2025, if there are **delayed VRE projects**.[5]

In the transition phase, gas infrastructure could be used to demonstrate low-carbon gases, such as hydrogen and biomethane, as blends of these gases require little change to existing gas infrastructure.

While renewable electricity is prioritised towards displacing coal-fired generation, natural gas and gas infrastructure can play a significant part in the transition. However, natural gas will also need to decarbonise during the transition.

With minimal modifications, existing gas infrastructure could be used to demonstrate the physical and economic feasibility of low-carbon gases and support their development by blending low-carbon gas into the distribution network. These low-carbon gases could be developed progressively, initially supporting distribution-connected residential or industrial customers with applications that are hard or expensive to electrify.



[5] AEMO, Gas Statement of Opportunities (2023)

3 Gas infrastructure could transport low-carbon gases in a lower-cost, integrated clean energy system in a net zero future

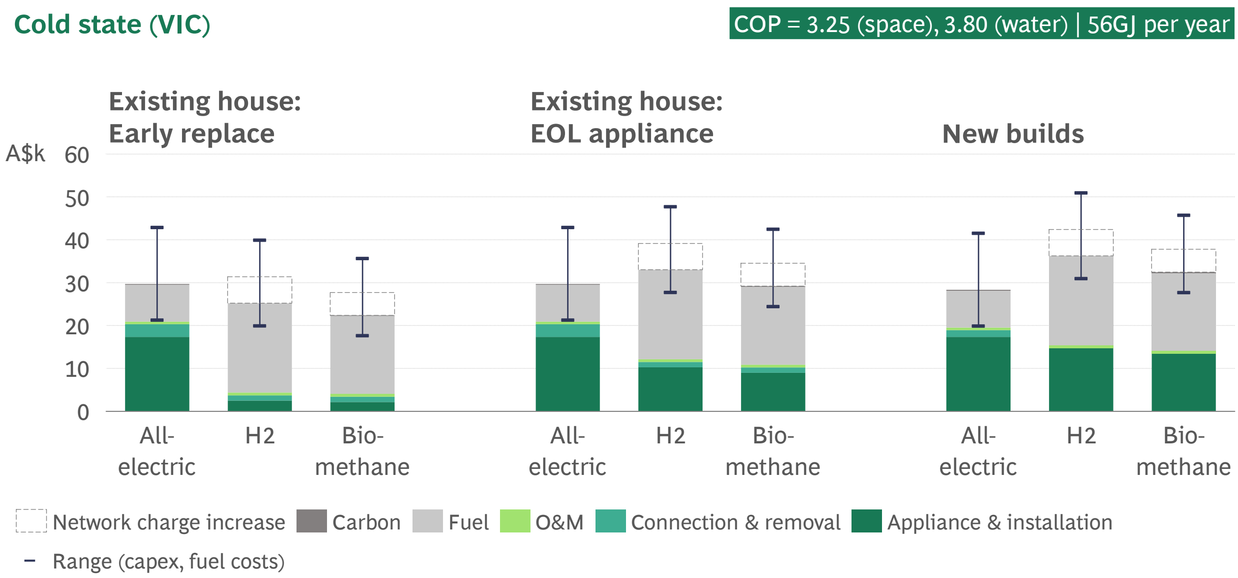
In a net zero future, all applications that use natural gas today will need to be decarbonised. There are two broad approaches: converting all applications to electric appliances only and using renewable electricity; or repurposing or upgrading existing infrastructure to carry low-carbon gases as part of an integrated clean energy system alongside electrification. Low-carbon gas in an integrated clean energy system could provide competitive offers at a total-cost level for some customers if low-carbon gas prices fall as anticipated and if network tariffs are managed. An integrated clean energy system could be equivalent or least-cost at a whole-of-system level in a net zero future, with reduced investment on the customer side, and offsetting higher running costs in the electricity system. The optimal solution for an integrated clean energy system likely differs by location and would require detailed regional-level planning (see Box 4).

