Towards 2050:
Gas infrastructure in a zero emissions economy

Interim report

INFRASTRUCTURE VICTORIA

Aboriginal acknowledgement

Infrastructure Victoria acknowledges the traditional owners of country in Victoria and pays respect to their elders past and present, as well as elders of other Aboriginal communities. We recognise that the state's infrastructure is built on land that has been managed by Aboriginal people for millennia.

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1. Executive summary

Mains or pipeline gas, commonly known as natural gas, plays a major role in Victoria. Since it was first turned on in Melbourne in 1969, gas has heated our homes and offices, cooked much of our food and supported our electricity system. We use gas for heat and as a raw input to support local manufacturing and industrial processes to generate thousands of jobs. Victoria has a large gas network which extends across the state, with storage facilities to help meet demand peaks and significant interconnections with other states. The Victorian gas network includes 1,900km of gas transmission pipelines, 32,000km of gas distribution pipelines and assets valued at nearly $6 billion.

Natural gas is a fossil fuel made predominantly of methane, a greenhouse gas which contributes to global warming. When natural gas is burnt to generate heat and energy, another greenhouse gas – carbon dioxide – is released. The climate of Victoria has been getting warmer, with the mean annual temperature rising by just over 1°C from 1910 to 2018.[1] Current projections show extreme events such as heatwaves, bushfires and heavy rainfall are expected to become more frequent in the decades to come, with climate change posing a serious risk to the health and future prosperity of all Victorians.

Victoria's energy system must transform to reduce greenhouse gas emissions and limit the impacts of climate change. The Victorian *Climate Change Act 2017* establishes a system of coordinated, whole-of-economy actions to achieve a net zero emissions target by 2050, including rolling five-year plans and targets to reduce emissions. In May 2021, the government set interim targets to reduce the state's greenhouse gas emissions from 2005 levels by 28–33% by 2025 and 45–50% by 2030. Reducing greenhouse gas emissions at the scale required to meet net zero emissions needs an economy-wide response, including by the gas sector. The Victorian Government has asked Infrastructure Victoria to provide advice on Victoria's gas transmission and distribution networks in a future where Victoria's net zero emissions targets are achieved.

With cold winters and access to historically cheap, locally sourced supply, Victoria is currently heavily reliant on gas for a range of purposes. Use of gas by over two million residential and commercial customers accounts for 53% of Victoria's total natural gas use, of which the majority is household use. Space heating, such as gas wall heaters and ducted heating systems, makes up more than 75% of total household gas use, with winter gas use about three times higher than summer.

The industrial sector is Victoria's second-largest consumer of natural gas, accounting for 29% of total use. Of this, the manufacturing sector is the biggest user, making up over two thirds of industrial use (or 21% of Victoria's total). Gas also plays a critical backstop function in electricity generation as its ability to quickly ramp production up and down can balance variations in supply from other sources. This 'firming', or stabilising, role is likely to become more important as the proportion of electricity supplied from renewable energy sources grows, although pumped hydro generation and batteries are also able to perform this role. Victoria has 11 gas-fired power generation plants, which collectively meet around 3% of the state's electricity demand. Gas-powered electricity generation accounts for 17% of Victoria's gas use.

The evidence gathered so far for this Infrastructure Victoria advice to the Victorian Government shows that significant change is required to meet interim emissions reduction targets and reach net zero by 2050. A suite of approaches is needed to reduce emissions, manage risks, minimise costs and create new opportunities for jobs and industry.

In developing our evidence base, we have considered four illustrative scenarios to achieve net zero emissions for gas use in Victoria by 2050. The scenarios test key variables regarding the potential technology mix (electrification, natural gas, hydrogen and biogas) and the mechanism by which net zero emissions can be achieved – that is, whether emissions are eliminated or managed by solutions such carbon offsets and/or carbon capture and storage (CCS). The scenarios illustrate the performance of these key variables but are not intended to be definitive or reflect an optimal scenario. In brief, the four scenarios are:

- Scenario A: full electrification, no natural gas (by 2050), no CCS
- Scenario B: partial electrification, limited natural gas use (in 2050), limited CCS
- Scenario C: green and blue hydrogen with carbon offsets, electrification, no natural gas (by 2050), no CCS
- Scenario D: large-scale brown hydrogen, large-scale CCS, no natural gas (by 2050)

[1] Clarke JM et al (2019)

Our initial scenario analysis indicates that a diversified approach to gas sector decarbonisation is needed. No single technology is a silver bullet, and not all technologies are ready to be deployed at scale. To reach the state’s interim emissions reduction targets, an immediate scaling up of proven, reliable and relatively low-cost solutions is likely to be required, including energy efficiency, electrification and biogas. Government can play a significant role in removing barriers and enabling widespread uptake of these three proven pathways. The next phase of our work will include refinement and analysis of scenarios that combine promising technologies and policies likely to help meet the state’s interim emission targets.

Victoria’s natural gas production has historically been greater than its gas use. However, production is forecast to fall 43% from 2021 to 2025, introducing the possibility that the state’s gas use will exceed Victorian supply. While natural gas can be imported to meet current demand or additional local production could be brought online, gas is a finite resource. Natural gas is not the relatively cheap energy source for Victoria that it once was and its use contributes to greenhouse gas emissions. Our research points to the importance of energy efficiency as a ‘no regrets’ measure to reduce demand, whichever pathway ultimately leads to gas sector decarbonisation. Investing in energy efficiency can allow time for consumer behaviour to change, as well as for further research and development into gas substitution and decarbonisation technologies. Reducing overall demand for natural gas will also help preserve available supplies for certain industrial uses which cannot yet move to other energy sources or chemical inputs.

Analysis of other jurisdictions highlights that electrification is a clear pathway to reduce gas use and associated emissions, where the electricity used is generated from renewable sources. Countries including the United Kingdom and the Netherlands are actively encouraging this approach. Whatever the future role for gas in electricity generation, including in firming supply from renewable sources, there are significant opportunities to further decentralise electricity supply and diversify the energy mix across multiple sectors, for example, in developing waste-to-energy and biogas technologies.

Under all scenarios that we considered, the opportunity to repurpose existing natural gas infrastructure over the long term (beyond 2040) is limited. Some existing infrastructure is reaching end of life, limiting its potential for reuse (for example, over half of Victoria’s onshore pipeline infrastructure is over 40 years old). However, careful development, blending and optimisation of biogas and hydrogen over the short to medium term could maximise re-use of some existing pipeline infrastructure, although hydrogen production and use is not yet proven at scale.

The future of low or net zero emissions gases, such as hydrogen produced with renewable electricity and seawater (known as green hydrogen), and decarbonisation pathways such as CCS remains uncertain. Victoria could support further research and development in these technologies until their economic and environmental viability at scale is known, with the aim of keeping Victoria’s options open rather than locking in a single approach which may not turn out to be the best course of action.

Each of the scenarios we considered suggest that Victoria’s reliance on natural gas will decline significantly in the years to 2050 in order to achieve net zero. Further expansion of natural gas infrastructure increases the risk of some assets becoming unused or stranded. This could end up costing consumers more money as infrastructure owners attempt to recover the cost of their investment more quickly. It could also lock in pathways which are not compatible with Victoria’s net zero emissions targets.

The changes required to Victoria’s energy sector, including gas, will have significant implications for consumers. These may include switching fuel, upgrading appliances, adopting new technologies and increasing energy efficiency efforts. The scale of the change required, and likely financial implications for energy users, suggest a clear role for government in managing affordability and equity issues associated with any transition away from gas, particularly given existing consumer concerns with energy affordability.

Other Australian and international jurisdictions are accelerating their emissions reduction commitments, backed up with significant action. Victoria has recently released interim emissions reduction targets, along with the first round of five-yearly sector pledges. However, opportunities remain to better align policies and regulation with net zero pathways, to provide a strong framework for achieving both interim and net zero 2050 targets. This could set Victoria up to be an exporter of low carbon goods, and potentially energy, given that several key trading partners have a carbon price or ambitious emissions reduction targets.

Infrastructure Victoria is now seeking feedback on the information in this report so we can develop our final recommendations to government on the future of Victoria’s gas infrastructure as the state moves towards net zero emissions by 2050.

2. Terms of reference

In December 2020, the Treasurer formally requested that Infrastructure Victoria provide advice on the future of Victoria's gas networks under a range of 2050 net zero emissions energy sector scenarios.

The Victorian Government requested advice on the nature and timing of decisions regarding Victoria's gas transmission and distribution networks in a future where:

- Victoria's carbon emission reduction targets are achieved
- sufficient and suitable energy and chemical feedstocks are available for domestic, commercial and industrial use, and
- an option is available for hydrogen and/or biomethane to be part of the future energy mix.

Infrastructure Victoria was asked to engage with industry, regulators, the community, government and other key stakeholders in developing this advice, and to draw on international comparators and research. We were asked to develop scenarios for a net zero emissions energy sector in 2050, and to assess the implications for gas production, electricity generation, and transmission and distribution networks under each scenario.

The advice was requested in two parts:

1. An interim report, within six months of the request, setting out key early findings and evidence, significant risks and/or opportunities, key issues for further consultation and the proposed strategic direction of the final advice (this report).
2. A final report, supported by evidence and analysis, detailing the potential role for gas in Victoria's future energy mix. The final advice will consider the regulatory, policy and market settings that underpin gas production, transmission and distribution, and identify potential timings for the infrastructure decisions needed to optimise opportunities for existing gas infrastructure.

The full terms of reference are available on our website at infrastructurevictoria.com.au.

This report presents evidence that will underpin our final advice and outlines the key early findings. Feedback on the evidence and analysis presented in this report will be considered before we provide our final advice to the Treasurer in December 2021.

2.1 Scope of this advice

The focus of this request for advice is gas infrastructure in a future where Victoria achieves net zero greenhouse gas emissions by 2050. We have therefore limited our analysis to the gas sector, its current greenhouse gas emissions and the sector's interplay with others (such as electricity generation, transport and manufacturing), rather than considering how Victoria can reach its net zero emissions targets more broadly (which is the subject of recently announced interim targets and pledges under the *Victorian Climate Change Act 2017)*.

Similarly, our consideration of potential substitutes or decarbonisation pathways for natural gas in the future energy mix focuses on those energy sources which can potentially replace the current role of natural gas, or sources which have the potential to use existing gas infrastructure. While we have considered additional electrification as an alternative to natural gas use, we have not analysed in detail different electricity generation mixes in a net zero emissions future for the energy network. Potential development of nuclear as a new source of low carbon energy generation is explicitly out of scope for this work, as it is prohibited by Victorian and Commonwealth legislation.

2.2 Relationship to other government work

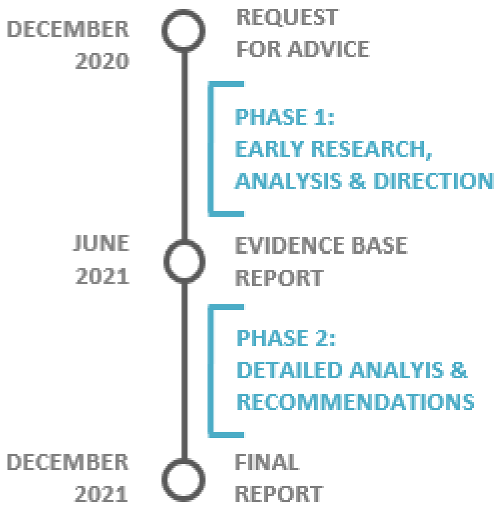
Work is underway across the Victorian Government to enable the legislated target of net zero emissions by 2050 to be achieved. In developing this advice, Infrastructure Victoria has been asked to consider, complement and build upon existing Victorian and Australian government strategies, plans, policies and regulatory documents in relation to gas infrastructure.

Our work will inform the Victorian Gas Substitution Roadmap, funded in the 2020–21 Victorian Budget and led by the Department of Environment, Land, Water and Planning (DELWP). The Roadmap will detail transition pathways for the gas sector and propose regulatory and policy mechanisms to achieve Victoria's emissions reduction targets through reduced fugitive emissions, more efficient use of gas, electrification and increased use of hydrogen and biogas while maintaining energy security, reliability, safety and affordability. The Roadmap will be developed over the course of 2021, and a consultation paper setting out options to reduce emissions from gas use was released in June 2021.[2] The advice that Infrastructure Victoria provides the government will help inform the Roadmap's development.

Our intention is to inform and complement, rather than duplicate, existing efforts led by DELWP. The focus of our work is therefore to determine how Victoria's existing and planned gas infrastructure can be best transitioned to a net zero emissions future. In considering the nature and timing of decisions to support gas sector decarbonisation, we will take into account the approach in other countries and interstate, and the potential for similar policies and approaches to be adopted in Victoria.

[2] Department of Environment, Land, Water and Planning (2021h)

3. Our approach



Our advice takes a multi-disciplinary approach to research, drawing on existing evidence and modelling where available. We have engaged extensively with stakeholders to build our understanding of the opportunities and challenges facing Victoria's gas sector and examined approaches from other Australian states and territories, as well as international jurisdictions.

Our work has two main phases:

Phase 1: Early research, analysis and strategic direction setting

Early research has focused on gathering quantitative and qualitative data to understand the key issues, players, current state and possible futures.

The evidence we have gathered so far is presented in this report and associated technical reports. We invite feedback in response to this evidence base and our analysis.

Literature review: A summary of key issues and opportunities identified in current literature sourced from academia, industry, think-tanks and governments to contribute to our understanding of the potential pathways towards net zero emissions for Victoria's gas infrastructure. This literature review was undertaken by Infrastructure Victoria.[3]

Interjurisdictional analysis: An assessment of other states, territories and countries currently transitioning away from a high reliance on natural gas to understand the potential for the Victorian Government to adopt and adapt similar policies and approaches. This interjurisdictional analysis was undertaken by Accenture.[4]

Scenario analysis: A qualitative analysis of the relative economic, social and environmental impacts of four illustrative 2050 net zero gas sector scenarios for Victoria. The scenarios illustrate the performance of key variables but are not intended to be definitive or reflect an optimal scenario This scenario analysis was undertaken by a consortium of technical experts led by DORIS Engineering.[5]

Technical work was undertaken on priority issues and to fill gaps in the available information. The full versions of all reports are available on our website at infrastructurevictoria.com.au.

Phase 2: Detailed analysis, recommendations and final advice

We will use quantitative social, environmental and economic analysis to understand the implications for Victoria of refined scenarios, drawing on the results of those developed during phase 1, and to determine relevant decisions, implications, policy levers and uncertainties. The refined scenarios will combine promising technologies and policies that are likely to help meet the state's interim emission targets.

This analysis, along with the feedback we receive in response to this report, will inform our recommendations. These will also reflect our assessment of interstate and international actions by governments to guide the future of gas in the energy mix. Our advice will identify the infrastructure decisions that need to be made, and consider the potential timing of these decisions.

[3] Infrastructure Victoria (2021) *Gas Infrastructure Advice - Literature Review*

[4] Accenture (2021) *Gas Infrastructure: International Comparisons*, report prepared for Infrastructure Victoria

[5] DORIS Engineering (2021) *Net Zero Emission Scenario Analysis*, report prepared for Infrastructure Victoria

3.1 Stakeholder engagement

Infrastructure Victoria is committed to meaningful consultation with community and industry stakeholders and developing our recommendations through an open, evidence-based and transparent process. The consultation program for this advice includes two main phases.

Phase 1

The first phase of consultation ran from March to May 2021. Engagement activities in this first phase consisted of:

- targeted questionnaires to key stakeholders, with questions tailored to each stakeholder group (academics and think tanks, government, consumer groups and industrial users, producers and distributors)
- one-on-one meetings with stakeholders.

We captured a broad representation of views from organisations and individuals across the gas sector, business, industry and government. Their valuable input helped us to refine the scope of our research and analysis. We also considered relevant submissions from stakeholders that were provided in response to *Victoria's draft 30-year infrastructure strategy* released in December 2020.

Phase 2

The second phase of consultation is to seek stakeholder and community views on this report. We welcome feedback on any of its content and accompanying technical reports which are available on our website. In particular, we invite responses to these specific questions:

- Do you have any further information, evidence or concerns that you wish to raise in relation to the scenario design and analysis?
- Do you have any further information or evidence that can help identify an optimum scenario for a net zero emissions gas sector in 2050?
- What policies and/or regulations, if any, are needed to support the development of low carbon pathways such as biogas, green hydrogen, and carbon capture and storage?
- What is your view on the best ways to maintain the reliability and affordability of Victoria's gas supply if natural gas use declines?
- What else can you tell us about the implications of decarbonisation pathways for the electricity generation, transmission and distribution networks?
- How can the use of Victoria's existing gas infrastructure be optimised during the transition to net zero emissions, over the short (10 years), medium (20 years) and long-term (30+ years)? How can the Victorian Government assist in this?
- What principles should apply or what measures will be needed to manage the impacts of gas decarbonisation on households and businesses?
- What policies, programs and/or regulations should the Victorian Government consider or expand to encourage households, commercial buildings and small businesses to reduce their gas use?
- What policies, regulations or other support, if any, do you think are needed to support industrial users to switch from natural gas to lower emissions energy sources or chemical feedstocks?

The final date for submissions is 16 August 2021. For more information on our consultation program or to get involved, visit our website at infrastructurevictoria.com.au.

3.2 Data and terminology

Multiple data sources are available to illustrate historical energy production and consumption in Australia, including the Department of Industry, Science, Energy and Resources' *Australian Energy Statistics*, and consumption and demand data from the Australian Energy Market Operator (AEMO). Each has its own accounting method, scope and reporting period, leading to variation in reported numbers across the different sources. Energy use also fluctuates daily, seasonally and year-on-year, meaning the proportion of energy ascribed to different sectors and uses can also vary significantly between time periods. We have drawn on a range of sources, selecting the data which best suit the analysis at hand.

Energy consumption forecasts are made publicly available by AEMO. We have relied on these forecasts when considering future gas and electricity demand in Victoria.

A note on terminology

Gas infrastructure is defined as infrastructure across the entire value chain of production, processing, transmission and distribution, storage, consumption, export and end use.

Other terminology which may benefit from further definition includes:

- **Biogas** is the raw product from anaerobic digestions and consists of about 60% methane. We have also used this term to cover biogas and biomethane in situations where both are likely to be used or where the use of one or the other is yet to be determined.
- **Biomethane** is upgraded and purified biogas, consisting of near 100% methane. Biomethane is identical to fossil fuel derived methane and can be used to substitute natural gas. Burning biomethane emits greenhouse gases but does not increase carbon dioxide (CO_2) levels in the atmosphere by the same amount as would be released if the organic matter the biomethane is produced from were left to decompose naturally.
- **Blue hydrogen** refers to hydrogen produced using natural gas through the process of steam methane reforming. CO_2 emissions generated during production must be captured and stored via carbon capture and storage for the hydrogen to be considered low or zero emissions.
- **Brown hydrogen** refers to hydrogen produced using coal gasification. CO_2 emissions generated during production are not captured and stored. Brown hydrogen accounts for the majority (approximately 95%) of current global hydrogen production.
- **Carbon** refers to the most prominent and dangerous greenhouse gas emissions, mainly carbon dioxide and methane.
- **Dispatchable energy** refers to a source of electricity that can be provided on demand in response to changes in supply and demand. It generally refers to fossil fuel or hydro power generation.
- **Embrittlement** occurs when metals become brittle as a result of the introduction and diffusion of hydrogen. This can occur in the steel pipelines commonly used in gas transmission networks.
- **Feedstock** refers to a raw material used to supply or fuel an industrial process, or converted to another form of energy.
- **Firming** uses an additional energy source or storage to provide backup for an intermittent power source, such as wind or solar.
- **Fugitive emissions** are losses, leaks and other releases of gases such as methane or carbon dioxide into the atmosphere that are associated with the production, transport and development of natural gas, oil and coal.
- **Green hydrogen** refers to hydrogen produced through electrolysis, using renewable electricity such as wind or solar to split water into hydrogen and oxygen. Green hydrogen production generates no greenhouse gas emissions.
- **Megatonnes of carbon dioxide equivalent** (Mt CO_2e) refers to a measure used to compare the emissions from greenhouse gases based on their global warming potential.
- **Stranded assets** are investments which are likely to see their economic life cut short due to a combination of technology, regulatory and/or market changes.

4. Gas in Victoria

Gas plays a major role in Victoria's current energy mix. It is used in residential and commercial buildings, for electricity generation and in transport. Gas is also used as a raw material and a source of heat for some manufacturing and industrial processes.

Victoria's gas production

Victoria is Australia's third-largest natural gas producer, accounting for around 9% of total production in 2018–19.[6] The majority is sourced from the Gippsland Basin and produced at the Longford processing plant. Gas is also supplied from other gas fields in Gippsland, the Otway Basin, offshore from the Bass Coast area and interstate.[7] Natural gas is produced at six processing plants in Victoria, including Longford in Gippsland and the Otway Basin. However, production is forecast to decline from 2021 as several Victorian fields cease production.

Victoria's gas use

Victoria's gas consumption is high relative to many other jurisdictions, due in part to historically abundant and low-cost supply from its onshore and offshore gas fields. Victoria's total natural gas use was 283.9 petajoules (PJ) in 2018–19, making up 22% of Victoria's primary energy use.[8]

Gas plays an important role in residential and commercial buildings. While Australian Government data indicates that total natural gas consumption in Western Australia and Queensland is higher than in Victoria (with total consumption of 668.7 PJ and 292.6 PJ respectively), this is driven mainly by gas-fired power generation and mining.[9] Victoria's use is primarily driven by the residential and commercial sectors. There are over two million residential and commercial gas customers in Victoria, and more than 80% of residential properties have a gas connection.

Residential and commercial use accounts for 53% of Victoria's total natural gas use. The industrial sector accounts for 29%, while power generation from Victoria's 11 gas-fired power generation plants accounts for 17% of the state's natural gas use.[10]

Victoria's gas transmission and distribution network

Victoria has an extensive gas network which crosses the state, with storage facilities to help meet demand peaks, and significant interconnections with other states. The network includes 1,900km of high pressure gas transmission pipelines, 32,000km of low pressure distribution pipelines and an asset base valued at nearly $6 billion.[11] The largest storage facility is the Iona Gas Plant, in Victoria's south-east. Figure 1 shows the location of Victoria's gas transmission and distribution infrastructure.

Construction of the Victorian transmission system began in the 1950s. Over half of Victoria's onshore pipeline infrastructure is greater than 40 years old. The latest major additions to the gas network were between 2014 and 2017. New housing and most commercial buildings in Victoria are currently built with both electricity and gas connections.

Victoria's gas infrastructure is all privately owned by a mix of Australian and international companies and investors.[12]

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[6] Department of Industry, Science, Energy and Resources (2020a)

[7] Department of Environment, Land, Water and Planning (2017)

[8] Department of Industry, Science, Energy and Resources (2020a). IV has used the Australian Government's *Australian Energy Statistics 2020* to illustrate natural gas use in Victoria, to allow us to make national comparisons and to drill deeper into gas usage by sector. As a point of comparison, data from the Australian Energy Market Operator indicates Victorian natural gas consumption of 214 PJ in 2020.

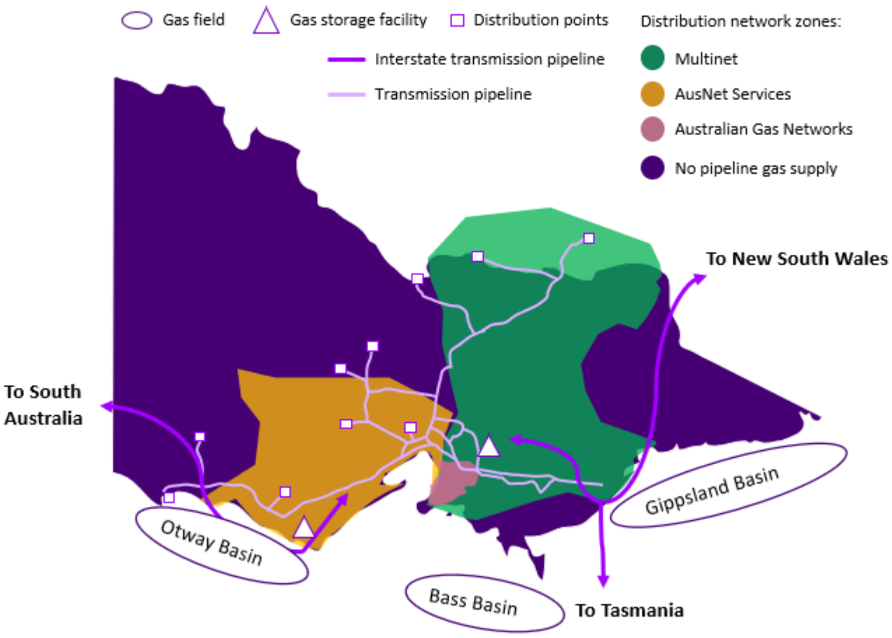
[9] Department of Industry, Science, Energy and Resources (2020a)

[10] Department of Industry, Science, Energy and Resources (2020a). Note that data is for natural gas only and therefore excludes LPG.

[11] Australian Energy Regulator (2020)

[12] Accenture (2021); DORIS Engineering (2021)

Figure 1 Victoria's transmission and distribution infrastructure



Source: Accenture (2021); IV analysis

4.1 What's the problem and opportunity?

Natural gas is methane, a fossil fuel which produces carbon dioxide, another environmentally harmful greenhouse gas, when it is developed, transported and converted into energy (combustion). The Victorian Government has committed to a target of net zero greenhouse gas emissions by 2050. Approximately 17% of Victoria's total greenhouse gas emissions came from natural gas in 2018.[13]

Under the Paris Agreement, the Australian Government has committed to reduce greenhouse gas emissions by 26–28% below 2005 levels by 2030.[14] The Australian Government has not yet set a target for net zero emissions by 2050. However, Australia's states and territories have each set their own net zero emissions targets, in effect giving Australia a 'de facto' national net zero emissions by 2050 target.

4.1.1 Gas emissions need to decline to meet Victoria's net zero emissions target

The Victorian Government has a vision for Victoria as Australia's cheapest, cleanest energy jurisdiction. The Victorian *Climate Change Act 2017* established a system of coordinated, whole-of-economy actions to achieve a net zero emissions target by 2050. This includes rolling five-year plans and targets to reduce emissions and adapt to climate change impacts, obliging all government policies, plans and decisions to consider climate change, and requiring all sectors of the economy to develop and action emissions reduction pledges.[15]

Victoria's interim emissions reduction targets for 2025 and 2030, along with the first round of five-yearly sector pledges, were finalised in May 2021. The targets aim to reduce Victoria's emissions by 28–33% from 2005 levels by 2025 and 45–50% by 2030.[16] The *Energy sector emissions reduction pledge* includes actions to reduce Victoria's emissions by an estimated 2.2 megatonnes of carbon dioxide equivalent (Mt CO_2e) in 2025 and 3.7 Mt CO_2e in 2030.[17]

Victoria's total emissions were 102.2 Mt CO_2e in 2017–18.[18] Figure 2 shows that annual emissions from natural gas were an estimated 17.4 Mt CO_2e, or 17% of the total. The largest source of natural gas emissions was direct combustion (12.2 Mt CO_2e, around 70%), which included burning gas for heat, steam and pressure for industrial operations and for space heating, hot water and cooking in households and businesses. This was followed by fugitive emissions from leaks or venting of gas in exploration, processing, storage, transmission and distribution (2.4 Mt CO_2e, or 14%), electricity

[13] Accenture (2021)

[14] Department of Industry, Science, Energy and Resources (2021a)

[15] *Climate Change Act 2017* (Vic)

[16] Department of Environment, Land, Water and Planning (2021d)

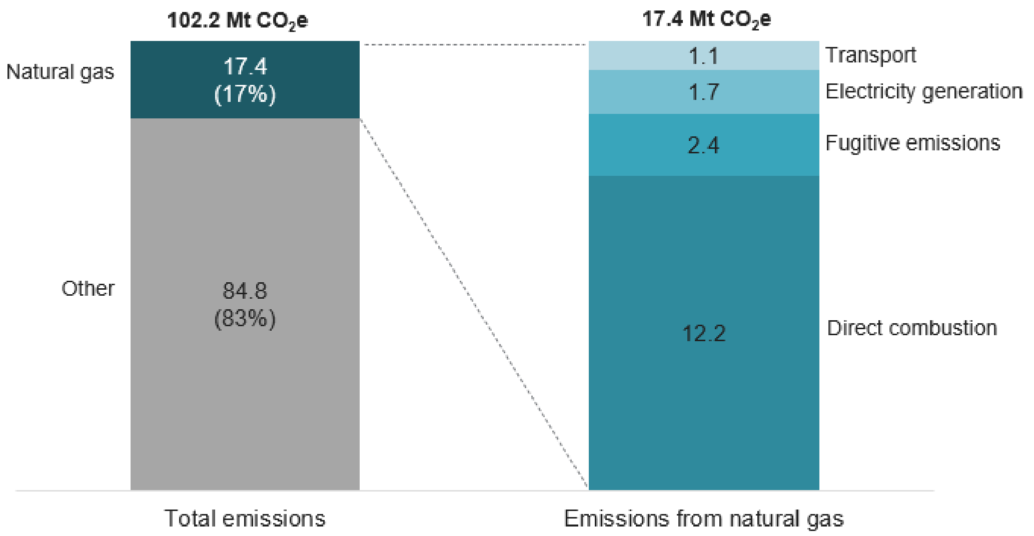
[17] Department of Environment, Land, Water and Planning (2021a)

[18] Department of Industry, Science, Energy and Resources (2020b)

generation (1.7 Mt CO_2e, or 10%) and transport (1.1 Mt CO_2e, or 6%).[19] Research has suggested the amount of fugitive emissions may be underestimated, meaning that natural gas's contribution to greenhouse gas emissions is potentially more significant.[20]

Natural gas is a major part of Victoria's emissions profile. Although Victoria's total emissions have been falling in recent years, partly due to increased renewable energy generation and the 2017 closure of the coal-fired Hazelwood Power Station,[21] emissions from natural gas will need to decline significantly in the coming decades to meet Victoria's net zero 2050 target and reduce the impacts of climate change.

Figure 2 Greenhouse gas emissions in Victoria, Mt CO_2e (2017-18)



Source: Department of Environment, Land, Water and Planning (2020); Accenture (2021)

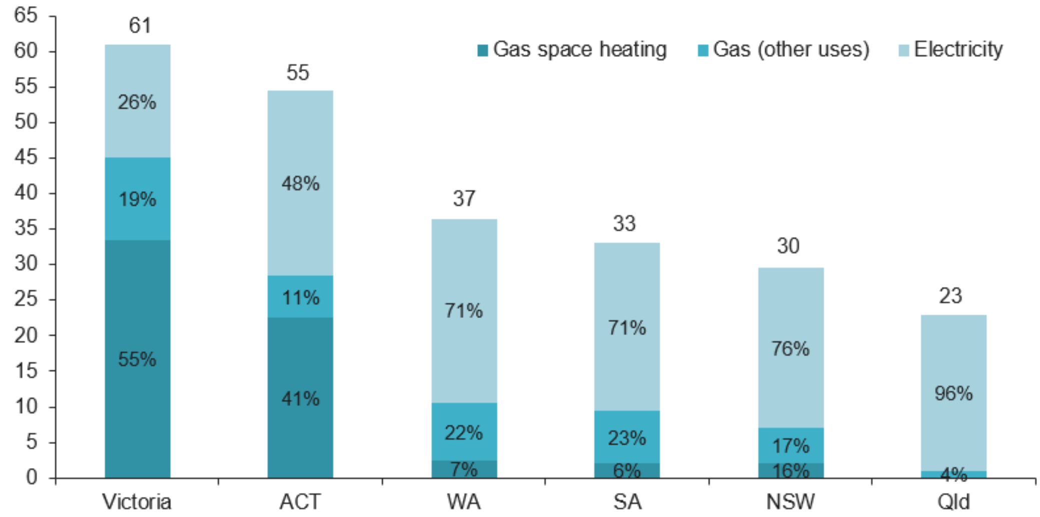
4.1.2 Victorian households use more gas and less electricity than most other jurisdictions

Victorian households account for 40% of Victoria's total natural gas use, a higher share than any other state or territory.[22] Altogether, Victoria accounts for around two-thirds of Australia's total household gas use.[23]

Victoria's high levels of household gas use are driven by its cold winters and reliance on gas for heating (associated with its previous history of abundant and low-cost natural gas). Figure 3 shows that space heating comprises more than half of total household energy use in Victoria while in the Australian Capital Territory, another cold-climate jurisdiction, it accounts for around 40%.[24] The prevalence of ducted gas heating in Victorian households means that winter gas use is about three times higher than during the summer. However, while indoor thermal comfort is an important health consideration,[25] electricity can be used as an alternative to gas.

[19] Accenture (2021)
[20] Plante L et al (2020)
[21] Department of Environment, Land, Water and Planning (2020)
[22] Department of Industry, Science, Energy and Resources
[23] Wood T and Dundas G (2020)
[24] Wood T and Dundas G (2020)
[25] World Health Organization (2018)

Figure 3 Australian household energy use by fuel and end use, gigajoules per household (2017-18)

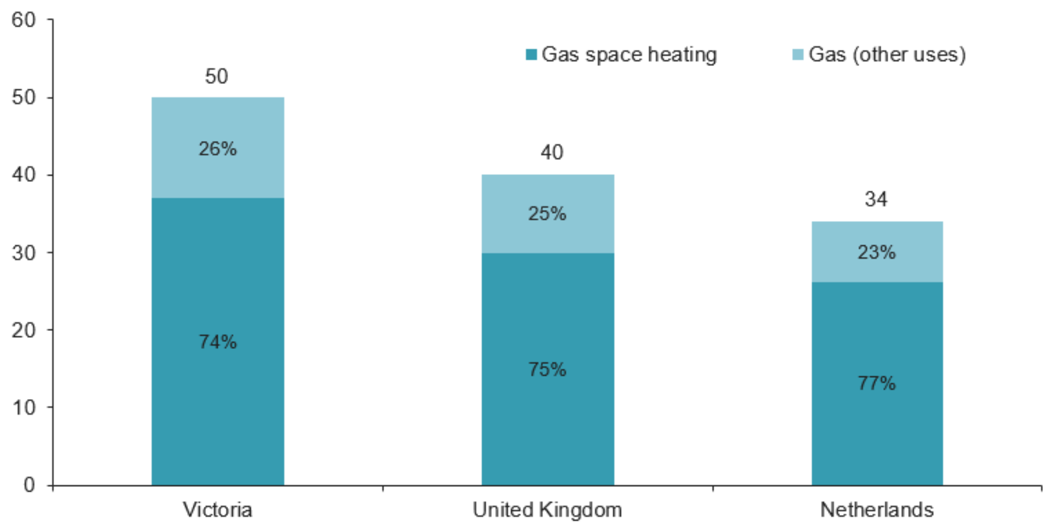


Source: Wood T and Dundas G (2020); Accenture (2021)

Other uses of gas in Victorian households include water heating and cooking. While space heating accounts for almost three quarters (74%) of Victoria's household gas use, water heating accounts for around one quarter (24%), and cooking makes up just 2% of total household use.

Household gas use in Victoria is also high compared with other countries, including those with cold climates. For example, Figure 4 shows that annual gas use in Victoria is 50 gigajoules (GJ) per household, compared with 40 GJ in the United Kingdom and 34 GJ in the Netherlands.[26]

Figure 4 Household gas use by end use, gigajoules per household (2017-18)



Source: Accenture (2021); Eurostat (2020); IV analysis

[26] Accenture (2021)

4.1.3 Industrial, power generation and commercial gas use is also significant

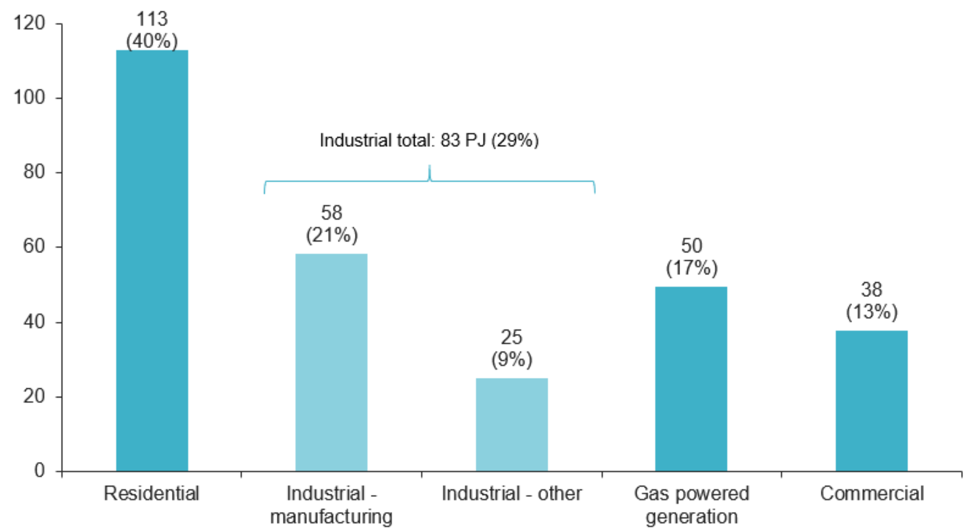
Figure 5 shows that after households, the industrial sector is Victoria's second-largest consumer of natural gas, accounting for a combined 29% of total use. The manufacturing sector is the biggest end-user, making up over two thirds of industrial use (or 21% of Victoria's total).[27]

Most gas in the manufacturing sector is used for producing heat. Gas is also used as a chemical input for some manufacturing processes, including ammonia and polyethylene production. In Victoria, the largest user of natural gas as a chemical input is the Qenos plastics manufacturing facility in Altona.[28]

Gas-powered electricity generation accounts for 17% of Victoria's gas use. Gas plays a critical backstop function in electricity generation as its ability to quickly ramp production up and down can balance variations in supply from other sources.[29] This 'firming', or stabilising, role is likely to become more important as the proportion of electricity supplied from renewable energy sources grows.[30] Victoria has 11 gas-fired power generation plants, which collectively meet around 3% of the state's electricity demand.

The commercial sector comprises the remaining 13% of Victoria's natural gas use. As in the residential sector, gas in the commercial sector is mostly used for space heating. For commercial buildings, there are some additional end-use applications like cooking and water heating in retail sectors, and dryers and pool heating in hotels.[31]

Figure 5 Victorian gas consumption for energy, by sector, PJ and % total (2018-19)



Numbers may not add to 100% due to rounding.
Source: Department of Industry, Science, Energy and Resources (2020a), Accenture (2021), IV analysis

4.1.4 Victoria's natural gas production is currently declining

Victoria produced 361 PJ of natural gas in 2020. Victoria's production has historically been greater than its gas use, meaning Victoria has been a net exporter of gas to other states. However, production is forecast to fall 43% from 360 PJ to 205 PJ from 2021 to 2025 as several fields in Gippsland cease production.[32]

Figure 6 shows that gas demand in Victoria is expected to fall 7% overall from 207 PJ to 192 PJ over the same period, as energy efficiency and electrification measures are implemented.[33] Despite this, Victoria may need to import gas to meet peak winter demand in the future. This has led to proposals for liquid natural gas (LNG) import terminals and expansion of interstate gas transmission. However, plans for a floating facility LNG at Crib Point were rejected by the

[27] Department of Industry, Science, Energy and Resources (2020a)

[28] Accenture (2021)

[29] Wood T and Ha J (2021)

[30] AEMO (2021b)

[31] Accenture (2021)

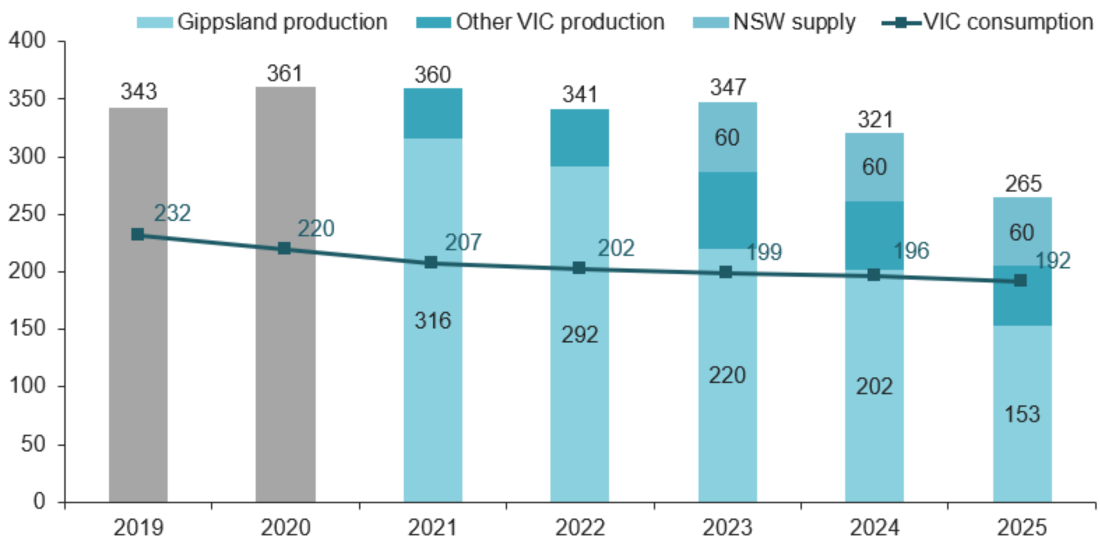
[32] AEMO (2021c)

[33] AEMO (2021c)

Victorian Government in 2021 due to environmental concerns.[34] Viva Energy Australia is currently seeking approval to develop a floating import terminal at Geelong's refinery.[35]

Alongside declining supply, gas prices have risen significantly in eastern Australia in recent years, including in Victoria. By 2018, wholesale gas prices has risen from historic levels of between $4–$6 per GJ to $8–$10 per GJ for new gas contracts. This primarily reflects rising costs, but also an increase in Australian LNG exports which has put pressure on domestic supply.[36]

Figure 6 Annual anticipated Victorian gas production and consumption (PJ) (2019-2025)



Source: AEMO (2021c)

Victoria's gas regions have seen lower levels of investment in recent years. In 2017, the Victorian Government imposed a moratorium on all onshore conventional gas exploration and development. A permanent ban on fracking and unconventional gas drilling is now in place in Victoria, although onshore conventional gas exploration and development is due to restart in July 2021, after three years of detailed scientific investigations by the Victorian Gas Program.[37]

The Victorian Gas Program has identified potential new onshore gas resources to help avoid Victoria's predicted gas shortfall. Their investigations concluded there is potentially 128 PJ to 830 PJ of commercially feasible onshore conventional gas yet to be discovered in Victoria, with potential locations including the Otway Basin and Gippsland.[38] The upper range for these new resources represents around four years of supply at current demand levels.