→ See Appendix 3

Low-carbon gases could be competitive options for some customers in an integrated clean energy system, if costs fall to anticipated levels

If the price of low-carbon gas falls as forecast, green hydrogen and biomethane could be cost-competitive options for some existing gas households. At around $2-3kg wholesale ($40-51/GJ retail), green hydrogen could be total-cost-competitive for electric appliances in some existing houses with gas appliances, particularly those where it is expensive to electrify. Biomethane below around $15/GJ wholesale ($37-48/GJ retail) is also total-cost competitive (see Exhibit 8), though estimates of level of the available economic supply vary greatly.

Exhibit 8: Cost comparison for electricity, green hydrogen and biomethane for residential users in 2040



Note: Inclusive of space heating, water heating and cooking. Costs reflect NPV over 10Y period using real discount rate of 3%. All-electric homes are grid-connected and no subsidies are considered. Network charge increase (dotted box) reflects 50% distribution-connected customers, per GSOO OSC scenario in 2040 for biomethane and hydrogen.
Source: Frontier Economics (2022); ATA and Reneweconomy (2018); Advisian, CEFC (2021), IEA and Deloitte; BCG Analysis

Low-carbon gas is also anticipated to be the least cost (or most competitive) decarbonisation pathway for other uses, such as feedstock, high-grade process heat, and marginal peak electricity generation. There is the possibility for low-carbon gas to serve other new use cases, such as hydrogen fuel cell vehicles, green steel and sustainable aviation fuel.

BOX 4: WHAT IS AN INTEGRATED CLEAN ENERGY SYSTEM?

An integrated clean energy system (ICES) would integrate energy vectors.

Renewable electricity serving a large proportion of primary energy demand

Low-carbon gas serving a portion of existing natural gas customers, and potentially new types of customers like hydrogen fuelling

The potential benefits of an ICES include:

- Optimised balance of customer and system costs of transition
- Interconnected sources and networks of energy to increase efficiency and reliability

Appendix 3 shows an illustrative example of such an integrated clean energy system

Gas infrastructure can be used to transport low-carbon gases

For existing gas infrastructure to shift to 100% biomethane, no significant modifications are required. For hydrogen with a >10-20% blend, or higher, the feasibility of adapting gas infrastructure depends on many factors, including age, material type, operating conditions (pressure and capacity) and region. Many of Australia's distribution networks and some transmission pipelines have been investigated in detail and are compatible with transporting a 10-20% hydrogen blend, and some distribution networks are compatible with 100% hydrogen – requiring only little modification. This places several networks in Australia well to adopt hydrogen as it becomes available for further trials or use at scale and costs reduce.

While the extent of infrastructure modifications is understood in some distribution and transmission networks, further study is needed – particularly for transmission pipelines. Compared to distribution networks, transmission networks may require more modification or new infrastructure.

Gas infrastructure could support a lower-cost and higher-resilience integrated system

It is possible that an integrated clean energy system could be lower cost than a fully electric system. A study by Frontier Economics (2020)[6] showed the lowest annual system cost in the Zero-carbon/Renewable Fuels scenarios. Net Zero Australia (2023)[7] charts rapid (E+) and slower (E-) electrification scenarios across buildings and transport. It estimates similar total domestic system costs across the two scenarios, with lower customer side costs in the E- scenario balancing higher supply costs. Both Frontier Economics Renewable Fuels and the Net Zero Australia E- scenario achieve net zero with a combination of renewable electricity and low-carbon gas.

---

[6] Frontier Economics, The Benefits of Gas Infrastructure to Decarbonise Australia (2020)

[7] Net Zero Australia, Final Modelling Results (2023)

Leveraging existing gas infrastructure could reduce costs for several reasons:

- Lower peak electricity demand reduces the need for electricity network and storage investment
- Repurposing gas distribution networks for low-carbon gases utilises an existing asset and network decommissioning costs can be avoided
- Less investment is needed in customer-side equipment.

Retaining gas infrastructure could increase energy system reliability, resilience and synergies through interconnections (e.g. through hydrogen storage) and redundancy from multiple energy networks (i.e. fewer single points of failure).