The Australian Government is planning new investment in gas production and infrastructure as part of its gas-fired recovery policy, which aims to avoid any anticipated shortfall in gas supply and limit gas price rises.[39] Among infrastructure priorities outlined in their interim *National Gas Infrastructure Plan*, the government identifies gas storage projects at Golden Beach and Iona in Victoria, the expansion of the South West Victorian pipeline and development of an import terminal as critical.[40]

4.1.5 The pathway to net zero, and the long-term role of gas, is unclear

There is significant global uncertainty about the role of gas in the future energy mix, given the need to reduce emissions from gas use. Further expansion of gas infrastructure may increase the risk of some infrastructure becoming underutilised or a stranded asset before the end of its useful life, and lock in pathways which are not compatible with net zero emissions targets, unless this infrastructure can be adapted to supply zero emissions gas or natural gas emissions can be fully offset.

[34] Premier of Victoria (2021b)
[35] Viva Energy Australia (2021)
[36] Wood T and Dundas G (2020)
[37] Premier of Victoria (2021a)
[38] Geological Survey of Victoria (2020)
[39] Prime Minister of Australia (2020)
[40] Department of Industry, Science, Energy and Resources (2021b)

A range of technologies and policy approaches have the potential to shape the role of gas in the future energy mix, including:

- increased **energy efficiency** through improvements to technologies or processes aimed at reducing overall gas use
- **electrification** of applicable thermal processes previously powered with gas, to reduce demand
- substitution of gas with **hydrogen**, **biogas** or **biomethane** in some applications
- **carbon capture and storage** (CCS) paired with gas combustion to provide low emissions options for gas in the future.

Some of these approaches, such as CCS or substitution with low carbon gases, such as hydrogen or biomethane, are at a relatively early stage of development and their potential as a viable decarbonisation pathway for the gas sector is not yet clear. The relative average carbon emissions intensity of existing energy alternatives and their reduction potential is shown in Table 1. The Table shows that generating electricity from coal has the highest emissions factor, followed by natural gas.

Table 1 Emissions factors

	Emissions factor
Electricity generation:	
• Coal	0.094 Mt CO_2e / PJ of coal
• Natural gas	0.052 Mt CO_2e / PJ of natural gas
• Solar or wind	0.000 Mt CO_2e / PJ
• Hydroelectric	0.000 Mt CO_2e / PJ
Direct combustion:	
• Natural gas	0.055 Mt CO_2e / PJ natural gas
• Biogas (including landfill gas)	-1.100 kg CO_2e / kWh electricity
Direct heat – geothermal	0.007 t CO_2e / PJ
Green hydrogen	0.000 Mt CO_2e / GWh electricity
Blue hydrogen	0.005 Mt CO_2e / PJ natural gas
Brown hydrogen (without CCS)	0.010 Mt CO_2e / PJ coal
Agro-forestry sequestration:	
• Forestry	-18.35 t CO_2e / hectare
• Marine	-830 t CO_2e / hectare
• Soil farming	-1172 t CO_2e / hectare
Carbon credits	-1.000 t CO_2e / credit

Source: DORIS Engineering (2021)

Each of the potential technologies and policy approaches for gas sector decarbonisation is summarised below. Further detail is available in the technical reports which accompany this evidence base, available on our website at infrastructurevictoria.com.au.

Energy efficiency

Energy efficiency is a cost-effective and proven way to reduce greenhouse gas emissions by reducing overall energy demand from households, businesses and industry. This can reduce the need for more infrastructure, support better use from the infrastructure we already have and deliver energy cost savings. Poor energy efficiency in housing has also been linked to health risks, particularly during extreme weather events and among vulnerable population groups.[41] Research from New Zealand has linked retrofitting home insulation with a reduction in hospital admission rates associated with cold weather.[42]

Governments in other jurisdictions (including the United Kingdom, the Netherlands and Canada) are adopting energy efficiency as a ‘no-regrets’ measure which has clear short-term benefits and which does not constrain future policy choices.[43]

Space heating during the colder months accounts for around 74% of Victoria’s total household gas use. Measures which can improve energy efficiency in homes and businesses include appliance upgrades, insulation and improved building standards. Measures which target the efficiency of space heating have the highest potential to reduce Victoria’s gas-related emissions.[44]

A range of initiatives at national and state level exist to deliver energy efficient new buildings. These include 7-star building standards with improved thermal performance and efficient appliances. Under the 2021 *Energy sector emissions pledge*, the Victorian Government will invest $515 million to drive energy efficiency and demand management.[45] A number of existing energy efficiency measures target households and industry:

- **Victorian Energy Upgrades** is the Victorian Government’s key energy efficiency program targeting households and businesses. The scheme provides a range of incentives to reduce the cost of upgrading to more energy efficient products and services, reducing power bills for energy users as well as greenhouse gas emissions.
- **Home Heating and Cooling Upgrades** program provides assistance for 250,000 low income and vulnerable households to improve their thermal comfort by offering rebates to upgrade inefficient heaters, or add heating where there was none, with reverse cycle air conditioning.
- **Energy efficiency upgrades** are improving thermal performance (with insulation and draft-proofing) and replacing inefficient appliances for up to 35,000 social housing properties.
- **Minimum standards for heating in rental homes** have been introduced, which require a fixed heater with an energy efficiency rating of 2 stars or above in the main living area of all residential rental properties from March 2023.
- High energy-using businesses can access the **Business Recovery Energy Efficiency Fund**, which offers grant funding for both capital works and energy demand management technologies.[46]

The Australian Government is also investing in energy efficiency measures, including the National Construction Code, mandating minimum energy efficiency standards for new buildings, and the Nationwide House Energy Rating Scheme (NatHERS) that rates the energy efficiency of homes based on their design.[47]

The Australian Energy Market Operator forecasts a 7% decrease in Victoria’s annual gas consumption over the next four years, from 207 PJ in 2021 to 192 PJ in 2025, due in part to increased energy efficiency as a result of Victorian Government programs and initiatives (including the Victorian Energy Upgrade program).[48] Modelling commissioned by Environment Victoria suggests this underestimates the impact that energy efficiency programs have on Victoria’s annual gas consumption.[49] The modelling estimates that Victoria could reduce its annual gas consumption by around half (98 to 113 PJ) by 2030, primarily by:

- replacing old gas ducted heating systems (estimated 48 PJ gas reduction)
- increasing use of existing air conditioners for space heating (5–15 PJ gas reduction)
- improving building insulation (more than 10 PJ gas reduction)
- replacing gas water heaters with heat pumps (10 PJ gas reduction).[50]

[41] Australian Council of Social Service (2019)

[42] Fyfe C et al (2020)

[43] Accenture (2021)

[44] Sustainability Victoria (2019)

[45] Department of Environment, Land, Water and Planning (2021a)

[46] Department of Environment, Land, Water and Planning (2021a); Department of Environment, Land, Water and Planning (2021g); Solar Victoria (2021)

[47] Accenture (2021)

[48] AEMO (2021c)

[49] Environment Victoria (2021)

[50] Northmore Gordon (2020)

Case study – United Kingdom: Future Homes Standard to improve residential energy efficiency

The United Kingdom Government will spend £1.3 billion on energy efficiency in 2021–22. The program includes the Future Homes Standard which targets insulation and appliance upgrades in new and existing buildings in England by 2025.[51]

Heating and power for buildings currently accounts for 40% of total energy usage in the United Kingdom. The Future Homes Standard will complement building regulations to ensure all homes and businesses meet rigorous new energy efficiency standards to lower energy consumption and bills, and reach zero emissions targets.

All **new buildings** will be highly energy efficient:

- New homes are expected to produce 75-80% lower carbon emissions from 2025 compared with current levels.
- No new homes will be able to connect to the gas network from 2025. Gas boilers and other fossil fuel heating systems are banned. Instead, homes will be equipped with energy efficient insulation and heated by low carbon heating such as air source heat pumps.

Building work in **existing buildings** must meet new standards:

- Existing homes will also be subject to higher standards with a significant improvement on standards for new extensions – making homes warmer in winter, cooler in summer, and reducing bills.
- Home improvers will need to use more energy efficient replacements, repairs and parts. This includes replacing older windows and building services such as heat pumps, cooling systems or fixed lighting with energy efficient upgrades.

Electrification

Replacing gas use with electricity can reduce emissions associated with natural gas and play a role in Victoria's transition to net zero emissions, especially as renewable energy increases its share of Victoria's electricity supply (the state has a legislated target of 50% renewable energy by 2030).[52] Electrification is a core strategy in many jurisdictions for reducing emissions associated with natural gas. For example, the Netherlands is actively transitioning households away from the gas network, aiming to have all dwellings disconnected from gas by 2050.[53]

Electrical appliances can be more efficient than gas appliances. For example, reverse cycle air conditioning is more energy efficient, and costs less to run, than gas heating for an equivalent heating load.[54] A 2015 Melbourne Energy Institute report estimated that households in Melbourne could save $658 a year in heating costs by switching off their gas heater and using an existing reverse cycle air conditioner instead.[55] The Victorian Government's Home Heating and Cooling Upgrades program supports low income households to replace inefficient heaters (including gas), and no heating, with reverse cycle air conditioning.[56]

Electrification can also increase energy efficiency and productivity in the industrial sector in some instances. This can include industrial-scale electric heat pumps and other heating technologies such as electromagnetic heating and electrical resistance heating. A 2018 Beyond Zero Emissions report estimated that switching to electrical heating using proven technologies could double the efficiency of many industrial heat processes.[57] However, current electrification technologies are not well suited to industrial process heating at very high temperatures and require further research and development. The Victorian Government's Business Recovery Energy Efficiency Fund supports electrification measures for high energy consuming businesses and large emitters, among other energy saving options.[58]

Any shift towards electricity in place of gas will have a significant impact on Victoria's electricity network. Peak electricity demand would shift from summer to winter, due to space heating use, and could increase by an estimated 40% compared with current summer peak demand. This could risk increasing electricity prices, for example if the electricity grid needs to be upgraded to support increased demand.[59] The early withdrawal of the Yallourn coal-fired power station in 2028 may increase the likelihood of supply shortfalls from 2028–29 even without a significant shift to electrification,

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[51] UK Government (2021)

[52] Department of Environment, Land, Water and Planning (2021e)

[53] Accenture (2021)

[54] AGL (n.d.)

[55] Forcey T (2015)

[56] Solar Victoria (2021)

[57] Beyond Zero Emissions (2018)

[58] Department of Environment, Land, Water and Planning (2021a)

[59] Wood T and Dundas G (2020)

although this can be offset if more dispatchable electricity (that is, electricity which can be provided on demand) is brought on board – such as Energy Australia's proposed 350 MW battery, announced alongside Yallourn's closure.[60]

Increased electrification will only be successful in reducing Victoria's greenhouse gas emissions if the electricity is generated from renewable sources, or the associated emissions can be fully offset. In addition, full electrification may mean that opportunities to repurpose the gas network are not maximised. However, there may still be a role for gas infrastructure where it serves low carbon gas export markets.

Case study – Australian Capital Territory: gas-free estates to go all-electric

Along with South Australia and Tasmania, the ACT Government has committed to net 100% renewables before 2030. The ACT has also set a target to phase out new and existing gas connections by 2045, the first Australian jurisdiction to do so.

In 2020, the ACT Government **removed the mandatory requirement for gas connections to new suburbs**:[61]

- Removing the mandatory gas connected requirement allows new developments to be all electric, powered by the ACT's 100% renewable electricity supply.
- Upgrades from gas to electric appliances will be supported by access to interest-free loans or other financing mechanisms.
- The Energy Efficiency Improvement Scheme, established in 2013, will be expanded to incentivise a transition from natural gas to efficient electric heating, hot water systems and electric stoves.

The Ginninderry development will pilot the ACT's first **gas-free precinct** comprising 350 homes:[62]

- The fully electric housing precinct will help reduce energy costs for residents and reduce greenhouse gas emissions, contributing towards the ACT's target of net zero emissions by 2050.
- Homes in the precinct will be built to high sustainability standards, producing renewable energy with mandatory solar panels, high-efficiency appliances like reverse cycle air conditioners for heating and cooling, heat pumps for hot water, induction cooktops and energy management systems with battery storage and smart meters.[63]

The ACT has also committed to addressing carbon emissions from **transport**:[64]

- Canberra's bus network will shift to a zero emissions fleet by 2040, building on the experience gained through previous trials of all-electric and hybrid buses.
- The ACT Government's vehicle fleet will switch to zero emissions alternatives, including Australia's first government fleet of hydrogen vehicles.

Substitution with hydrogen

Hydrogen is being considered as a low carbon alternative to natural gas, as it is a flexible energy carrier that could replace many current gas applications. Hydrogen can be used as both an energy supply and an industrial feedstock for chemical production. It can contribute to emissions reduction depending on how it is produced.[65]

There are several different types of hydrogen production, including brown, blue and green hydrogen, as illustrated in Figure 7 (the colour attributes help to describe the emissions intensity of the production process, although the hydrogen produced is a colourless gas).

[60] AEMO (2021a)

[61] ACT Government (2020a)

[62] ACT Government (2018)

[63] Ginninderry (2021)

[64] ACT Government (2020b); ACT Government (2021)

[65] Bruce S et al (2018)

Figure 7 Types of hydrogen production – brown, blue and green

Brown hydrogen	Blue hydrogen	Green hydrogen
• Fossil fuel (coal) • CO_2 emissions	• Fossil fuel (gas) • CO_2 storage	• Renewable electricity • Water electrolysis

Brown hydrogen – is produced using brown coal through the process of gasification. However, if the greenhouse gas emissions generated during production are not captured and stored, expanding production of brown hydrogen will add greenhouse gas emissions. Annual global hydrogen production is around 70 million tonnes today, made almost entirely from fossil fuels. As a result, global hydrogen production is currently responsible for carbon emissions of around 830 Mt CO_2e each year – equivalent to around 150% of Australia's total greenhouse gas emissions.[66] If the greenhouse gas emissions generated during brown hydrogen production are captured and stored, the climate impact of this technology can be significantly reduced. Current trial projects to this effect are discussed below.

Blue hydrogen – is produced using natural gas through the process of steam methane reforming. Greenhouse gas emissions generated during production must be captured and stored via carbon capture and storage (CCS) for the hydrogen to be considered low or zero emissions. Blue hydrogen using CCS still results in some emissions. The proportion of carbon emissions commonly captured in blue hydrogen production is estimated at between 65–90%.[67] Blue hydrogen may be a possible pathway to replace or decarbonise natural gas in Victoria, using existing gas infrastructure while producing only moderate emissions which can be offset or captured and stored, but there are still significant uncertainties about the economic and technical feasibility of this technology at scale.

Green hydrogen – renewable electricity, such as wind or solar, is used to split water into hydrogen and oxygen using electrolysis. Green hydrogen production generates no emissions when supported by 100% renewable electricity. However, although the production of hydrogen through electrolysis is a known technology, it is currently inefficient and therefore very costly to produce at large scale. This may change rapidly in the future, given significant interest in this technology. In addition, more work is needed to understand the potential, energy demand and costs of producing green hydrogen from stormwater, wastewater or seawater, so that our limited fresh water can be used for drinking, the environment and growing food.

The long-term role of hydrogen in the global energy mix, and its potential as a substitute for natural gas, is uncertain as many questions remain about its storage, distribution and end use. The major technical risk is that hydrogen transmission at high pressure causes steel transmission pipelines to become brittle and fail (known as 'embrittlement'). In the smaller distribution pipelines to commercial and residential users, plastic pipes are common. Plastic pipes are safe to use with hydrogen. Blending hydrogen with natural gas would allow existing infrastructure to be used, offsetting an immediate need for purpose-built hydrogen infrastructure and providing a transition pathway. However, the upper limit of hydrogen which can be used in existing infrastructure and appliances is variable and needs additional testing. While existing pipelines may allow a blend of up to 20% hydrogen (depending on pipeline pressure),[68] domestic appliances are likely suitable for a maximum of 10% hydrogen blending without being modified.[69]

In addition, unlike natural gas, hydrogen cannot be odourised and is flammable. While its use is currently well managed in an industrial setting, future hydrogen use in homes could result in undetected gas leaks, ignition and explosions. One simple risk reduction measure could be to consider hydrogen for heating, installing piping which remains external to the home, and replace gas cooking appliances with electrical appliances.[70]

Despite these uncertainties, countries such as Japan, the Netherlands and the United Kingdom are investing in hydrogen projects to create a potential low carbon pathway. Large-scale hydrogen production is not yet available in Australia but there are several pilot, demonstration and small-scale projects in various stages of operation.[71] The Australian Government recently provided $32 million in funding to the Australian Gas Infrastructure Group's Hydrogen Park Murray Valley project in Wodonga. The project aims to develop a 10 MW electrolyser to produce green hydrogen for blending with natural gas and is one of three projects funded under the Renewable Hydrogen Deployment Funding Round.[72]

[66] International Energy Agency (2019)

[67] Powell D (2020)

[68] DORIS Engineering (2021)

[69] GPA Engineering (2019)

[70] DORIS Engineering (2021)

[71] Geoscience Australia (n.d.)

[72] Australian Renewable Energy Agency (2021)

Victoria is considered to have potential for future hydrogen development due to its significant brown coal reserves in Gippsland and a developed offshore reservoir with geology suitable for CCS.[73] However, brown hydrogen production with CCS still generates significant greenhouse gas emissions (CCS does not capture all emissions from a given source), meaning that this method of hydrogen production will need to be combined with equally significant emissions offsets along with policy changes (such as a long-term carbon price or emissions regulation) if the gas sector is to reach net zero emissions targets.[74] The Hydrogen Energy Supply Chain pilot in the Latrobe Valley aims to be the first commercially viable hydrogen export project in Australia.[75] Hydrogen will be produced from brown coal, with carbon emissions captured and stored via the CarbonNet project (see below for further details on CarbonNet). Realisation is dependent on CCS technologies which are still undergoing proving in Victoria at scale. It will also require sufficient CCS capacity to support a long-term hydrogen export industry.

The Victorian and Australian governments are supporting the development of hydrogen production in Victoria. In addition to the Hydrogen Energy Supply Chain pilot project, which is jointly funded, hydrogen development initiatives include:

- The $10 million *Renewable Hydrogen Industry Development Plan*, which outlines the Victorian Government's strategy for the development of renewable and zero emissions hydrogen production. The plan provides funding for pilot and demonstration projects as well as business cases for industrial users.[76]
- *Australia's National Hydrogen Strategy* sets a national vision for a clean, innovative, safe and competitive hydrogen industry. It aims to position Australia as a major global player by 2030.[77]
- The 2021–22 Australian Budget provided $275.5 million to develop up to four additional hydrogen hubs, as well as $24.9 million to assist new gas generators become 'hydrogen ready'.[78]

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[73] Bruce S et al (2018)

[74] Longdon T et at (2021)

[75] HESC (2020)

[76] Department of Environment, Land, Water and Planning (2021c)

[77] COAG Energy Council (2019a)

[78] Australian Government (2021b)

Case study – United Kingdom: the first hydrogen town by 2030

The United Kingdom's *Hydrogen Network Plan* sets out how gas network companies will deliver the world's first extensive 100% hydrogen network.

Building on the UK Government's ***Ten Point Plan*** and ***Hydrogen Strategy***, supported by a Net Zero Hydrogen Fund of £240 million, Britain's five gas grid companies have set out their plan for building the UK's hydrogen economy and delivering the first hydrogen town by 2030.[79]

The ***Hydrogen Network Plan*** will be delivered in four stages:

- **Preparing for Transition** (2020–2025) – including mains replacement, completing the safety case, trialling 100% hydrogen in homes and network modelling to ensure security of supply. Hydrogen-ready boilers roll out at a rate of around 1.5 million a year, similar to the current level of annual boiler replacements.
- **Solution Pilots** (2025–2030) – includes 100% hydrogen domestic pilots, 20% hydrogen blending in parts of the network and continued mains replacement. Hydrogen-ready boilers continue to roll out at around 1.5 million a year and, following on from pilots, the first 100% hydrogen conversions take place.
- **Scaling Up** (2030–2040) – includes building new hydrogen pipelines between industrial clusters and connecting hydrogen production and storage facilities to the networks. Mains replacement is completed and 100% hydrogen use in homes is rolled out. Nearly all domestic properties are now hydrogen ready, with boilers and other appliances converted. Dedicated hydrogen production at scale is now available, and widespread conversion of housing to 100% hydrogen is underway.
- **Full Transition** (2040–2050) – full conversion of the gas networks to net zero is now complete. Domestic conversion is complete. The gas and electricity networks are interconnected and mutually supportive.

Further policy development will be a critical enabler of the later stages of the ***Hydrogen Network Plan***. For example:

- mandate hydrogen-ready appliances such as hydrogen-ready boilers and hybrid heating systems in force before 2025 to facilitate network conversion and roll-out at scale by 2040
- support hydrogen producers to meet the UK's hydrogen production target of 1GW by 2025 and 5GW by 2030
- support hydrogen storage capacity and network conversion from 2025, funded through the regulated asset base framework
- ensure CCS is developed at scale in several clusters by 2030, with blue hydrogen delivering the required scale in the interim and replaced over time with green hydrogen as the production method of choice.

Substitution with biogas or biomethane

Biogas is a form of renewable energy that can be used to decarbonise gas. Biogas is the raw product from anaerobic digestion of organic matter and consists of about 60% methane. It can contribute to Victoria's emissions reduction targets by replacing the combustion of natural gas with biogas for energy purposes and by capturing methane emissions from organic feedstocks (such as animal waste, other organic matter sourced from landfills, and wastewater processing plants) that would otherwise be released without benefit.

Biogas can be used as a cost-effective source of energy for heat or electricity generation in some applications, in locations where organic feedstock is readily available. It can be used directly onsite to produce local heat via a biogas-fuelled boiler, at locations such as wastewater treatment plants or meat processing plants. Biogas can be converted into electricity via a combined heat and power unit, for use onsite or for export into the grid.

Biogas can also be upgraded and purified to create biomethane. Biomethane's chemical characteristics are close to natural gas. It can therefore be injected into the existing gas network for industrial and residential gas end-use without the need to modify gas pipelines or appliances. If biomethane is converted and compressed to a liquefied form, it can be transported in bottles or used as a vehicle fuel. Where biomethane is to be injected into gas networks rather than used locally, proximity to the gas network is a significant cost factor. Plants must generally be located close to gas grids to be cost effective. There is currently no biomethane production plant operating in Australia.[80]

Internationally, countries including the United Kingdom, the Netherlands and Canada are introducing policies to support biomethane production and injection into the grid. Some jurisdictions are also pursuing biomethane as a strategy to reduce emissions from agriculture.

Australia is considered to have several comparative advantages that increase its potential to develop a sustainable and competitive bioenergy industry, including a suitable climate, agricultural land and strength in natural resources and

[79] Energy Networks Association (2021)

[80] Carlu E, Truong T and Kundevski M (2019)

infrastructure development.[81] There is limited available information to fully assess the role of biogas in decarbonising natural gas in Victoria. However, one study estimated that Victoria has a biogas supply potential of 48 PJ, which is approximately one quarter of its current gas consumption.[82] This means replacing all of Victoria's household gas use with biomethane would require additional biomass resources in the form of new plant crops, which would add to pressures on land and water resources. Despite these potential limitations, this technology has a role to play in the overall technology mix needed to achieve net zero emissions for the gas sector.

There are several projects in Victoria using biogas to supply energy for their own use, including wastewater treatment plants and food processing businesses.

Case study – Biogas in Victoria: turning organic waste into energy

Yarra Valley Water's ReWaste facility is the first biogas solution for the water industry in Australia:[83]

- ReWaste provides a disposal solution for commercial organic waste, diverting 33,000 tonnes of organic waste (or 100 tonnes a day) from landfill every year. Commercial food waste is transported to the site in trucks, then fed into the 'digester'. Biogas is produced using anaerobic digestion, which is then converted into renewable electricity.
- The waste-to-energy facility produces enough biogas to power the neighbouring Aurora sewage treatment plant, with surplus energy being exported to the electricity grid. It generates around 22,000 kilowatt hours of electricity per day, the equivalent power demand of around 1,300 homes.
- Located in Wollert, in Melbourne's north, the facility became fully operational in 2017. At full capacity, ReWaste covers 25% of Yarra Valley Water's annual electricity demand. Current and planned ReWaste facilities will make a large contribution to Yarra Valley Water's ability to reduce its reliance on coal-powered energy and generate 100% of its energy requirements by 2025.

Renewable Organics Network Colac turns waste into energy, hot water and fertiliser:[84]

- In the regional centre of Colac in south-west Victoria, food manufacturers Bulla Dairy Foods and the Australian Lamb Company, together with regional water corporation Barwon Water, are collaborating to build a waste-to-energy facility. Using organic waste such as milk solids and meat scraps, biogas will be produced to generate renewable electricity and hot water.
- The biogas facility will produce 5.5 gigawatt hours of renewable electricity each year. Around 50% will be used to power the Colac Water Reclamation Plant, taking it off the grid. Barwon Water's target is to achieve 100% renewable electricity by 2025 and net zero emission by 2030. The remaining electricity generated will be exported into the grid, enough to power about 500 homes.
- In an Australian-first, the project will also generate renewable hot water for supply to the Australian Lamb Company via an innovative hot water pipeline, which will offset the natural gas consumption of the business by 21.4 terajoules each year, equivalent to the gas use of 350 households.
- Solid waste left over at the end of the anerobic digestion process will be collected and used for soil conditioning and fertiliser on farms.

Carbon capture and storage

Carbon capture and storage (CCS) involves capturing, transporting and storing greenhouse gas emissions from fossil fuel power stations, energy intensive industries, and oil and gas fields. It removes carbon emissions from the source or the atmosphere, and stores carbon permanently underground (as a gas or liquid), or in solid form through a reaction with metal oxides to produce stable chemical compounds.[85] Natural processes which remove and store carbon dioxide from the atmosphere, such as biomass, soils and oceans, are not included in the definition of CCS.

Carbon emissions may be permanently stored underground in two areas:[86]

- **Oil and gas fields** – various depleted oil and gas fields have the capacity to meet carbon storage requirements, but their geographic distribution is limited and potentially distant from carbon-intensive industries. To date, carbon storage in depleted oil and gas wells has been limited to pilot demonstrations.

[81] IEA Bioenergy (2018)

[82] Deloitte Access Economics (2017)

[83] Rewaste (2021)

[84] Barwon Water (2021)

[85] DORIS Engineering (2021)

[86] Global CCS Institute (2020)

- **Deep saline formations** – these are underground porous rock formations which are filled with saltwater. These formations can be found worldwide and are considered to have the highest potential capacity globally for carbon storage. To date there has been some research investment in Victoria and around the world to understand their full storage potential.

Once captured, carbon emissions need to be transported to the final storage location via pipeline, truck or ship (normally pipeline, since costs associated with transport via truck or ship can be prohibitive). It is therefore more efficient to have carbon separation and storage situated together.[87] The captured carbon emissions can also be used as an input to some industrial processes. This is known as carbon capture, utilisation and storage (CCUS).

The amount of suitable underground storage is uncertain and finite. CCS with underground storage may therefore be best considered as a transition technology rather than a long-term solution. However, it may play an important future role in reducing emissions from natural gas where geology is favourable. CCS can support an ongoing role for natural gas if available at a competitive price. It should also be noted that blue hydrogen production depends on the availability and reliability of CCS at sufficient scale, as does Victoria's Hydrogen Energy Supply Chain project.[88]

CCS projects tend to be very large and complex. In general, they have high capital investment requirements and even higher operating costs. Carbon capture and purification requires some complex processes, and the gaseous carbon must be compressed to high pressure for injection and storage. In addition, the underground storage must be continuously monitored to ensure there are no leaks. Where the storage site is located offshore rather than on land, costs will escalate further.[89] In 2021 there are approximately 26 commercial-scale CCS projects operating globally, capturing a combined approximately 40 Mt CO_2e annually. Evidence from overseas indicates that large-scale CCS projects need a long-term carbon price or emissions regulation to attract capital commitments.[90]

CCS projects undertaken to date do not capture all carbon emissions from a given source and so additional carbon offsets will be required to achieve net zero. For example, the Quest oil sands production facility in Alberta, Canada, captures and stores one third of its total emissions, and the Gorgon LNG offshore production facility off Western Australia is designed to capture and store up to 80% of its emissions.[91]

Australia is considered well situated to take advantage of CCS technologies because of its numerous depleted oil and gas fields and existing pipeline infrastructure but the total potential storage has not been quantified. The 2021–22 Australian Budget has provided $263.7 million to accelerate the development of CCUS projects across Australia.[92]

The primary purpose of CCS in Victoria is the removal of carbon emissions produced by coal-fired power stations or coal gasification plants (for production of carbon-neutral brown hydrogen) located in the Latrobe Valley. The CarbonNet project, jointly funded by the Victorian and Australian governments, aims to establish a commercial-scale CCS location in the nearshore area of the Gippsland Basin to provide permanent and safe storage for 1 to 5 Mt CO_2 a year initially, rising to 20 Mt a year. This would total 25 to 125 Mt CO_2 over a 25-year project life.[93] In addition, the CO2CRC pilot in south-west Victoria has injected around 65,000 tonnes of carbon-rich gas in depleted gas reservoirs in the Otway Basin.[94]

Even though CCS is a mature technology, it is highly dependent on site-specific geological formations. Given that neither small-scale nor large-scale operating CCS projects have yet been established in the offshore Gippsland Basin, the achievable injection rates, storage volumes and long-term containment for this location have yet to be demonstrated. There are three commercial CCS projects operating globally where the storage sites are located offshore.[95]

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[87] Deloitte Access Economics (2017)

[88] HESC (2020)

[89] DORIS Engineering (2021)

[90] Accenture (2021)

[91] Shell (2020); Macdonald Smith A (2021)

[92] Australian Government (2021b)

[93] Earth Resources (2021)

[94] CO2CRC (2021)

[95] DORIS Engineering (2021)

Case study – Canada: major funding commitments in CCS

Alberta is an ideal location for CCS, with deep saline aquifers and depleted oil fields providing wide options for safe underground carbon storage. The Alberta Government has committed CAD$1.24 billion to 2025 to support two commercial-scale CCS projects. Both are operational, capturing up to 2.8 Mt CO_2e a year.[96]

Quest began operation in 2018 and captures and stores emissions from energy-intensive oil sands production:

- The project retrofitted Shell's Scotford upgrader for CCS (a facility which processes crude bitumen from oil sands into crude oil). The project captures carbon from oil sands, upgrading and transporting it 65 km north for permanent storage in a sandstone rock reservoir, approximately 2 km below the earth's surface.
- Quest is designed to capture up to 1.08 Mt CO_2e per year, approximately 35% of all carbon emissions produced by the upgrader. The Quest project is the world's first application of carbon capture and storage technology at an oil sands upgrader.

The **Alberta Carbon Trunk Link** (ACTL) system began operating in 2019 and transports carbon emissions from industrial production for use and storage:

- ACTL is a 240-km pipeline that carries carbon captured from the Sturgeon Oil Refinery and the Nutrien Redwater fertiliser plant to oil fields in Central Alberta for use in enhanced oil recovery projects before permanent storage.
- The two industrial facilities provide around 1.6 million tonnes a year of high purity CO_2. The designed capacity of the ACTL pipeline is 14.6 million tonnes of CO_2 a year, which will allow future CCS projects to use it as the energy and agriculture industries grow.

[96] Alberta Government (2021)

5. Key early findings

Building on our assessment of the current challenges and opportunities facing Victoria's gas sector, our key early findings start to address the questions detailed in the terms of reference for this advice. We were asked to develop scenarios for a net zero emissions energy sector in 2050, to assess the implications for gas infrastructure and gas users under each scenario, to consider the role for government, and to identify the key uncertainties, interdependencies and infrastructure decisions that need to be made. We have summarised our findings under each of these questions.

5.1 What are the scenarios for a net zero emissions energy sector in 2050?

The focus of this request for advice is gas infrastructure in a future where Victoria achieves net zero greenhouse gas emissions by 2050. We have therefore limited our scenario design and analysis to the gas sector, its current greenhouse gas emissions, and the sector's interplay with others (such as electricity generation, transport and manufacturing). Potential decarbonisation pathways for the gas sector were explored in our literature review, with relevant work identified from Energy Safe Victoria, Energy Networks Australia, Frontier Economics, ClimateWorks Australia and CSIRO.[97]

We have developed four illustrative scenarios to achieve net zero emissions for gas use in Victoria by 2050. Scenarios have been selected and developed on the basis they all aim to achieve net zero emissions by 2050, but test key variables regarding:

- the technology mix – namely electrification, natural gas, hydrogen and biogas
- the mechanism by which net zero emissions are achieved – that is, whether emissions are eliminated (zero emissions) or managed by solutions such carbon offsets and/or CCS.

The scenarios illustrate the performance of these key variables but are not intended to be definitive or reflect an optimal scenario. Victoria's interim emissions reduction targets for 2025 and 2030 were released by the Victorian Government after Infrastructure Victoria had completed the initial scenario analysis and so could not be incorporated into the scenario design. This will be revisited in the next phase of our scenario analysis work. The next phase of Infrastructure Victoria's work will include refinement and analysis of scenarios which combine promising technologies and policies likely to help meet the state's interim emission targets. The four scenarios are summarised in Table 2.

Table 2 Scenarios to achieve net zero emissions for gas use in Victoria by 2050

Scenario A: Zero emissions electrification – no natural gas	Scenario B: Net zero emissions electrification supported by natural gas	Scenario C: Zero emissions hydrogen with biogas and electrification	Scenario D: Net zero emissions hydrogen with biogas and electrification
• Almost full electrification using renewable sources, utility-scale battery storage and some pumped hydroelectric • Very little natural gas except where it is irreplaceable – and none by 2050 • No CCS by 2050	• Extensive electrification with renewable sources, significant small-medium battery storage and limited pumped hydroelectric • Some natural gas to support the renewable electricity system and some industrial uses • Made net zero by CCS and offsets	• Hydrogen using renewable sources really takes off as a substitute for natural gas • Some waste to energy, biogas and renewable electricity sources with some battery storage • No CCS • No natural gas by 2050	• Hydrogen using both renewable sources and coal with CCS • Some waste to energy and biogas and renewable electricity sources with some battery storage • No natural gas by 2050

[97] Infrastructure Victoria (2021)

A brief overview of each scenario is outlined below. All scenarios assume a baseline annual energy demand in Victoria of 1,298 PJ in 2018-19, with a forecast increase in energy consumption of 15% per decade.[98] Population growth forecasts are in line with the Department of Environment, Land, Water and Planning's *Victoria in Future* population projections.[99] More detail on the assumptions underpinning these scenarios are available in Appendix A and in the technical report available on our website.[100]

Common to all scenarios is a gradual decline over time in the consumption of fossil fuels for energy generation, notably brown coal (primarily electricity), natural gas (primarily space and water heating), diesel and gasoline (primarily transport). Each scenario represents a model of the gradual replacement of fossil fuels by specific combinations of renewable and zero-carbon energy sources, energy storage, and carbon offsets to cover the entire energy-emissions-offset supply chain. A small to moderate uptake of energy efficiency measures is assumed.

Scenario A: full electrification, no natural gas (by 2050), no CCS

The key feature of this scenario is its focus on solar, wind and hydro renewable electricity to replace fossil fuels by 2050. Its advantage is reduced carbon emissions for electricity generation meaning no requirement for CCS. Scenario A proposes to meet gas demand through production of biogas and green hydrogen to replace natural gas. Moderate uptake of energy efficiency measures is included for residential and commercial buildings including insulation, ground source heat pumps and installation of smart grid systems. By 2050, gas, petrol and diesel-powered road vehicles are replaced primarily by battery electric vehicles and, to a lesser extent, with hydrogen fuel cell vehicles.

Scenario B: partial electrification, limited natural gas, limited CCS

Scenario B's key differentiator is the continued use of a limited amount of natural gas through to 2050 to provide firming of renewable energy sources and support hard to abate manufacturing industries such as plastics and alumina production. No other scenario has any natural gas being consumed in 2050, and for this reason Scenario B maintains the greatest proportion of the current hydrocarbon energy supply chain of all scenarios. This aspect defines the key advantage of Scenario B, being the high level of energy infrastructure efficiency achievable through use of natural gas to balance variable renewable loads and satisfy hard to abate feedstock demand, while also using pre-existing natural gas infrastructure.

Scenario B is most closely aligned to Scenario A due to the relatively high proportion of renewable electricity rather than gas in the overall energy mix. In addition to a minimal loading of natural gas, Scenario B satisfies gas demand through a combination of biogas/biomethane and hydrogen. Carbon emissions are offset by a combination of CCS and agroforestry. A small uptake of energy efficiency measures is assumed for residential and commercial buildings. As per Scenario A, hydrocarbon-fuelled road vehicles are replaced in Scenario B primarily by battery electric vehicles and, to a lesser extent, with hydrogen fuel cell vehicles.

Scenario C: green and blue hydrogen with offsets, electrification, no natural gas (by 2050), no CCS

Scenario C proposes the most comprehensive energy mix of all scenarios. It has the least focus on any one type of low carbon energy source. This is the primary advantage of Scenario C, as it reduces the risks associated with newer technologies through moderated levels of production and scale. Scenario C is more closely aligned to Scenario D, due to the relatively high proportion of gas rather than renewable electricity in the overall energy mix.

Scenario C satisfies gas demand primarily through production of green hydrogen, with use of blue hydrogen scaled to use Victorian natural gas production through to its natural decline. Carbon emissions are offset by a combination of agroforestry and carbon trading certificates. A moderate uptake of energy efficiency measures is assumed for residential and commercial buildings. Hydrocarbon-fuelled road vehicles are replaced by a balanced mix of battery electric vehicles and hydrogen fuel cell vehicles.

Scenario D: large-scale brown hydrogen, large-scale CCS, no natural gas (by 2050)

Compared with the other scenarios, Scenario D has the highest proportion of gas, primarily hydrogen, and its advantage is the export potential of brown hydrogen produced by gasification of Victoria's large brown coal reserves. Compared with the other scenarios, Scenario D is more closely aligned to Scenario C due to the high proportion of gas (hydrogen) in the overall energy mix.