The least-cost integrated clean energy system will likely differ by location
The relative attractiveness of repurposing gas infrastructure to deliver low-carbon gases will differ along a number of location-based factors, including:

- **Climate** – the coincidence of gas and electricity peaks is greatest in cold climates, whereas in warmer climates electrification might not add to peak demand
- **Network capacity** – a constrained local electricity network would need to build additional peak capacity for newly electrified demand
- **Marginal supply** – while the marginal supply of electricity is fossil-fuelled, there is less emissions benefit to electrification
- **Customer profile** – demand for low-carbon gases from industrial customers will support the ability for other customers to use low-carbon gas
- **Availability of low-carbon gases** – abundant and nearby biomethane or hydrogen allow the low-carbon gas system to deliver more competitive customer offers.

Therefore, granular planning at regional and network level will be needed to design the optimal integrated clean energy system or fully electric system.

4 Action is needed to make it possible for gas infrastructure to play this role

Without action, a number of risks could prevent gas infrastructure from fulfilling the potential role described in this article. Active choices would need to be made to ensure that there is sufficient supply in the near-term, that relevant and valuable infrastructure is preserved in the medium-term, and that new low-carbon gas is economically available in the long-term.

Avoid natural gas supply shortages in the near term

AEMO has forecast the risk of supply shortfalls in southeast Australia between 2023-2027 and called for near-term investment to ensure solutions from 2027.[8] Reliable and affordable natural gas supply will help to continue to meet power generation and customers' energy needs, particularly for customers who cannot afford to switch. This risk will not be completely avoided by switching away from gas appliances. For Victorian households in particular, gas consumption is correlated with electricity demand and electrification would likely lead to an increase in natural gas consumption for gas-powered generation.

Minimise the emissions from natural gas

Fugitive and operational emissions must be abated to reduce emissions from natural gas production and transport if natural gas use continues during the transition. The Safeguard Mechanism will encourage progress and a number of technical levers exist to reduce these emissions; however, concerted action will be needed as methane emissions cannot be offset in the same way as carbon dioxide.

Align planning, regulatory and pricing mechanisms for a more integrated energy system

System planning will need to reflect the increasing integration of the energy system. This includes across energy sources (gas and electricity) and along the value chain (generation, transmission, distribution and customers). System planning will also have to account for different requirements and outcomes by location. Some European countries (e.g. Netherlands, Germany) are increasingly conducting energy system planning at a regional level to make location-specific decisions during the transition.

Cost recovery and pricing mechanisms will need to account for true whole-of-system trade-offs. For instance, declining gas volumes could challenge the cost recovery and maintenance of regulated gas infrastructure and high tariffs, creating equity challenges through the transition.

Advance low-carbon gas technology to reduce costs

If the cost of low-carbon gases declines as forecast, they could be competitive with electricity for some customers (see section 3). Hydrogen and biomethane technology are advancing, and their feasibility is being demonstrated in Australia, for example by the Malabar Biomethane Injection Project (NSW) or Hydrogen Park Murray Valley (Victoria). More action will be needed to scale green hydrogen production to reduce costs, increase feedstock availability for biomethane, and to plan for and demonstrate how gas infrastructure can adapt for low-carbon gases.

---

[8] AEMO, Gas Statement of Opportunities (GSOO) (2023)

Appendices: How the energy system can evolve

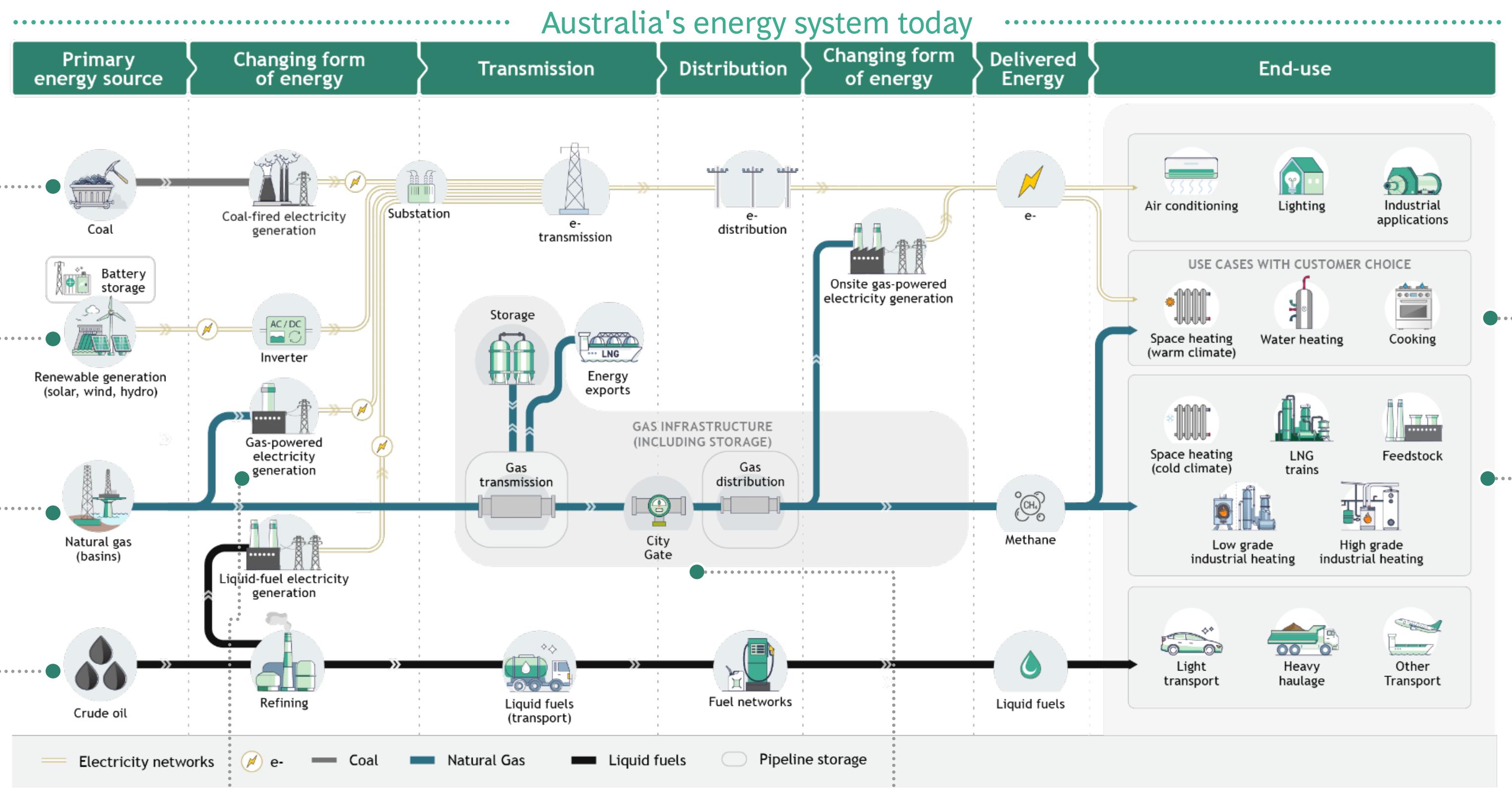
Appendix 1: Natural gas and gas infrastructure form one of three pillars of today's energy system

Coal contributes to ~**29%** of Australia's primary energy supply[1]

Renewable energy contributes to ~**8%** of Australia's primary energy supply[1]

Natural gas contributes to ~**27%** of Australia's primary energy supply[1]

Oil contributes to ~**36%** of Australia's primary energy supply[1]



Natural gas customers: 5.1m residential 190k small and large business[4]

11% of natural gas is consumed by **households**[5]

Natural gas provides ~**34% of end-use household energy,** primarily for heating, 60% in Victoria[5]

28% of natural gas is used for **low-grade heat, high-grade heat and feedstock**[5]

31% of natural gas is used for **LNG production** (compression)[5]

Natural gas provides electricity during **critical peaks:** 6-10% of generation and 20-25% of dispatchable capacity[2]

~**40,000 transmission** and ~**90,000km distribution** gas pipeline infrastructure assets (of which >$17bn fully regulated) that transport natural gas today[3]