Scenario D satisfies gas demand primarily through production of brown hydrogen, with some contribution from biogas/biomethane and green hydrogen. Carbon emissions are reduced through extremely large-scale CCS and offsets. This would require a significant expansion of CarbonNet and development of numerous other large-scale CCS and offset projects. A small uptake of energy efficiency measures is assumed for residential and commercial buildings. As with

98 Baseline annual energy demand data are sourced from Department of Industry, Science, Energy and Resources (2020a). Forecast energy demand is based on AEMO's *2020 Integrated System Plan Inputs and Assumptions*. Available at https://aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp/2020-isp-inputs-and-assumptions

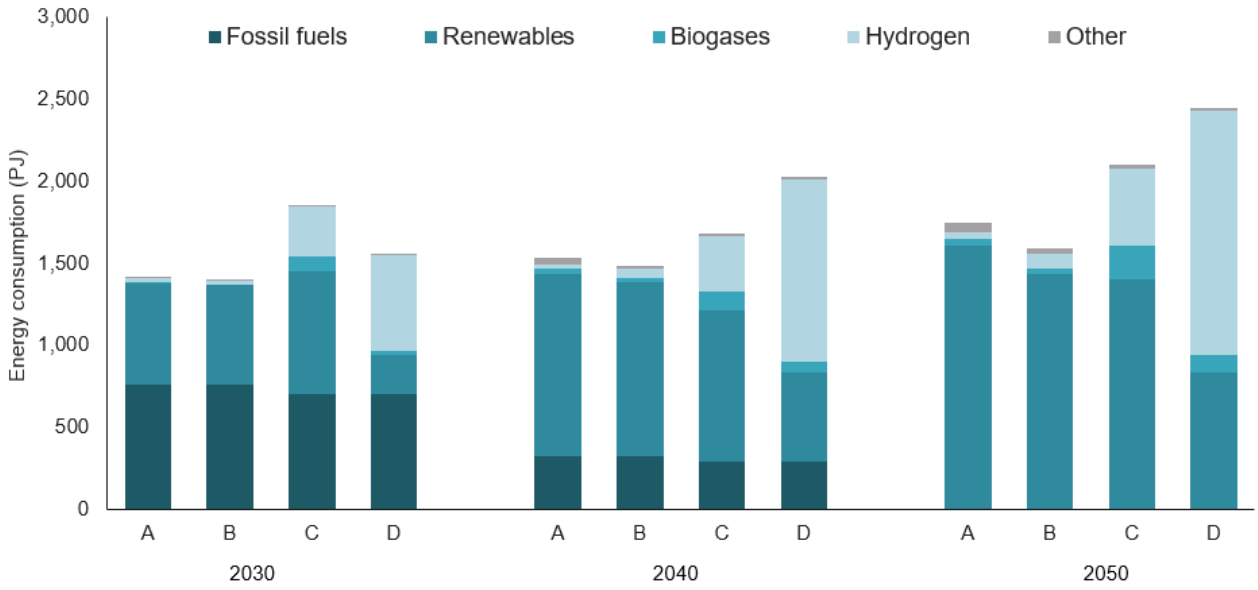
99 See *Victoria in Future* [website]. Available at www.planning.vic.gov.au/land-use-and-population-research/victoria-in-future

100 DORIS Engineering (2021)

Scenario C, hydrocarbon-fuelled road vehicles are replaced by a balanced mix of battery electric vehicles and hydrogen fuel cell vehicles.

Figure 8 summarises how energy demand is met under each scenario in 2030, 2040 and 2050, illustrating relative reliance on fossil fuels, renewables, biogases and hydrogen during the transition. A more detailed breakdown is provided in Appendix B.

Figure 8 Energy demand by scenario and energy type (2030, 2040 and 2050)



'Other' includes include combined heat and power (waste-to-energy/biogas/biomass), geothermal and energy efficiency improvements.
Source: DORIS Engineering (2021); IV analysis

5.2 What are the implications for gas infrastructure and gas users under the scenarios?

Our analysis modelled the energy mix, carbon emissions and relative costs at 2030, 2040 and 2050 for each scenario. Environmental, economic, technical, social and safety risks and opportunities were identified and assessed.

This is a preliminary analysis and many simplifications have been made. These simplifications mean the scenario results should be considered as useful comparative data only. More detailed analysis will be conducted in the next phase of our work, to inform our final recommendations. More detail on the scenario analysis can be found in the technical report on our website at infrastructurevictoria.com.au.

5.2.1 Scenario analysis results

Table 3 Summary of key results

	Scenario A	Scenario B	Scenario C	Scenario D
Time to net zero	Before 2050	Before 2050	Before 2040	2050
Cost to achieve net zero (comparative cost index)*	1.1	1.1	1.0	4.3
Annual hydrogen export by 2050 (PJ)	0	0	>125	>470
Absolute carbon emissions 2030 (Mt CO_2e)	59	59	28	366
Absolute carbon emissions 2050 (Mt CO_2e)	-8	-5	-56	715
Carbon capture and storage loadings 2050 (Mt CO_2e)	0	1	0	698
Potential job creation by 2050	8,767	8,826	13,013	17,477
Estimated infrastructure upgrades				
Decommissioning of existing gas pipelines (2040)	40%	50-60%	75%	75%
Decommissioning of existing gas pipelines (2050)	80%	90%	100%	100%
Installation of hydrogen infrastructure (2050)	0	100%	100%	100%
Relative extent of electrical upgrades (2030)**	2	2	1	1
Relative extent of electrical upgrades (2050)**	5	5	3	2

* Represents a comparison of the relative capital and operating infrastructure costs between the scenarios, based on early strategic level assessments, where 1 represents the lowest cost scenario.
** Represents the relative extent of of new or upgraded electrical infrastructure required in each scenario, over and above the existing infrastructure. Values are a relative index, where 1 is the lowest level of electrical infrastructure required.

Scenario A achieves net zero slightly before 2050 through a high reliance on renewable electricity in the energy mix

Scenario A targets a complete replacement of natural gas and coal, relying on take-up of renewables with a moderate contribution from biogas, green hydrogen and energy efficiency. Renewables account for over 90% of the energy mix in 2050, while biogases, hydrogen and energy efficiency each comprise less than 5%.

Use of the existing natural gas infrastructure in Scenario A is limited given the low proportion of gas (including hydrogen and biogas) in the overall energy mix. However, a slow phase out of natural gas and use of biogas enables some infrastructure to be retained. Natural gas use will drop off in 2040 after the closure of the Longford facility, and completely cease by 2050 when all Victorian gas plants are expected to reach their end of life. Decommissioning of the gas distribution network will begin before 2030, as users begin to switch over to electricity. Around 40% of existing transmission and distribution infrastructure will be decommissioned by 2040, rising to 80% by 2050. Remaining infrastructure is used primarily for biogas, although the relatively low proportion of biogas in the energy mix may not warrant its retention.

Scenario A requires significant upgrades to electrical infrastructure across the whole network to accommodate increased demand and storage requirements. This scenario has significant renewable generation capacity in north-west Victoria, which would be under-utilised without upgrades to transmission lines. High-capacity electrical infrastructure in the Latrobe Valley would also be under-utilised, as coal-fired power stations are closed and the electricity they generate is removed from the grid. The significant additional electrical infrastructure needed to supply power around the state from Renewable Energy Zones would see an increase in bushfire risk, which could be reduced by burying overhead transmission lines in bushfire areas. Transmission lines were assumed to be above ground in areas of low bushfire risk due to the very significant cost of burial. This, however, may have other amenity impacts.

Scenario A relies on hydro power to level out peak demand. There is a technical risk there are not enough locations in Victoria with the topography required to support hydro power. However, hydro power can be sourced from other states to provide backup with the use of state interconnections (for example, TasNetworks' Bass Strait Interconnector or the Snowy 2.0 hydro project in NSW).

Scenario B has a similar energy-emissions-offset profile to Scenario A, but requires some CCS to account for limited natural gas use beyond 2050

Scenario B targets a near complete replacement of natural gas and a total replacement of coal, relying primarily on the adoption of renewables with a contribution from biogas and hydrogen. Renewables make up just under 90% of the overall energy mix in 2050. Hydrogen uptake is slightly higher than in Scenario A, at 5% of the energy mix, while biogases account for less than 5%. Natural gas use represents 1% of the 2050 energy mix, declining from 17% in 2030 and 7% in 2040.

Phased blending of hydrogen, natural gas and biogas/biomethane in Scenario B could allow a small amount of existing natural gas infrastructure to be used during the transition and beyond 2050. As in Scenario A, natural gas use will drop off after the closure of Longford. By 2050, use of gas production and pipeline infrastructure will be limited to supporting peak electricity supply using gas fired power plants. It is anticipated that one of the Otway gas plants and the Iona storage facility will be operational in 2050.

Some of Victoria's gas pipeline infrastructure is reaching end of life, limiting its potential for long-term retention and reuse. Over half of Victoria's onshore pipeline infrastructure is greater than 40 years old, and operators need certainty around the potential use and development of an ongoing viable gas network to confidently invest in replacing aging infrastructure. In Scenario B, replacement of existing gas assets beyond their current life would require careful assessment of costs against the alternative of installing new hydrogen infrastructure. Despite the ongoing use of natural gas, the larger proportion and quicker introduction of hydrogen in this scenario could actually reduce the use of the existing infrastructure when compared with Scenario A. By 2050, it is anticipated that 90% of existing pipeline infrastructure will have been decommissioned, following a phased transition to allow for construction of a new hydrogen network.

Risk in Scenario B is mainly associated with the development of the CarbonNet facility, which is still undergoing technical assessment, to offset emissions associated with continuing natural gas use. It is unlikely that any existing pipeline infrastructure could be reused for CCS due to the requirement for high operating pressure in offshore carbon storage. If more ongoing natural gas use occurred up to and after 2050 than was modelled in Scenario B (e.g. if significant residential gas use was to continue), the associated emissions would need to be captured and stored, or offset in some way. This would increase the risk and the cost.

Scenario B requires slightly lower transmission upgrades than Scenario A, although they are still significant. Like Scenario A, it has under-utilised renewable generation in north-west Victoria, but better use of the Latrobe Valley's existing high-capacity electrical infrastructure due to increased use of offshore wind turbines (for example, the Star of the South project currently under development). As in Scenario A, increased bushfire risk associated with additional electrical infrastructure could be reduced by burying transmission lines in bushfire areas.

Scenario C achieves net zero significantly earlier than 2050, given the relatively high proportion of zero and negative emissions electricity and gas in the energy mix

Scenario C targets a complete replacement of natural gas and coal, relying primarily on the balanced adoption of renewable electricity, green hydrogen and biogas. These comprise around 65%, 20% and 10% respectively of the energy mix in 2050. Scenario C has the most balanced mix of energy sources, providing flexibility for adoption of new technologies that may reach competitive pricing in the future, and a level of risk mitigation in the event that large-scale green hydrogen production cannot be achieved. This is the only scenario under which Victoria's interim emissions target of 45–50% below 2005 levels by 2030 is achieved.

Scenario C has the greatest potential to maximise use of existing natural gas infrastructure during the transition to net zero, due to the relatively high proportion of gas (biogas, biomethane and hydrogen) in the energy mix. Existing infrastructure is initially reused for biogas/biomethane and hydrogen, subject to careful phasing and blending of these gases, plus the introduction of natural gas to support blue hydrogen production (before Victorian natural gas production ceases sometime before 2050). However, reuse of the existing natural gas network beyond the initial transition will be limited by its ability to deal with the eventual high hydrogen levels in the gas stream, due to the potential for pipeline embrittlement. By 2050, all existing natural gas infrastructure is expected to be decommissioned.

Given the high level of hydrogen production in Scenario C, new hydrogen infrastructure will need to be in place by 2030, with further expansion through to 2050. As new hydrogen facilities become operational, existing gas infrastructure will be more rapidly decommissioned. Hydrogen plants installed in 2030 are all situated along the coast or in Renewable Energy Zones close to water, while biogas facilities are located to the north of the state to maximise use of existing gas infrastructure during the transition. The hydrogen facility located at the Geelong Energy Hub is ideally located close to a suitable port, to take advantage of green hydrogen's export potential.

Higher biogas production offers the opportunity to produce biomethane to substitute for natural gas. An advantage of Scenario C is that biogas facilities can be distributed across the state, meaning they can be located closer to users (minimising transmission and distribution infrastructure) and can maximise the use of different feedstocks. In this scenario, annual biomethane production is ramped up to over 100 PJ, which is high compared with the upper end of Victoria's potential biogas supply estimates. However, further work is needed to fully understand the potential for biogas and biomethane production in Victoria. By 2050, new technologies such as gasification of waste and biomass could also be used to produce biomethane, complementing existing supply potential.

Significant energy from gas, including hydrogen and biogas, results in a greatly reduced electrical load in Scenario C. The electricity required to produce green hydrogen is largely decentralised and located close to end users, to avoid impacting the transmission system. As a result, lower levels of electrical infrastructure upgrades are required compared with Scenarios A and B. Scenario C still includes some under-utilisation of renewable generation in north-west Victoria and of the Latrobe Valley's electrical infrastructure. The ability to supply power reliably for both electricity generation and hydrogen production represents a technical risk for this scenario.

Scenario D has very large-scale CCS and significantly higher capital expenditure

Scenario D targets a complete replacement of natural gas, relying primarily on the adoption of brown hydrogen (gasification of brown coal) with some contribution from renewables, biogas and green hydrogen. Under this scenario, hydrogen comprises approximately 60% of the energy mix in 2050, with renewable energy making up over 30% and biogases around 5% of the total. Scenario D is the slowest of the four to reach the target of net zero emissions, achieving it just on 2050. It is the only scenario under which carbon emissions increase in absolute terms and as a result net zero emissions are only achieved through great reliance on CCS and carbon offsets. Consequently, this scenario would be expensive to realise relative to the other scenarios.

The reliance on carbon storage in Scenario D requires rapid installation of extremely large-scale CCS. The CarbonNet project is a good first step in developing this capacity for Victoria. However, the amount of carbon storage capacity required by Scenario D is many times the nominal capacity of the CarbonNet project, whose aim is not to replace natural gas in Victoria but to create brown hydrogen for export. Scenario D's complete replacement of natural gas with brown hydrogen is of an entirely different scale to that of the current Hydrogen Energy Supply Chain project. Large levels of new storage capacity would have to be identified to meet the needs of Scenario D and this may not be feasible within the required timescale. If adequate CCS storage capacity was not available in time, Scenario D would significantly increase the risk of net zero emissions targets not being realised. Scenario D requires rapid installation of large-scale hydrogen transportation infrastructure, given the specific location of the brown coal resource used to produce brown hydrogen (this scenario represents a centralised energy production model similar to present day). A major coal-gasification-to-hydrogen plant would also need to be developed, with significant capital costs and a long lead time to plan and build.

Scenario D has the most significant gas usage (hydrogen and biogas), but use of existing natural gas infrastructure would be limited given the embrittlement issues associated with transporting hydrogen in metal pipelines. The degree of new pipeline infrastructure required is significant, tripling the expected capacity of the hydrogen pipelines required for Scenario C. In addition, it is unlikely that existing pipelines could be reused for carbon capture at the pressure required to support offshore storage locations such as CarbonNet.

Scenario D requires the least amount of upgrades to electrical infrastructure, with most upgrades supporting connections to hydro energy storage. This scenario still indicates under-utilised electrical infrastructure in the Latrobe Valley and renewable generation in north-west Victoria.

5.2.2 Implications for gas users

Residential and commercial gas users

The main social risk in each scenario is the ability for society to adapt to the degree of change necessary to move to the reality of a zero-carbon economy. The changes may include:

- adoption of electric heating and cooking appliances
- significant increases in the numbers of wind and solar farms and associated battery storage in Victoria
- at least one large new hydroelectric power plant and large dam
- even more significant increases in the amount of rooftop solar, and house-based battery storage systems, changing the dynamic of power supply and demand
- adoption of hydrogen for different uses, and consideration of associated safety requirements

- significant increase in the electricity distribution infrastructure
- as biogases take off, greatly increased focus on recycling and waste segregation.

All these changes are required to a certain extent for all scenarios, but are most clearly seen for Scenario A.

Our research found very few consumer studies which relate specifically to the gas transition in Victoria. Most consumer-focused research explores attitudes on the electricity transition and energy efficiency, and on energy costs and providers.

Research into energy affordability suggests that it has become a major concern for consumers. Electricity bills rose by 30% in real terms between 2003-04 and 2015-16, despite per capita use falling by 8%. Gas bills rose by 37% over the same period, leading to a negative shift in perceptions of affordability. Consumers view electricity as the least affordable form of infrastructure, with over 60% perceiving it as costly or very costly. Gas affordability also rates poorly, with 38% viewing it as costly or very costly.[101]

These attitudes may influence the willingness of consumers to shift from one energy source to another, or to invest further in the changes likely needed, such as appliance upgrades, to support Victoria's energy transition. Other research indicates that consumers look to governments to lead long-term change in the energy sector, but believe governments have only a short-term focus. Similarly, consumers have little faith in energy companies making changes for the better. These results suggest a need to restore and maintain trust in energy system pricing and regulation to achieve future changes in consumer behaviour.[102]

Some gas-related survey data from the Australia Institute's *Climate of the Nation 2020* found:[103]

- Only 12% of Australians would prefer Australia's economic recovery to be primarily powered by gas, compared with 59% who prefer it to be powered by investment in renewables. The popularity of a renewables-led recovery was consistent across all states, genders, ages and voting intentions.
- Australians overestimate the size of Australia's gas industry employment by a factor of 40. Excluding those who say they do not know, respondents on average believe that gas mining and exploration makes up 8.2% of the total workforce. In reality, gas mining and exploration employs less than 0.2%.
- Australians also overestimate the economic value of the gas industry. Respondents on average believe that the industry accounts for 10.3% of Australia's gross domestic product, when the actual figure is less than 2.3%.

Gaps in the current knowledge base include:

- consumer attitudes to gas and an understanding of its role in relation to Victoria's emissions profile and climate change
- community/consumer understanding of new technologies which may replace gas (biomethane, hydrogen and carbon capture and storage)
- community attitudes to investment in electrification (available now) versus investment in zero emissions gas infrastructure (not yet available at scale)
- community and consumer attitudes to the ongoing exploration and production of gas and investment in gas infrastructure in a zero emissions economy
- community and consumer attitudes to the gas transition and what it could mean for their home or small business (for example, appliance changeovers for cooking/space heating/water heating)
- consumer attitudes to, and effectiveness of, potential policy initiatives to support the transition away from natural gas
- the impacts of the transition on vulnerable/low income households.

Infrastructure Victoria will seek to fill some of these gaps in understanding by commissioning our own research and analysis in the next phase of this work.

Industrial gas users

The scenario analysis assumes that industrial gas users will either retain their own source of natural gas on the transmission lines that exist, or that the cost of upgrading the networks to hydrogen will cover connections to their facilities. The most likely outcome for industrial gas users under all scenarios, given the significant decentralisation and scaling back of existing gas infrastructure common to each, will be to pay for connection to an alternative gas source (i.e. hydrogen, biogas or biomethane), unless located near to an existing pipeline where gas blending allows use to be maintained.

[101] Infrastructure Australia (2019)

[102] Energy Consumers Australia (2021)

[103] Quicke A and Bennett E (2020)

For industrial users in **Scenario A**:

- Renewables supply approximately 40% of the industrial energy mix by 2050 – predominantly wind, with limited solar and hydroelectricity.
- Gases build to 40% of the mix by 2050, predominantly biogases including combined heat and power, with limited green hydrogen. The logistical challenges would typically favour a regional 'biogas hubs' model, creating a distribution of biogas production centres with each having a modest level of gas production.
- Efficiency upgrades contribute approximately 15% of the energy mix in 2050, while geothermal provides a low proportion, building to 5% of the energy mix over time.
- The logistical challenges would typically favour a regional 'biogas hubs' model, creating a distribution of biogas production centres with each having a modest level of gas production.

Scenario B retains a relatively small level of natural gas beyond transition (20 PJ in 2050), to provide peak electricity coverage to firm variable renewable power and support hard to abate manufacturing such as plastics and alumina production. Otherwise, for industrial users:

- Renewables are around 45% of the energy mix by 2050 (falling from over 80% in 2030) as the contribution from biogases and geothermal energy builds.
- By 2030, a biogas facility will be in an urban location, close to the industrial zone in Laverton to support chemical manufacturing. Gases build to 40% of the mix by 2050, predominantly biogases including combined heat and power, with limited green and blue hydrogen.
- Energy efficiency upgrades contribute a low proportion, around 5% of the mix by 2050. Geothermal energy is a slightly higher proportion, building to almost 10% of the mix.

For industrial users in **Scenario C**:

- Renewables supply approximately 30% of the energy mix by 2050 (falling from over 70% in 2030) as the contribution from biogases and geothermal energy builds.
- Gases build to over 50% of the mix by 2050, predominantly biogases including combined heat and power, and green hydrogen. Blue hydrogen from natural gas contributes 10% of the energy mix in 2030, equivalent to green hydrogen. However, while green hydrogen production continues to build through to 2050, blue hydrogen declines to 0%following the decline of Victorian natural gas production.
- Efficiency upgrades are a low proportion, building to approximately 5% of the energy mix over time. Geothermal energy is a low proportion, building to 5% of the mix over time.

In **Scenario D,** the major energy stream for industrial users is brown hydrogen with CCS:

- Renewables are a very low proportion of the industrial energy mix by 2050, less than 5%.
- Gases build to approximately 90% of the mix by 2050, predominantly brown hydrogen (at just over 60%), with moderate loading of biogases including combined heat and power building to approximately 20%. There is also a small proportion of green hydrogen in the energy mix, building to around 7% by 2050.
- Efficiency upgrades are not allocated in this scenario, while geothermal energy is a low proportion, building to around 7% of the mix by 2050.