1. Australian Energy Statistics 2. OpenNEM 3. AER, Regulated Gas Pipelines; Access arrangements used for WA. Does not include value of assets under light regulation or unregulated assets. 4. Totals do not include NT and TAS customers; AER; Economic Regulation Authority; Essential Services Commission 5. Australian Energy Statistics; APPEA, Key Statistics 2022; AEMO GSOO 2021; AEMO WA GSOO 2020; Australia Institute, On the make (2020); Energy Consult, Residential Energy Baseline Study Australia (2015)
Source: BCG analysis

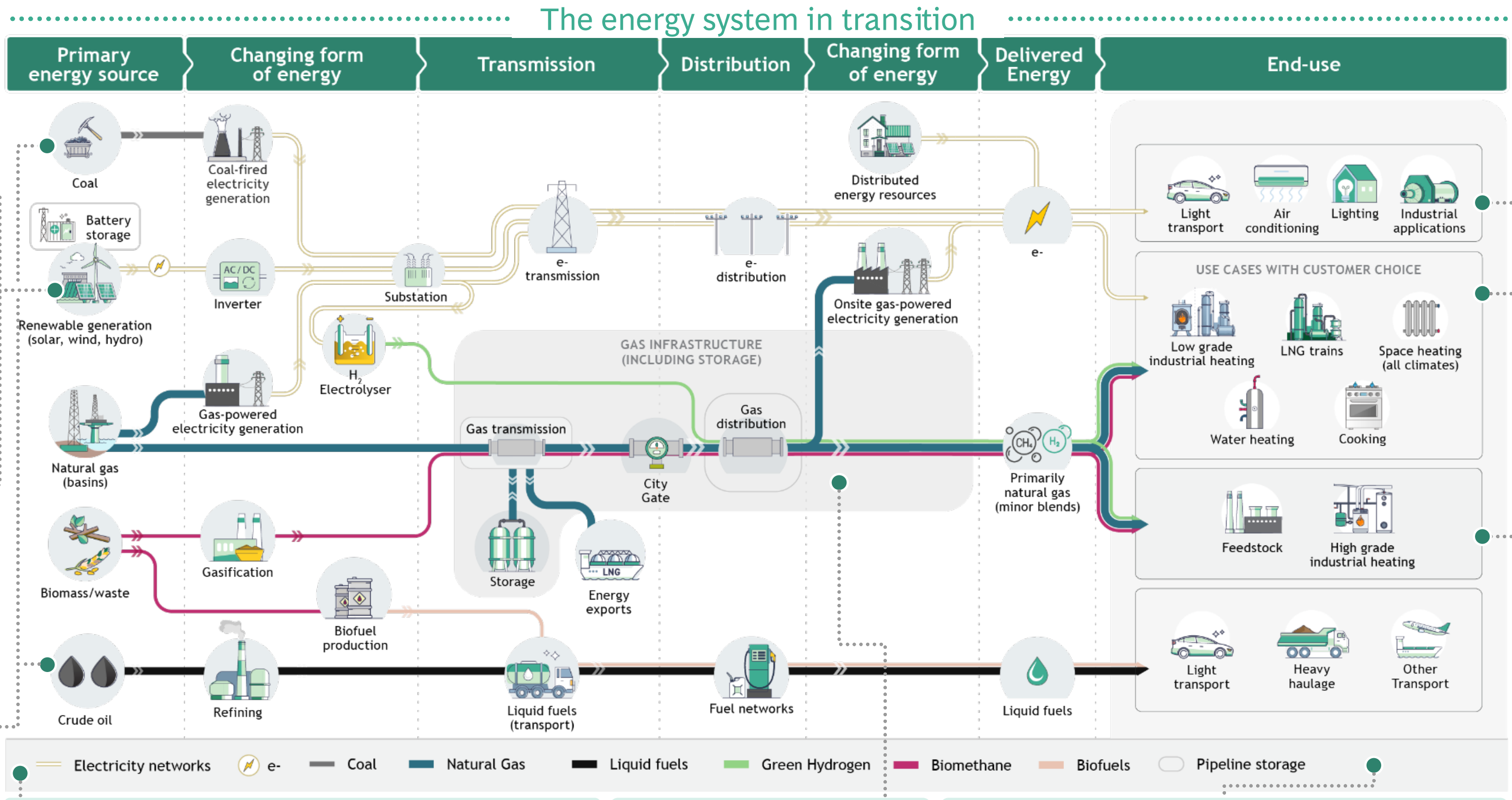
Back to Exhibit 1

Appendix 2: In the transition to a clean energy system, the growth of renewable primary energy sources will drive a realignment of the energy system architecture