5.2.3 Summary of decarbonisation pathway impacts on gas infrastructure

The most promising pathways to decarbonise the gas sector, as per our scenario analysis and the literature consensus, are a combination of electrification, biogas, hydrogen and CCS, with no single pathway able to provide a complete solution. The section above details likely impacts on gas infrastructure and users associated with specific mixes of each pathway as defined in our scenarios. Likely impacts of each pathway for gas infrastructure owners and users covering the entire gas value chain are summarised in Table 4.

Table 4 Summary of decarbonisation pathways and impacts on gas infrastructure

Potential net cost to owner/user | Potential net benefit to owner/user | Neutral or ambiguous effect on owner/user

Lever for reducing emissions from gas	Expected impact on gas infrastructure			Expected impact on gas users		
	Exploration, production, imports, processing	Gas networks	Gas storage	Residential and commercial gas users	Industrial gas users	Gas-powered electricity generators
Energy efficiency (gas)	Lowers demand for natural gas, reducing upstream opportunities Note: lower upstream leakage reduces emissions	Lowers demand for natural gas, reducing required network investment; addressing leaks may in-crease network investment	Lowers demand for natural gas, reducing storage needs	Requires investment in upgrades for gas customers, with mix of long and short paybacks	Requires investment in equipment and process re-engineering	Lowers demand for natural gas, potentially reducing gas input costs; electrification could see higher electricity demand
Electrification	Increases electricity demand, potentially increasing demand for gas for power generation	Increases electricity demand, potentially increasing demand for gas transmission for power generation	May increase role for gas storage for flexible electricity generation or seasonal storage	Requires investment in upgrades for gas customers, with mix of long and short paybacks	Requires investment for electrification of process heat and process re-engineering	Supports higher electricity demand, potentially supporting demand for gas for power generation
Carbon capture and storage	Upstream firms could participate in carbon storage; CCS could support demand for natural gas	Supports network connections to CCS-equipped gas users; networks may play a role in carbon dioxide transport	No direct impact	No direct impact	Supports extended role for gas at facilities in CCS clusters; investment required in carbon capture and transport	Supports a longer-term role for gas-powered generation; investment required in carbon capture and transport
Hydrogen	Investment opportunities for upstream segment in hydrogen export	Requires significant network upgrades to transport and store hydrogen, extending network life	No direct impact	May require new meters and safety devices for blending; requires appliance upgrades at higher blending levels	Requires process and equipment upgrades; hydrogen may replace natural gas in some industrial processes	Opportunity to build or convert to hydrogen-powered generators
Biomethane	Biomethane blending lowers demand for natural gas, reducing required investment (minor effect)	Opportunity for biomethane production and blending trials	No direct impact	No direct impact	No direct impact	Opportunity for biomethane-powered generation (potentially with CCS)

Source: Accenture (2021)

5.3 What is the role of government?

The Victorian Government can play a crucial role to support the gas sector's transition to net zero. Our research explored a range of jurisdictions where gas plays a material role in the energy mix to understand how other governments are approaching the transition and identify potential lessons for Victoria. This identified a range of policy options associated with the different transition pathways being applied in different jurisdictions, which are summarised in Table 5.

Table 5 Policy options associated with gas transition pathways

Pathway	Policy approach
Energy efficiency	Provide **rebates** and **incentives** for energy upgrades
	Update **building codes** to energy neutral standard
Electrification	Provide **rebates** and **incentives** for electrification
	Ban new gas connections
	Remove existing buildings from the gas network
Carbon capture, utilisation and storage	Provide **site appraisal**, long-term **revenue support**, **grants** and **incentives** for major strategic projects
Substitution (hydrogen/biomethane)	Support market **demand** and hydrogen **supply** concurrently, possibly with brown or blue hydrogen production in the interim
	Introduce consumer-funded **blending** mechanisms, such as a levy on gas distribution networks
	Test a consumer-led '**opt-in**' approach
	Provide **industry funding** and support

Source: Accenture (2021)

Across the jurisdictions included in this analysis – the United Kingdom, the Netherlands, Canada (western provinces) and Japan – there are some lessons for Victoria.

- **There is as yet no single clear pathway to net zero 2050 for gas** – none of the comparison jurisdictions have yet committed to fully decommission their gas networks. Jurisdictions are instead using a range of policy levers and investing in multiple alternative technologies to keep their options open.
- **Energy efficiency is a 'no regrets' measure which can be undertaken now** – jurisdictions are focused on increasing gas use efficiency and reducing gas use to provide short-term emissions reduction benefits and lower costs while keeping other options open.
- **Longer-term investments are aimed at diversifying options in an uncertain future** – while investments in CCS and substitution with hydrogen and/or biomethane involve some risk, they can open up future transition pathways for gas.
- **A long-term carbon price or emissions regulation** may be required to attract capital commitments for large-scale CCS and other capital-intensive projects. CCS will take significant policy support and government action to become a feasible pathway for gas decarbonisation. Governments can play an important role in directly funding CCS projects and coordinating clusters of CCUS customers.
- **Policies and regulations across the Victorian Government need to align with net zero targets** – aligning policies and regulations across government will provide a strong framework to deliver net zero targets over time, and allow for all infrastructure and network investment decisions to be compatible with pathways towards net zero.
- **Gas infrastructure transition is a long-term commitment** – jurisdictions expect to take at least 30 years to upgrade or decommission infrastructure and complete their transition to net zero gas.
  - Major energy system reform requires changes to regulations, safety rules, consumer tariffs, workforce skills and training, and supply chains.
  - Changes are likely to take many years to achieve widespread acceptance, so interventions that affect many customers or involve changing consumer behaviour should start early.

The scale of change required is likely to incur significant costs whichever pathway is ultimately taken. These include costs associated with decommissioning certain assets, while upgrading others and building new infrastructure. A key consideration for government will be to manage the risks associated with transition, including financial risks for taxpayers alongside environmental risks and the consequences of inaction.[104] More detailed analysis of the approaches of other jurisdictions to gas within the future energy mix can be found in the technical report, available on our website at infrastructurevictoria.com.au.[105]

United Kingdom: reduction targets driving a green industrial revolution

In 2019, the United Kingdom Government legislated its target for net zero emissions by 2050, with interim targets and five yearly 'carbon budgets'.

- The **Climate Change Committee** is an independent body that advises the government on carbon budgets and policy pathways to achieve national emissions targets in five yearly intervals. The United Kingdom released its ***Sixth Carbon Budget***, covering the period 2033–2037, in December 2020. The pathway recommended in the budget requires a 78% reduction in United Kingdom emissions from 1990 to 2035, bringing forward the previous 80% target by nearly 15 years.
- The government's ***10 Point Plan for a Green Industrial Revolution*** was released in 2020. The plan identifies the broad areas of expected policy action that will define the country's pathway to net zero. Detailed roadmaps for specific sectors aligned with the *10 Point Plan* are expected in 2021, including a *Net Zero Strategy*, a *Hydrogen Strategy*, an *Industrial Decarbonisation Strategy* and a *Heat and Buildings Strategy*.
- In 2020, the UK Government updated its interim target to a 68% reduction in 1990 levels of greenhouse gas emissions by 2030 (previous commitment was a 53% reduction). In April 2021, the government announced plans to cut emissions by 78% by 2035 compared with 1990 levels – the most ambitious targets so far globally.

Regulation of UK gas networks is aligned to emissions targets, providing a framework to fund the path to net zero.

- The UK energy network regulator **Ofgem** has considerations for net zero built into its pricing approach, providing a framework to support the energy market transition to low emissions technologies.
  - Up to £20 million a year in funding is available for gas network operators to demonstrate options for low carbon gas networks.
  - A total £40 billion has been allocated to supporting energy networks to meet net zero, including funding for network upgrades and maintenance.
- The **North Sea Transition Deal** is a partnership between the **UK Government and the oil and gas sector to reduce emissions, electrify offshore production and** drive investment in new energy technologies including CCUS and hydrogen.
- **Carbon pricing** provides signals and incentives to the market to reduce emissions and transition to low carbon alternatives (since Brexit, the UK and the European Union have operated separate carbon markets).
- Support has also been provided for **electrification**, gas **decarbonisation** and gas **substitution** projects, as well as multiple funding pools to transition to **lower carbon and more efficient heating**, including:
  - **electrification** – funding to support transitions to electric alternatives for gas in building and industry
  - **decarbonisation** – establishment of two industrial CCS clusters by 2025, with two more by 2030; innovation funding to reduce the costs of CCS

    substitution – innovation funding to accelerate production of low carbon hydrogen; Green Gas Support Scheme, funded by a Green Gas Levy on gas suppliers, to support the injection of biomethane in the grid; Gas Network Innovation Competition for demonstration projects trialling hydrogen-powered homes
  - **gas efficiency** – building heating and energy efficiency grants; efficiency and low carbon options for industrial processes incentivised through funding and innovation competitions.

5.3.1 Key legislation and regulatory settings

We have undertaken a review of the legislative and regulatory settings relevant to gas infrastructure in Victoria, to better understand the different energy bodies and their role within the gas sector.

Victoria's energy sector is almost entirely under private ownership, and operates under various legislative frameworks depending on the activity. It is a complex system, with national regulatory arrangements working alongside state-based regulation to address safety, environmental and development issues that require a local response.

[104] OECD (2015)

[105] Accenture (2021)

The Victorian Government retains responsibility for Victoria's overall energy and climate policy, but works in collaboration with other jurisdictions. As a result, some gas sector activities fall strictly within Victoria's key responsibilities, such as safety, but some operations and economic regulatory activities are delegated to national bodies, such as the Australian Energy Market Operator (AEMO) and the Australian Energy Regulator (AER). In summary:

- **Gas exploration and production** activities are regulated by state agencies when the activities are onshore or within three nautical miles of Victoria's shores. Beyond three nautical miles, it is regulated by the National Offshore Petroleum Safety and Environmental Management Authority. Commonwealth and state ministers jointly decide on the release of exploration areas and petroleum titles, supported by the National Offshore Petroleum Titles Administrator.
- **Gas transmission and distribution infrastructure** operates under national arrangements, with economic rule making and regulation enforcement delegated to national bodies. Pipeline safety and other consumer protections, such as business licensing for those involved in supplying gas along with performance monitoring, are undertaken by various state agencies including DELWP, Energy Safety Victoria and the Essential Services Commission.
- State-based **land use planning, environment, building and development** regulations govern gas infrastructure development, involving various government agencies and local councils.
- **Health and safety** across the gas value chain is regulated by WorkSafe Victoria, the health and safety regulator for all Victorian workplaces.

A more detailed overview of key regulatory bodies, their role in the gas sector and the relevant legislation in provided in Appendix C.

5.3.2 Legislative, regulatory and policy considerations for gas sector decarbonisation

Each of our four scenarios assume a radical change in energy sources by 2050. Each scenario has very different consequences for gas infrastructure, but common considerations are shared across all scenarios.

A key consideration is the National Gas Law, which aims to 'promote efficient investment in, and efficient operation and use of, natural gas services for the long-term interests of consumers of natural gas with respect to price, quality, safety, reliability and security of supply of natural gas'. Australian energy bodies must have regard to this objective, which does not specifically incorporate emissions reduction considerations, climate risks or impacts on the environment. However, energy bodies may take climate change and the environment into account if it impacts on price, quality, safety, reliability and security of supply.[106]

Other legislative, regulatory and policy considerations are summarised below.

Clear policy direction on future gas use will allow governments and stakeholders to manage risk

A significant shift to electricity in place of gas by 2050 would mean retiring large parts of the gas network. This would, in turn, reduce the revenue that gas distribution network businesses can expect to recover from customers for using their networks. Businesses therefore need clear direction from the Victorian Government on future gas use to enable them to recover the costs of their investment in a shorter timeframe if necessary (approval would be required from the Australian Energy Regulator). This has occurred in the Australian Capital Territory, where the ACT Government, in addition to its legislated net zero emissions by 2045 commitment,[107] has a clear policy of phasing out new and existing gas connections.[108] Clear policy direction on gas connections will also benefit electricity network planning, which may need to upgrade or build additional infrastructure in some areas to respond to increased demand.

Moves to reduce the use of natural gas in response to Victoria's net zero emissions targets create a clear risk to gas infrastructure owners and operators. Robust regulatory frameworks will need to be developed to ensure safety and appropriate levels of investment are maintained by gas network infrastructure owners while parts of the network are simultaneously retired. Decommissioning and rehabilitating orphaned or abandoned assets, such as gas wells in the Gippsland Basin, may also pose a risk to Victorian taxpayers if the liability for decommissioning costs is not clear. Policy frameworks may be needed to guide decommissioning assets and any required remediation. Lessons from other transitions may prove useful, such as the rationalisation and modernisation of Australia's agricultural water infrastructure.

Legislation, regulations and standards need to align with Victoria's net zero emissions targets

Regardless of the ultimate pathway to decarbonise the gas sector, the Victorian Government will need to ensure all legislation, regulations and standards are aligned with the state's net zero emissions target, which is not currently the case.

[106] AEMC (2019)

[107] ACT Government (n.d.(b))

[108] Australian Energy Regulator (2021); ACT Government (n.d.(a))

To enable greater electrification for example, new buildings will need to be electric only, while existing buildings connected to the reticulated gas network would need to change fittings and appliances to electric. Victoria's planning and building regulations currently make this challenging:

- The *Victorian Planning Provisions* state that residential developments should be connected to gas infrastructure 'where available'.[109] This requirement has likely caused land development projects, like the Quandong Precinct in Wyndham,[110] to include an expensive gas network as a requirement of the planning permit.
- Current plumbing regulations further embed gas connections. For example, new solar hot water heaters must be boosted with gas in every instance where reticulated supply is available for connection to the relevant building despite electric alternatives being available.[111]

From an infrastructure perspective, the greater concern is expanding a gas network to new developments which may become stranded before the end of its useful life of several decades unless they can be built or retrofitted to accommodate low carbon gases. New connections to existing gas infrastructure present less risk. However, both embed gas use and emissions if there is no conversion plan.

Similarly, legislation, regulations and standards will need updating to enable existing gas networks to transport hydrogen or biogas to homes, businesses and industries (assuming this can be achieved by 2050). Existing research suggests amendments to the definition of natural gas in the National Gas Law will be needed at a minimum, as its current definition precludes the injection of future fuels such as hydrogen or biogas into existing gas infrastructure.[112] The Future Fuels Cooperative Research Centre has completed a regulatory mapping project across all aspects of the gas supply chain. For Victoria, it suggests:

- expanding the definition of natural gas in the *Gas Industry Act 2001* to include non-naturally occurring substances
- broadening gas quality provisions in the Gas Safety (Safety Case) Regulations 2018 to include gases other than natural gas and LPG and/or include hydrogen and biogas
- communicating the differing risk profile of hydrogen to land use planning authorities, and incorporating this into decision-making frameworks for development near hydrogen manufacturing facilities, transmission and distribution pipelines; this covers the *Planning and Environment Act 1987* and the Occupational Health and Safety Regulations 2017.[113]

In addition, national laws and standards would need review. For example, the National Construction Code does not currently permit hydrogen blended at 50% or more in gas water heaters.[114] Standards Australia has formed a Hydrogen Technologies Technical Committee to develop national hydrogen standards. Standards Australia is also working with other bodies to include specific requirements for hydrogen in other standards.[115]

Achieving net zero emissions will require significant infrastructure in terms of electrical transmission, battery and solar panel connections, hydrogen and carbon dioxide pipeline networks, production and storage facilities – all of which require planning applications, licence applications and compliance. This represents an economic cost to the developer, and to the regulator, in terms of the costs associated with managing the level and speed of infrastructure development necessary to achieve net zero.

The complexities of the national system mean that significant coordination and cooperation will be needed across jurisdictions

Energy, including gas, is part of a national system. The Victorian Government will need to work in close collaboration with other jurisdictions to achieve its net zero emissions target. This is potentially challenging where policy objectives across different jurisdictions do not align. The Australian Government is yet to commit to net zero emissions by 2050, committing instead to reduce greenhouse gas emissions by 26–28% below 2005 levels by 2030.[116]

One area for further examination is gas production and links with other states. Even today, Victoria's key gas fields are in decline,[117] and significant gas production and pipelines may need decommissioning in the future. The Australian Government is considering an enhanced framework for offshore oil and gas decommissioning, aiming to ensure effective regulatory oversight and financial safety nets to strengthen protections for the environment, industry, government and

[109] Department of Environment, Land, Water and Planning (2021f) Clause 56.09-2

[110] City of Wyndham (2018)

[111] Plumbing Regulations 2018, s.11(4)(a)

[112] Sandri O et al (2020)

[113] Sandri O et al (2020)

[114] Sandri O et al (2020)

[115] COAG Energy Council (2019a)

[116] Department of Industry, Science, Energy and Resources (2021a)

[117] AEMO (2021c)

community as companies manage their maturing assets.[118] For pipelines supplying gas to other states, significant coordination will be needed to ensure net zero goals can be achieved while maintaining energy security across Australia.

Australia's National Hydrogen Strategy demonstrates all jurisdictions working together to further the development of potential future technologies. The strategy has been agreed by all energy ministers across Australia[119] and outlines shared principles for nationally consistent regulation, including collaboration. The strategy sets actions to set up the foundations for an expanded hydrogen industry. This includes:

- supporting research, pilots, trials and demonstrations along the supply chain, including for gas distribution networks where it is safe and suitable
- reviewing the application of the National Gas Law and relevant jurisdictional laws and regulations to hydrogen
- reviewing existing legislation, regulation and standards across all jurisdictions to determine if existing frameworks can support hydrogen safety and industry development
- developing and incorporating 'hydrogen-ready' capabilities into planning and regulatory approvals mechanisms
- Australia leading design and development of an international guarantee of origin scheme to verify and track production technology, carbon emissions and location
- training, including industry skills development and updated training for emergency services and regulators.[120]

Improving thermal performance of buildings is a 'no regrets' measure for all future scenarios

Globally, energy efficiency is set to be the single largest contributor to reducing greenhouse gas emissions from energy.[121] With households the biggest user of gas use in Victoria, improved thermal performance of buildings is a clear 'no regrets' measure. It reduces the amount of gas needed to heat a home, which would relieve some of the near-term gas supply pressures and reduce the need for new gas infrastructure. If electrification is pursued, improved efficiency also reduces the need for new electricity infrastructure. Measures include improving building standards for new homes, and encouraging upgrades to existing buildings.

The Victorian Government's flagship program, Victorian Energy Upgrades, has been running since 2016. However, the last target period will end 31 December 2029,[122] meaning there may be gaps in encouraging energy efficiency improvement from 2030. In addition, not all effective energy efficiency measures are supported. For example, there is currently no scheme to support households to improve insulation, which research has identified as the most cost-effective energy improvement and which can reduce the cost of heating and cooling a home by 40–50%.[123]

An offsets regime can further support the transition to a cleaner future

There are likely some gas uses that cannot shift based on current technology. This includes industrial processes that require significant heating, and potentially existing gas-fired electricity generation to maintain system security and reliability.[124] A clear and broad offsets regime can support the transition to a cleaner future.

The *Climate Change Act 2017* is designed to work effectively alongside, or to supplement, national action. It requires Victoria to reduce its emissions as close to zero as possible, maximise removal of greenhouse gas emissions from the atmosphere through sequestration activities in Victoria and, if the amount of sequestration does not balance any remaining emissions, secure eligible offsets from outside Victoria.[125]

The *Land use, land use change and forestry sector emissions reduction pledge* contains some actions to protect and add to existing sources of natural carbon storage. The pledge actions are estimated to reduce Victoria's emissions by 1.4 Mt CO_2e in 2030, but this represents less than 10% of 2018 emissions from direct combustion alone.[126] Regulations to prescribe eligible offsets are yet to be made.

Carbon capture and storage access for industry could also be important but will take significant policy support and government action. Overseas experience indicates that large-scale CCS projects need a long-term carbon price or

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118 Department of Industry, Science, Energy and Resources (2021c)

119 COAG Energy Council (2019b)

120 COAG Energy Council (2019a)

121 International Energy Agency (2018)

122 *Victorian Energy Efficiency Target Act 2007*, s. 30(g)

123 Sustainability Victoria (2021)

124 Wood T and Ha J (2021)

125 Victorian Parliamentary Debates (2016)

126 Department of Environment, Land, Water and Planning (2021b); Department of Environment, Land, Water and Planning (2020)

emissions regulation to attract capital commitments.[127] The Clean Energy Regulator is examining CCS methods for the Emissions Reduction Fund.[128]

Governments can continue to support the development of new technologies through trials, pilots and demonstrations

As the technical and economic feasibility of hydrogen, biogas and CCS is developing, governments can support trials, pilots and demonstrations. The Victorian and Australian governments are supporting the potential development of hydrogen production and CCS in Victoria. The Australian Budget 2021–22 includes $1.2 billion over 10 years for investments in low emissions technology, including support for hydrogen hubs and carbon capture, utilisation and storage.[129]

Support includes ensuring adequate safety and other frameworks for testing to occur. For instance, the Australian Energy Market Commission has prepared rule changes to make it easier for businesses to do test runs of innovative ways to deliver energy services to consumers.[130] Research support into natural gas replacement options could also be examined, such as research into heating and feedstock for industrial uses.

Our literature review and stakeholder consultations identified other potential policy measures to support new technologies, including:

- broad-based zero emissions policies, supporting a range of decarbonisation options including biogas and hydrogen
- policies that encourage co-location of hydrogen supply and demand
- establishing near-term aspirational targets for renewable gas injection into networks, or blending and technology targets
- certification and trading schemes
- zero emissions gas contracting schemes, similar to electricity Power Purchase Agreements
- subsidies, investment funds, tax credit schemes.[131]

Some policy levers will need to be balanced with the extent to which decarbonisation of the gas network through zero emissions gas is proven. It may be too early to tell for some of these levers.

Governments can also act early to prepare the community for the changes ahead

All future scenarios represent change. The Victorian Government will have a key role in building community knowledge and engagement on these changes. Consumer engagement in decision-making is critical from the outset as they will bear much of the transition burden. End-users will need to be ready for new energy sources, either upgrading appliances for electricity or hydrogen. The community will also need to be engaged on risks, benefits and safe use.

A gas transition will also have financial implications for households. For example, bringing forward payments to gas distribution network businesses for infrastructure to allow them to mitigate risk would likely mean higher gas bills for customers. While this may encourage customers to switch to electricity, those who cannot afford an upfront investment to make changes to their heating and cooking, or who are unable to make changes to their properties such as renters, may wear significant financial burden. There is a clear role for government in managing affordability and equity issues associated with any transition away from gas, particularly given existing consumer concerns with energy affordability.[132]

All future scenarios for net zero emissions will require significant infrastructure installation, which will require many planning, manufacturing, construction and maintenance jobs. While many of these skills exist in Victoria and can be transferred from fossil fuel industries, the government must play a role in identifying gaps and developing appropriate training programs. Large and rapid infrastructure construction programs present greater risks, particularly for new technologies, and can be challenging to deliver.

5.4 What are the key uncertainties, trigger points and interdependencies?

There are several uncertainties and interdependencies when considering the role for gas in Victoria's future energy mix. A summary of our early findings is provided below. These issues, and their implications, will be analysed in more detail in the next phase of this work.

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[127] Accenture (2021)

[128] Clean Energy Regulator (2021)

[129] Australian Government (2021a)

[130] AEMC (2020)

[131] Infrastructure Victoria (2021)

[132] Infrastructure Australia (2021)

Replacing gas use with electricity will increase demands on the electricity grid

Electrification as a transition pathway from natural gas use will inevitably place additional demands on electricity supply. As households and the commercial sector shift to electricity instead of gas, peak demand in Victoria will likely move from summer to winter, largely due to space heating, and increase by around 40%. When combined with likely increases in demand associated with electric vehicle use, this could place stress on the electricity grid and require additional investment in generation and storage.[133]

Demand patterns for electricity are also changing due to the strong uptake of rooftop solar and other distributed energy resources, where consumers can generate and store electricity. This reduces demand for electricity during the day, but increased reliance on renewables for electricity generation creates new challenges around reliability and security as supply is weather dependent. Renewable generation therefore needs to be supported by 'firming' capacity so that power supply can be assured.[134] Gas-powered electricity generation is suited to this firming role as it can be ramped up and down quickly in response to changes in demand.[135] However, hydro generation and batteries are also able to perform this role, and demand response (that is, financial incentives for electricity users to temporarily cut their electricity use from the grid when it is under pressure) will also be important in responding to sudden shifts in output from renewable generators.[136]

There are significant opportunities to further decentralise electricity supply and diversify the energy mix to solve problems in a holistic way, across multiple sectors, for example by further developing waste-to-energy and biogas technologies.

Uncertainty remains about gas substitution and carbon capture and storage technologies at scale

As highlighted throughout this report, significant uncertainties remain over alternatives to natural gas use at scale, the ability to repurpose existing gas infrastructure and the use of CCS as a decarbonisation pathway. It is prudent to continue investing in research and pilot projects for at least the next five years to test which of these technologies have a potential future, even though all may not ultimately prove to be viable at the required scale, to help ensure the widest range of future options available to Victoria.

Our analysis to date indicates that it is highly likely that a mix of all available options will prove to be the best (and lowest cost) solution. This does not imply that all technologies will be deployed to the same extent, but rather that pursuing a mix is most likely to result in Victoria's net zero emissions target being achieved and will mitigate the risk should any of the anticipated opportunities of newer technologies be unrealised. Cost and feasibility of alternative technologies will change over time, but at present there is no single cost-efficient, low-risk pathway to achieving net zero. It is therefore advisable to work towards multiple options that can create a range of viable pathways to achieving net zero emissions, that can also deliver reliable and cost-effective energy and will best use existing and planned infrastructure.

Gas supply will need to be maintained until alternatives are viable

Victoria's reliance on gas means that reliable and affordable gas supply will need to be maintained until low emissions alternatives become available at scale, so that households and businesses can continue to access the fuel they need. Ongoing investment in the network will therefore be needed to ensure it remains fit for purpose. This will potentially increase risks to network infrastructure owners, including the risk of over-investing in infrastructure which may not have a long-term future.

Too rapid a transition away from gas may mean that options to use existing gas infrastructure, such as hydrogen blends or biomethane, are ruled out before the technology can be proven at the required scale. Demand management initiatives and targeted energy substitution can support an orderly transition, prioritising measures which will have the most impact in the first instance while allowing time to further explore options – including emerging technologies – for hard to abate industries such as plastics manufacturing.

Regulatory complexity reflects interdependence between states and the Commonwealth

Our review of the legislative and regulatory settings relevant to gas infrastructure in Victoria has highlighted a complex system where national regulatory arrangements sit alongside state-based regulations. Many different Victorian and Australian government departments and bodies are responsible for regulating and overseeing different parts of the sector, as well as determining policies which may affect its future.

This means that policy objectives are not always consistent across jurisdictions. An obvious example is the different approaches between the Victorian and Australian governments towards a net zero 2050 emissions target. The energy system is nationally connected, meaning future coordination will be required between the Australian and state and territory governments even though policy objectives may differ.

[133] Wood T and Dundas G (2020); Wood T and Ha J (2021)

[134] Australian Energy Regulator (2020)

[135] Wood T and Ha J (2021)

[136] Australian Energy Regulator (2020)

5.5 What decisions need to be made to ensure opportunities for existing gas infrastructure can be optimised?

The decisions needed to ensure that opportunities for gas infrastructure can be optimised in the transition to a zero emissions future will be outlined in specific recommendations in our final advice. However, our work has identified several considerations which will inform these recommendations.

Doing nothing cannot be an option

The Victorian Government has committed to reducing Victoria's emissions to net zero by 2050 and to meeting interim emissions targets and sector pledges. This cannot be done without a pathway and detailed planning for decarbonising the gas sector, a challenge the Victorian Government has recognised in funding the development of a Victorian Gas Substitution Roadmap.

Lessons from overseas indicate that a gas transition will likely take multiple decades. Relative to the countries studied in our interjurisdictional analysis,[137] Victoria is starting from behind. Recent analysis has highlighted that the next decade will be critical in international efforts to reach net zero by 2050.[138] Inaction, or any long delay, will be environmentally, economically and financially expensive.

Victoria cannot wait for the perfect solution to present itself and should instead prepare for the changes to come. Gas infrastructure owners and operators need clarity about the sector's future potential so they can support innovation, make appropriate investment decisions and minimise the risk of over-investment or stranded assets. While Victoria's industries need a reliable and affordable gas supply – or a viable alternative – there is a risk they will be left behind if the global shift to decarbonisation is ignored. Similarly, Victorian households need to recognise the potential implications of continued gas use for Victoria's net zero targets and be supported to consider alternatives.

Decisions taken now should aim to keep Victoria's future options open

The uncertainty about the role of gas in the future energy mix, as well as the viability of substitute fuels and decarbonisation technologies at sufficient scale, mean it is too early to pick a winner. Our work has highlighted the importance of keeping all options open, rather than locking in a single course or pathway which may turn out not to be the best course of action. Victoria must diversify its strategy.

This means investigating multiple potential pathways and technologies, even if it is not yet certain these investments will deliver the necessary results. There is an ongoing role for the Victorian and Australian governments in providing financial incentives as well as non-monetary support (such as legislation or regulatory change) to enable investigation of all pathways.

Victoria's reliance on natural gas for space heating indicates that significant change will be needed for households and businesses in any transition from natural gas. Experience overseas points to the importance of starting work to change consumer behaviour early, particularly given the large number of households and businesses affected.[139] The International Energy Agency further emphasises that the scale of the transition to net zero will require the sustained support and participation of individuals and households.[140] The low levels of consumer trust in energy companies and governments to lead change in the sector will likely add to complexities of behaviour change.[141]

Decarbonising the gas sector will also impact the existing and future workforce, including the gas production, distribution and transmission workforces as well as relevant supply chains such as construction, manufacturing and maintenance. Early consideration of the potential skills impact will be needed to ensure that future skills needs are identified and that the workforce can retrain as needed throughout the transition.

A gas transition cannot be achieved without addressing demand as well as supply

Our research to date points to the importance of energy efficiency as a 'no regrets' measure, whichever pathway ultimately leads to gas sector decarbonisation. Investing in energy efficiency where it can be achieved will allow time for consumer behaviour to change, as well as for further research and development into replacement and decarbonisation technologies. Reducing overall demand for gas also helps minimise the need for carbon offsets in any instances where natural gas cannot yet be replaced, such as some industrial processes, and reduce the risk of over-investing in infrastructure.

Given that households account for the major proportion of gas use, the immediate focus for energy efficiency and demand management initiatives should continue to be the residential sector. While improved building standards have

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[137] Accenture (2021)

[138] International Energy Agency (2021)

[139] Accenture (2021)

[140] International Energy Agency (2021)

[141] Energy Consumers Australia (2021)

significantly increased energy efficiency in new dwellings, there are opportunities to develop initiatives which focus on improving the thermal performance of existing buildings.

As the second-biggest user of natural gas in Victoria, the industrial sector should also be the focus of further energy efficiency measures. However, more work needs to be done in understanding the full potential for energy efficiency in Victoria's industries, including manufacturing.

The policy and regulatory environment needs to fully align with Victoria's net zero commitment

Our analysis indicates that opportunities remain for the Victorian Government to better align policies and regulation with net zero pathways, to provide a strong framework to deliver Victoria's net zero 2050 emissions target. Significant progress has been made with the release of interim emissions reduction targets for 2025 and 2030, along with the first round of five-yearly sector pledges, in May 2021.[142]

However, some Victorian policies still encourage gas network expansion or further embed gas use (for example, plumbing regulations which require gas-boosted solar hot water).[143] In addition, our interjurisdictional analysis indicates there is no direct consideration of Victoria's net zero target in the regulatory frameworks for the gas transmission and distribution networks, or for energy retailers. All future infrastructure and network investment decisions should be tested for compatibility with pathways to net zero.[144]

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[142] Department of Environment, Land, Water and Planning (2021d)

[143] Plumbing Regulations 2018, s.11(4)(a)

[144] Accenture (2021)

6. Next steps

This report summarises the evidence we have gathered on gas infrastructure. All the technical reports underpinning this evidence base are available on our website at infrastructurevictoria.com.au.

6.1 Getting involved

Infrastructure Victoria is now seeking feedback on the evidence set out in this report and potential actions identified.

We welcome feedback from the community, industry and other stakeholders on all aspects of the report.

The following questions have been developed as a guide to preparing a submission.

Questions for consideration include:

- Do you have any further information, evidence or concerns that you wish to raise in relation to the scenario design and analysis?
- Do you have any further information or evidence that can help identify an optimum scenario for a net zero emissions gas sector in 2050?
- What policies and/or regulations, if any, are needed to support the development of low carbon pathways such as biogas, green hydrogen, and carbon capture and storage?
- What is your view on the best ways to maintain the reliability and affordability of Victoria's gas supply if natural gas use declines?
- What else can you tell us about the implications of decarbonisation pathways for the electricity generation, transmission and distribution networks?
- How can the use of Victoria's existing gas infrastructure be optimised during the transition to net zero emissions, over the short (10 years), medium (20 years) and long-term (30+ years)? How can the Victorian Government assist in this?
- What principles should apply or what measures will be needed to manage the impacts of gas decarbonisation on households and businesses?
- What policies, programs and/or regulations should the Victorian Government consider or expand to encourage households, commercial buildings and small businesses to reduce their gas use?
- What policies, regulations or other support, if any, do you think are needed to support industrial users to switch from natural gas to lower emissions energy sources or chemical feedstocks?

A submissions template is available on the Engage Victoria website at engage.vic.gov.au. The submissions template is a guide only and is not compulsory. Your submission can relate to all or just part of this report. Please upload your submission on Engage Victoria. We will accept submissions until 16 August 2021.

Late submissions cannot be accepted.

If you have any further queries you can email enquiries@infrastructurevictoria.com.au

6.2 Developing our advice

All submissions will be analysed alongside the findings of our next round of technical work, to include:

- **Consumer research** into household gas use and the transition to net zero emissions, to help inform our understanding of the opportunities and risks for household gas infrastructure, as well as the barriers and enablers to a net zero emissions energy sector in Victoria at a household level.
- **Energy efficiency investment analysis** to identify cost-effective gas use reduction initiatives.
- An **asset life review** to understand the condition and capacity of Victoria's existing gas infrastructure and assess potential pathways to upgrade and/or decommission.
- A second, more detailed phase of the **scenario analysis** to assess the role of gas in a net zero emissions energy sector in Victoria, to include the relative costs of maintaining a gas network under different scenarios. This work will

also consider how the scenarios can meet Victoria's recently-published interim emissions reduction targets for 2025 and 2030.

Our final advice will address potential sequencing, the timing and extent of infrastructure impacts, and identify key decisions and trigger points. A report outlining our recommendations will be provided to the Treasurer no later than December 2021.

Our findings and recommendations will help inform the final Victorian Gas Substitution Roadmap being developed by the Department of Environment, Land, Water and Planning (DELWP), as well as wider energy sector, industry transition and emissions reduction policies developed by the Victorian Government.

7. Appendix A Scenarios in detail

Table_A1: Detailed scenario descriptions

Scenario	A. zero emissions electrification – no natural gas	B. net zero emissions electrification supported by natural gas	C. zero emissions hydrogen with biogas and electrification	D. net zero emissions hydrogen with biogas and electrification
Description	• Almost full electrification using renewable sources, utility-scale battery storage and some pumped hydroelectric • Very little natural gas except where it is irreplaceable – and none by 2050 • No CCS by 2050	• Extensive electrification with renewable sources, significant small-medium battery storage and limited pumped hydroelectric • Some natural gas to support the renewable electricity system and some industrial uses • Made net zero by CCS and offsets	• Hydrogen using renewable sources really takes off as a substitute for natural gas • Some waste to energy, biogas and renewable electricity sources with some battery storage • No CCS • No natural gas by 2050	• Hydrogen using both renewable sources and coal with CCS • Some waste to energy and biogas and renewable electricity sources with some battery storage • No natural gas by 2050
Electricity generation	• Renewable energy (mainly solar and wind) generation supported by pumped hydro, waste-to energy • Large upscale of renewables • Utility-scale solar farms and small-scale solar • Utility-scale onshore and offshore farms • Smart networks at all scales for grid reliability	• Renewable energy (mainly solar and wind) generation supported by natural gas plants for peak supply (with CCS), waste-to energy • Large upscale of renewables • Utility-scale solar farms and small-scale residential solar • Utility-scale onshore and offshore farms • Smart networks ensure grid reliability	• Renewable energy generation supported by green hydrogen, waste-to energy and biogas-fired plants • Large upscale of renewables for both electricity and green hydrogen production	• Renewable energy generation supported by hydrogen, waste-to energy and biogas-fired plants • Moderate upscale of renewables mainly solar and wind
Gaseous fuels	• Small upscale of hydrogen, mainly for industrial feedstock • Major biogas upscale behind-the-meter lessens requirement for centralised generation	• Small upscale of hydrogen, mainly for industrial feedstock • Small upscale of biogas, focus on local use in farms, WWTP and waste facilities	• Massive upscale in green hydrogen production, upscale of blue hydrogen to support transition • Moderate upscale of biogas	• Decreased hydrogen production and associated CCS costs • VIC hydrogen (incl export) hubs • Biomethane in gas network for regional use

Scenario	A. zero emissions electrification – no natural gas	B. net zero emissions electrification supported by natural gas	C. zero emissions hydrogen with biogas and electrification	D. net zero emissions hydrogen with biogas and electrification
				• Combined heat and power
Energy storage	• Major improvements in battery technology • Large-scale pumped hydro and battery farms • Networked batteries for large-scale 'smart' demand side response	• Moderate improvements in battery efficiency and cost meaning more peak generation is required • Small-scale (non-networked) residential batteries for demand side response	• Significant improvements in both battery and chemical hydrogen storage, supported by pumped hydro and batteries	• High reliance on hydrogen as energy storage in gas pipelines and gas storage facilities (above- and underground) supported by small-scale batteries and pumped hydro
Carbon offset	• Limited offsets • No CCS	• Small-scale CCS for gas-fired energy production and suitable heavy industry • Small-scale carbon forestry	• Blue and green hydrogen develops extensively – limited offsets required	• Large-scale CCS enables low-carbon hydrogen (SMR and gasification) • CarbonNet is successful (and possibly others) • Large-scale carbon sequestration
Transmission and distribution	• Moderate upgrade electricity network due to higher demand but lower transmission due to regional-scale generation, storage and networking • Gas network unused	• Major upgrade electricity network due to higher demand • Gas network primarily unused, stranded asset • Select gas pipelines repurposed for transport of CO_2	• Major upgrades to electricity network due to higher demand • Conversion of gas networks for hydrogen, CO_2 and biogas • LNG terminal(s) become hydrogen hubs	• Smaller upgrades of electricity network • Conversion of gas networks for hydrogen, CO_2 and biomethane • LNG terminal(s) become hydrogen hubs
Residential and commercial use (space and water heating, cooking)	• District combined heat and power in high-density and industrial areas • Electric and small-scale geothermal heating in low-density areas • Electric cooking	• High efficiency upgrades and decreased energy demand • Energy-sufficient homes • Upgrades to electric or geothermal appliances • Upgrades to electric induction stoves	• Significant efficiency upgrades (decreased energy demand) • Biogas and hydrogen-fired heating with appropriate appliance upgrades • Mix of biogas, electric and hydrogen cooking	• Small efficiency upgrades (slightly decreased energy demand) • Biogas and hydrogen-fired heating with appropriate appliance upgrades • Biogas and hydrogen cooking
Industrial use	• Extensive efficiency and innovation (decreased energy demand) • High intensity electric or biogas heating • Some hydrogen/ biogas for chemical uses	• High industrial efficiency upgrades and decreased energy demand • Upgrades to electric or biogas heating • Some ongoing industrial use of natural gas where displacement is particularly difficult	• Biogas and hydrogen-fired heating • Upgrade of heating technology • Large-scale blue and green hydrogen to replace chemical feedstock	• Biogas and hydrogen-fired heating • Upgrade of heating technology • Large-scale hydrogen (gasification) to replace chemical feedstock

Scenario	A. zero emissions electrification – no natural gas	B. net zero emissions electrification supported by natural gas	C. zero emissions hydrogen with biogas and electrification	D. net zero emissions hydrogen with biogas and electrification
Transport	• Strong uptake of EVs for most transport • Renewable fuels for air transport	• Strong uptake of EVs for personal and public transport • Small-scale uptake of hydrogen for heavy and air transport	• Strong uptake of hydrogen-fuelled transport for personal, public, air and heavy vehicles	• Strong uptake of EVs for personal and public transport • Strong uptake of hydrogen-fuelled transport for air and heavy vehicles
Energy efficiency	• Large-scale energy efficiency improvements (public/ private investment)	• Moderate-scale energy efficiency improvements due to large public and private investments	• Moderate energy efficiency improvements	• Small-scale energy efficiency improvements for residential and industrial use
Export	• No energy exports • Export of expertise and technology	• No energy exports • International carbon emission certificate trade	• Export renewable and hydrogen tech/ expertise • Hydrogen export	• Global hydrogen export leader

Key assumptions underpinning the scenarios

Energy demand

Scenarios assume a baseline annual energy demand in Victoria of 1,298 PJ in 2018-19, with a forecast increase in energy consumption of 15% per decade. Baseline annual energy demand data are sourced from Department of Industry, Science, Energy and Resources' *Australian Energy Update 2020*. Forecast energy demand is based on AEMO's *2020 Integrated System Plan Inputs and Assumptions*.