Renewable electricity build will accelerate, with ~25 TWh/year of wind and solar planned, plus ~40 TWh/year of rooftop PV forecast by 2030[1]. The renewable electricity **build rate will be critical to the pace of transition**

Wind and solar will be **Australia's cheapest sources of renewable primary energy,** projected to cost $50-70/MWh compared to biomethane/green hydrogen at $75-95/MWh in 2025[2]

Displacing coal-fired electricity generation and liquid fuels with renewable electricity delivers the greatest system savings and emissions reduction



Increasing connection between gas and electricity energy systems e.g. gas is used to produce hydrogen and firm renewable electricity

Gas infrastructure supports **targeted blending of H_2 and biomethane**

System interdependencies highlight the need for **integrated system planning which needs to account for locational differences**

Transport: ICEs (liquid fuels) start being replaced by EVs (electricity)[3]

Households **have greater choice** with electric appliances becoming more **cost competitive** in most cases[5] (natural gas + offsets remains a cost competitive option)

LNG trains: gas turbine compressors could be replaced by electric drive motors[4]

Natural gas will continue to serve end uses that are **hard-to-electrify** or deliver **lower system savings** from transitioning to renewable electricity

1. AEMO NEM Generation Information; AEMO NEM ISP Generation Outlook 2022 (Step Change scenario) 2. Wind and solar LCOEs from CSIRO, GenCost 2022-23 with blended average LCOE calculated based on 60% wind and 40% solar mix; green hydrogen cost is from Advisian and CEFC, Australian Hydrogen Market Study; biomethane cost is from IEA, Outlook for biogas and biomethane, and from Deloitte, Decarbonising Australia's gas network 3. CSIRO, Electric Vehicle Projections 2021; Advisian, Australian hydrogen market study 2021 4. IEA; ABB; company data; RFF; OIES 5. Grattan, Flame out (2020); Frontier, Cost of switching from gas to electric appliances in the home (2022); ATA/Reneweconomy, Household fuel choice in the NEM
Source: BCG analysis

Back to Exhibit 1

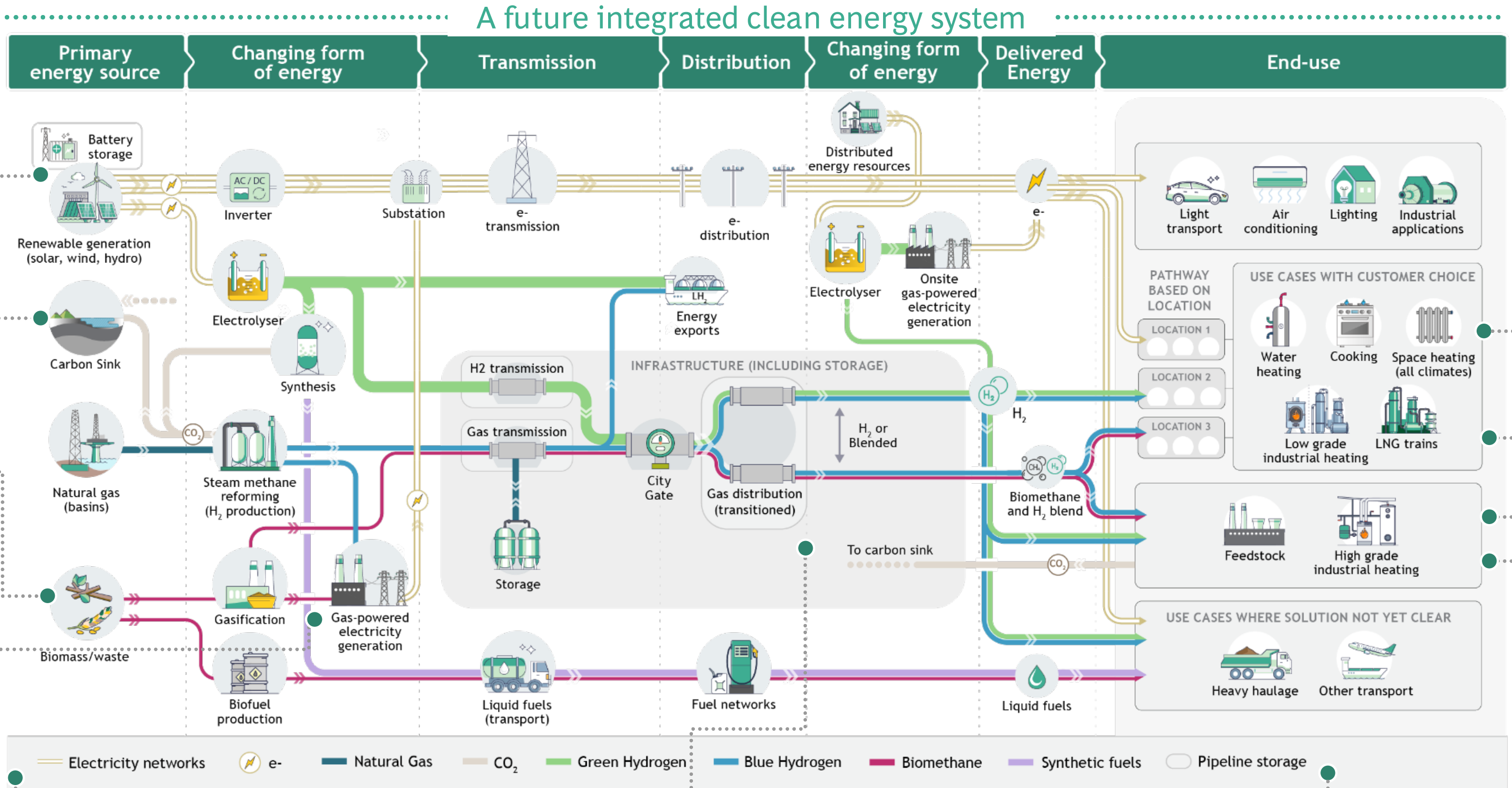
Appendix 3: In a clean energy system, low-carbon gas pathways could provide alternatives to natural gas and increase network resilience

Primary energy source maximises use of **renewable electricity** where **cost effective and available**, and then uses low-carbon gas

Carbon sinks are used to store captured CO_2 from steam methane reforming or GPG

Biogas (from biomass) can be upgraded to **biomethane** – demand will be contested by multiple end uses

Gas-powered generation remains; **least-cost future energy systems have ~5-11% GPG capacity**[1]



At anticipated costs, customers will have **competitive, low-carbon options to choose from** across electricity and low-carbon gas (e.g. H_2 and biomethane)[3]

Individual **customer choice will depend** on a number of factors

Decarbonisation pathway will be **subject to location** (e.g. climate, infrastructure availability, energy source proximity)

High-grade process heat and feedstock can be served with **low-carbon gas** (e.g. H_2 and biomethane)[4]

Greater **interconnectedness increases system resilience** through features such as green hydrogen storage

Gas distribution can transition to transport low-carbon gases with some **minor modification,** while **transmission networks may need greater modification or additional pipelines**

A system using low-carbon fuels can incur **less than 50% incremental annual costs (vs. today)**, compared to electrification alone[2]

1. Gilmore, Nelson and Nolan, Firming technologies to reach 100% renewable energy production in Australia's National Electricity Market; based on lowest average energy cost for a 100% VRE system. 2. Frontier Economics, The benefits of gas infrastructure to decarbonise Australia; 3. Advisian and CEFC, Australian hydrogen market study (2021); 4. ETI, Pathways to industrial decarbonisation (2023); ARENA, Renewable energy options for industrial process heat (2019)
Source: BCG analysis

Back to Exhibit 1