Population

Population growth forecasts are in line with the Department of Environment, Land, Water and Planning's *Victoria in Future* population projections. The change in Victoria's population of Victoria is used as a proxy for the change in energy demand in each of years 2030, 2040 and 2050. This comparison has been used to validate the assumption of 15% growth in energy consumption.

Geographical boundaries

Victoria is assumed to be an island, with no access to external energy sources. A critical implication of this simplified approach is to over-estimate the level of new energy infrastructure required to reach the net zero emissions target, in part from being unable to access the transient excess energy from differentials in load and demand cycles that occur in a diverse, complex, inter-connected system.

Renewable firming capacity such as batteries or pumped hydro are treated as stranded from inter-state grid connections.

All new renewable generation is assumed to be located in a Renewable Energy Zone. Renewable energy has also been located in the Renewable Energy Zones best suited to weather conditions and geography.

Natural gas production capacity and infrastructure

AEMO's *Gas Statement of Opportunities*, *Gas Bulletin Board* website and DORIS consultants' knowledge has been used to predict available gas production. Existing infrastructure capacity, length, age and layout was taken from the *Gas Statement of Opportunities*, the Australian Pipelines and Gas Association's website and the Australian Pipeline License Database.

The Dandenong LNG Storage Iona Gas Plant Storage facilities are assumed to be operational in 2030–2050. The Iona Gas Plant Storage facility will act purely as a storage facility and its capacity will be expanded. The phasing of existing gas infrastructure decommissioning allows for the Viva LNG Import Terminal being operational by 2030, but the production capacity is assumed to come from existing Victorian gas plants.

Electricity generation and storage

AEMO's website has been used to set a basis for the current capacity of installed electrical infrastructure in Victoria. Historical data was reviewed and data for a high-demand day, where most electricity produced in Victoria was consumed in-state, was selected as the basis to estimate the maximum capacity through the installed infrastructure.

Estimation of new additional renewable electricity capacity does not consider decommissioning of the existing assets.

Given the magnitude of renewable electricity storage required and its criticality in firming a high proportion of variable renewable power, two major types of storage were considered:

- battery storage, used to compensate 24 hours of solar power generation
- pumped hydro, used to compensate 168 hours of wind power generation.

Battery charging has been considered as part of the input to electrical generation capacity requirements.

Hydrogen production

Green hydrogen is delivered by standalone renewable electricity generators dedicated to specific green hydrogen production plants.

Carbon capture and storage

Capture of point source CO_2 emissions in the Latrobe Valley is assumed, with transport by pipeline to underground storage sites in the offshore Gippsland Basin.

Emissions factors

Emissions factors are based on Scope 1 emissions as defined in the Department of Industry, Science, Energy and Resources' *National Greenhouse Accounts Factors*. Where this source does not provide an emission factor, alternatives were sourced from the US Environmental Protection Agency, CSIRO, Parks Victoria and the United Nations Food and Agriculture Organization.

Exclusions

The following items are excluded from the scenario analysis:

- emissions from agriculture
- infrastructure to support transport – i.e. road, rail, air transport
- infrastructure to support the export of hydrogen including ports and loadout.

8. Appendix B Scenario energy consumption estimates

Table_A2: Energy consumption estimates – Scenario A

Energy consumed (PJ)	2030	2040	2050
Fossil fuels			
coal	308	150	0
vehicle fuel	217	99	0
natural gas	233	70	0
Renewables			
solar	312	588	850
wind	245	438	600
hydro	62	88	155
Combined heat and power			
Waste-to-energy / biogas / biomass	3	14	18
Heat			
geothermal	0	5	7
Gas			
biogas / landfill gas	3	19	28
biomethane	2	11	14
Hydrogen			
green hydrogen	23	28	42
blue hydrogen	0	0	0
brown hydrogen	0	0	0
Energy efficiency			
improvements	8	23	32
Total energy consumption	**1,416**	**1,53**1	**1,74**7

Source: DORIS Engineering (2021); IV analysis

Table_A3: Energy consumption estimates – Scenario B

Energy consumed (PJ)	2030	2040	2050
Fossil fuels			
coal	308	150	0
vehicle fuel	217	99	0
natural gas	233	100	20
Renewables			
solar	361	594	787
wind	226	411	591
hydro	21	57	104
Combined heat and power			
Waste-to-energy / biogas / biomass	1	5	9
Heat			
geothermal	1	6	10
Gas			
biogas / landfill gas	1	11	16
biomethane	1	11	16
Hydrogen			
green hydrogen	22	34	48
blue hydrogen	3	25	43
brown hydrogen	0	0	0
Energy efficiency			
improvements	1	7	14
Total energy consumption	**1,395**	**1,509**	**1,656**

Source: DORIS Engineering (2021); IV analysis

Table_A4: Energy consumption estimates – Scenario C

Energy consumed (PJ)	2030	2040	2050
Fossil fuels			
coal	300	150	0
vehicle fuel	163	69	0
natural gas	233	70	0
Renewables			
solar	431	529	798
wind	268	322	476
hydro	55	72	124
Combined heat and power			
Waste-to-energy / biogas / biomass	0	2	5
Heat			
geothermal	0	2	5
Gas			
biogas / landfill gas	36	43	95
biomethane	53	67	112
Hydrogen			
green hydrogen	253	279	470
blue hydrogen	47	64	0
brown hydrogen	0	0	0
Energy efficiency			
improvements	1	7	14
Total energy consumption	**1,841**	**1,678**	**2,098**

Source: DORIS Engineering (2021); IV analysis

Table_A5: Energy consumption estimates – Scenario D

Energy consumed (PJ)	2030	2040	2050
Fossil fuels			
coal	300	150	0
vehicle fuel	163	69	0
natural gas	233	70	0
Renewables			
solar	431	529	798
wind	268	322	476
hydro	55	72	124
Combined heat and power			
Waste-to-energy / biogas / biomass	1	6	9
Heat			
geothermal	1	5	3
Gas			
biogas / landfill gas	11	31	54
biomethane	11	31	54
Hydrogen			
green hydrogen	13	38	67
blue hydrogen	0	0	0
brown hydrogen	574	1,073	1,420
Energy efficiency			
improvements	1	3	6
Total energy consumption	**1,550**	**2,020**	**2,444**

Source: DORIS Engineering (2021); IV analysis

9. Appendix C Key gas sector regulatory bodies

Table_A6: Gas sector regulatory bodies, responsibilities and legislation

Body	Role	Key legislation
Exploration and production		
National Offshore Petroleum Titles Administrator (NOPTA) (Commonwealth) Joint authorities	Administers titles and applications for exploration and production for offshore oil and gas operations and greenhouse gas storage activities in Commonwealth waters (generally 3 nautical miles offshore – approximately 5.5km). NOPTA does this through supporting the Joint Authorities' decision-making with information, assessment and analysis. It also grants short term titles, manages data releases, maintains title registers and ensures good petroleum resource management. The decision-maker for releasing offshore petroleum exploration areas, decisions relating to those areas, grants/refusals of offshore petroleum titles, title conditions including suspension, extension, surrender and cancellation of titles. The Joint Authorities in Victoria are the Commonwealth Minister for Resources, Water and Northern Australia and the Victorian Minister for Resources.	Established under the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cmwth)
National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) (Commonwealth)	The independent regulator for offshore oil and gas operations and greenhouse gas storage activities in Commonwealth waters. It regulates for health and safety, well integrity and environmental management. NOPSEMA assesses risk management plans for offshore petroleum activities, inspects to monitor compliance, investigates breaches and non-compliance, takes enforcement actions, and engages with industry.	*Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cmwth) *Environment Protection and Biodiversity Conservation Act 1999* (Cmwth) *Offshore Petroleum and Greenhouse Gas Storage (Regulatory Levies) Act 2003* (Cmwth)
Earth Resources Regulation	Victoria's regulator of exploration, mining, quarrying, petroleum, recreational prospecting and other earth resource activities, a branch within the Victorian Department of Jobs, Precincts and Regions. Earth Resources Regulation licenses earth resources exploration and production, assesses and approves applications for operations or works, undertakes engagement, education and enforcement activities.	*Mineral Resources (Sustainable Development) Act 1990* and associated regulations *Petroleum Act 1998* and Petroleum Regulations 2011 *Greenhouse Gas Geological Sequestration Act 2008* and associated regulations *Offshore Petroleum and Greenhouse Gas Storage Act 2010* and Offshore Petroleum and Greenhouse Gas Storage Regulations 2011

Body	Role	Key legislation
		Geothermal Energy Resource Act 2005 and associated regulations
Mine Land Rehabilitation Authority	An independent body established in June 2020 which oversees the rehabilitation of declared mine land. It oversees implementation of the Latrobe Valley Regional rehabilitation Strategy by public sector bodies and mine licensees, including registering, monitoring, and owning declared mine land post-closure.	*Mineral Resources (Sustainable Development) Act 1990*
Gas transmission and distribution infrastructure		
Energy Minister (Commonwealth)	Responsible for setting policy and agreeing changes to the national laws and frameworks within which Australian energy markets operate. The National Gas Law provides a national framework for third-party access to natural gas pipeline services.	The National Gas Law is a schedule to the *National Gas (South Australia) Act 2008*. It is supported by further regulations and the National Gas Rules. The National Energy Retail Law is a schedule to the *National Energy Retail Law (South Australia) Act 2011*, further supported by regulations and the National Energy Retail Rules.
Australian Energy Market Commission (AEMC) (Commonwealth)	An independent statutory authority responsible for making and amending the National Gas Rules. The AEMC can also undertake reviews and provide advice to governments on improvements to regulatory and energy market arrangements.	
Australian Energy Market Operator (AMEO) (Commonwealth)	Operates Victoria's gas transmission system, including substantial review and planning functions. AMEO also operates the gas market, including facilitating the gas retail market. The AEMO's ownership is shared between governments and industry. It operates on a user-pays cost-recovery basis, and recovers all operating costs through fees paid by industry participants.	
Australian Energy Regulator (AER) (Commonwealth)	Regulates covered gas pipelines, setting the amount of revenue that network businesses can recover from customers for using these networks. The AER enforces laws for gas markets in southern and eastern Australia, and monitors and reports on market participant conduct and the effectiveness of competition. In Victoria, gas distributors and the Victorian Transmission System are covered pipelines.	
Minister for Energy, Environment and Climate Change	Responsible for energy and climate policy in Victoria, and key legislation including the *National Gas (Victoria) Act 2008* that applies the National Gas Law and National Gas Rules as laws of Victoria. The National Energy Retail Laws apply in a limited manner in Victoria, but similar provisions exist in the *Gas Industry Act 2001*. The Minister also licenses pipelines, along with Energy Safe Victoria.	*National Gas (Victoria) Act 2008* *Gas Industry Act 2001* *Pipelines Act 2005* *Fuel Emergency Act 1977*
Essential Services Commission (ESC)	Licenses businesses involved in supplying gas, establishes and maintains codes and guidelines for gas distribution and for retail energy sale, and reports on energy businesses performance as well as energy prices. The ESC also administers the Victorian Energy Upgrades program.	*Essential Services Commission Act 2001* *Gas Industry Act 2001* Responsible for the Gas Distribution System Code and the Energy Retail Code.

Body	Role	Key legislation
Energy Safe Victoria (ESV)	An independent government agency responsible for the safe generation, supply and use of gas, electricity and pipelines. ESV ensures gas and electrical appliances are approved and safe for use, investigates gas and electrical incidents and undertakes safety awareness campaigns (for example, *Be Sure,* on gas safety in the home, and *Know the drill before you grill,* on gas BBQ safety). It oversees major industry safety cases and safety management schemes for the design, construction and maintenance of gas, electricity and pipeline networks across Victoria. ESV is responsible for the safety and technical regulation of gas and pipelines in Victoria. The Minister also licenses pipelines, along with ESV.	*Energy Safe Victoria Act 2005* *Gas Safety Act 1997* including the Gas Safety (Gas Installation) Regulations 2018 and Gas Safety (Safety Case) Regulations 2018 *Pipelines Act 2005*, including Pipelines Regulations 2017
Department of Environment, Land, Water and Planning	Issues pipeline licences and co-regulates licensees with Energy Safe Victoria.	*Pipelines Act 2005*, including Pipelines Regulations 2017
Clean Energy Regulator (Commonwealth)	An independent statutory authority that administers schemes legislated by the Australian Government for measuring, managing, reducing or offsetting Australia's carbon emissions.	*National Greenhouse and Energy Reporting Act 2007 (Cmwth)* *Carbon Credits (Carbon Farming Initiative) Act 2011 (Cmwth)* which establishes the Emissions Reduction Fund *Australian National Registry of Emissions Units Act 2011 (Cmwth)*
Land use planning, environment, building and development		
Minister for Planning	Responsible for the Victorian Planning System, including planning policy, provisions and approves planning scheme changes. The Minister for Planning can require proposals for projects which could have a significant effect on the environment to undergo an Environmental Effects Statement.	*Planning and Environment Act 1987* *Environmental Effects Act 1978*
Local councils	Responsible for local planning schemes and assessing planning permit applications. Most councils have municipal building surveyors on staff, who are responsible for the building control functions of council. This includes issuing building permits. Councils are responsible for the administration and enforcement of certain parts of the Building Act and regulations in their local government area.	*Planning and Environment Act 1987* *Building Act 1993*
Environment Protection Authority Victoria (EPA)	Victoria's independent environmental regulator. The EPA works with community and industry to prevent and reduce environmental and health impacts from pollution and waste. The EPA assesses works approval applications for certain gas projects. For example, the EPA has a regulatory role in part of the Golden Beach gas project as the proposed gas compressor is scheduled under its regulations. This means the project needs a works approval to install the equipment and an EPA licence to operate it. The EPA is currently undergoing significant reform with new laws coming into effect from 1 July 2021. It will issue licences, permits and registrations depending on the activity being conducted and the level of control that will be needed.	*Environment Protection Act 1970* *Environment Protection Act 2017* (to come into effect on 1 July 2021)

Body	Role	Key legislation
Victorian Building Authority (VBA)	Regulates Victoria's building and plumbing industries. This includes registering, licensing and disciplining plumbers in Victoria, registering and disciplining building practitioners, undertaking inspections, investigations and audits to enforce compliance, and works with other regulators and agencies to ensure compliance. The VBA also monitors building permit levies and oversees the work of building surveyors (both council and private) and Victoria's building permit system. The VBA is represented on the Australian Building Codes Board which is responsible for the National Construction Code.	*Building Act 1993* and the Building Regulations 2018 and Plumbing Regulations 2018, which adopt the Building Code of Australia, which is part of the National Construction Code *Building and Construction Industry Security of Payment Act 2002*
Other		
Greenhouse and Energy Minimum Standards Regulator (Commonwealth)	Administers the national framework for product energy efficiency across Australia, based in the Australian Government Department of Industry, Science, Energy and Resources. The Energy Rating Label is the visible face of this work, but it also specifies the minimum energy performance of appliances before they can be sold in Australia or New Zealand.	*Greenhouse and Energy Efficiency Minimum Standards (GEMS) Act 2012 (Cmwth)*
Standards Australia	An independent, non-government, not-for-profit standards organisation. Standards Australia brings together specialists to develop and assist adoption of internationally-aligned standards in Australia. Standards are voluntary. However, governments often refer to Australian Standards or joint Australian / New Zealand Standards in legislation, which can then make them mandatory.	As an example, Victoria's *Pipelines Act 2005* requires licensed pipelines constructed and operated in accordance with Australian Standard 2885: Pipelines – Gas and liquid petroleum.
Australian Competition and Consumer Commission (ACCC) (Commonwealth)	An independent Australian statutory authority that enforces the *Competition and Consumer Act 2010*. Broadly, the ACCC covers product safety and labelling, unfair market practices, price monitoring, industry codes, industry regulation including gas, and mergers and acquisitions. The ACCC can also be directed by the Australian Government to undertake inquiries, such as the current inquiry into the supply of and demand for natural gas in Australia.	*Competition and Consumer Act 2010*
WorkSafe Victoria	The health and safety regulator for all Victorian workplaces, and manages Victoria's workers compensation scheme. WorkSafe Victoria aims to keep all workplaces healthy and safe, and to deliver high quality care and treatment when workers are injured. It administers a number of Acts and regulations.	*Occupational Health and Safety Act 2004* *Workers Compensation Act 1958* *Equipment (Public Safety) Act 1994* *Dangerous Goods Act 1985* and Dangerous Goods (Transport by Road or Rail) Regulations 2018

10. Sources

Accenture (2021) *Gas Infrastructure: International Comparisons*, report prepared for Infrastructure Victoria

ACT Government (n.d.(a)) *Buildings and Land Use* [website]. Available at www.environment.act.gov.au/cc/act-climate-change-strategy/buildings-and-land-use

ACT Government (n.d.(b)) *Emission Reduction Targets* [website]. Available at www.environment.act.gov.au/cc/act-climate-change-strategy/emission-reduction-targets

ACT Government (2018) *Ginninderry Pilots ACT's First Gas-free Housing Trial for 350 Homes* [media release], 2 February. Available at www.cmtedd.act.gov.au/open_government/inform/act_government_media_releases/yvette-berry-mla-media-releases/2018/ginninderry-pilots-acts-first-gas-free-housing-trial-for-350-homes

ACT Government (2020) *Now We're Cooking With … Electricity! Gas No Longer a Requirement in Canberra Suburbs* [media release], 17 January. Available at www.cmtedd.act.gov.au/open_government/inform/act_government_media_releases/rattenbury/2020/now-were-cooking-with-electricity!-gas-no-longer-a-requirement-in-canberra-suburbs

ACT Government (2020) *Zero-Emission Plan for Transport Canberra*, Transport Canberra and City Services Directorate, Canberra. Available at www.transport.act.gov.au/__data/assets/pdf_file/0010/1625095/ZERO-EMISSION-TRANSITION-FINAL-.pdf

ACT Government (2021) *Australia Takes Another Step Forward in the Transition to Zero Emissions Vehicles* [media release], 1 April. Available at www.environment.act.gov.au/home/home-news-listing/australia-takes-another-step-forward-in-the-transition-to-zero-emissions-vehicles

AGL (n.d.) *A Guide to Heat Pumps: What Are They and Are They More Efficient?* [website]. Available at https://discover.agl.com.au/your-home/heat-pumps-why-are-they-more-efficient/

Alberta Government (2021) *Carbon Capture, Utilization and Storage* [website]. Available at www.alberta.ca/carbon-capture-and-storage.aspx

AEMC (2019) *Applying the Energy Market Objectives*, Australian Energy Market Commission, Sydney. Available at www.aemc.gov.au/sites/default/files/2019-07/Applying%20the%20energy%20market%20objectives_4.pdf

AEMC (2020) *Recommended Rules for Regulatory Sandboxes* [media release], 26 March. Available at www.aemc.gov.au/news-centre/media-releases/recommended-rules-regulatory-sandboxes

AEMO (2021a) *Electricity Statement of Opportunities – May 2021 Update*, Australian Energy Market Operator. Available at www.aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2021/may-2021-electricity-statement-of-opportunities-update.pdf

AEMO (2021b) *Gas Statement of Opportunities*, Australian Energy Market Operator. Available at www.aemo.com.au/-/media/files/gas/national_planning_and_forecasting/gsoo/2021/2021-gas-statement-of-opportunities.pdf

AEMO (2021c) *Victorian Gas Planning Report 2021*, Australian Energy Market Operator. Available at www.aemo.com.au/-/media/files/gas/national_planning_and_forecasting/vgpr/2021/2021-victorian-gas-planning-report.pdf

Australian Council of Social Service (2019) *All Australian Deserve a Healthy, Safe, Affordable Home*, Australian Council of Social Service. Available at www.acoss.org.au/wp-content/uploads/2019/09/Joint-statement-for-Healthy-Affordable-Homes.pdf

Australian Energy Regulator (2020) *State of the Energy Market 2020*, Australian Competition and Consumer Commission, Melbourne. Available at www.aer.gov.au/publications/state-of-the-energy-market-reports/state-of-the-energy-market-2020

Australian Energy Regulator (2021) *Final Decision – Evoenergy Access Arrangement 2021-26*, Australian Competition and Consumer, Melbourne. Available at www.aer.gov.au/system/files/AER%20-%20Final%20decision%20-%20Evoenergy%20access%20arrangement%202021-26%20-%20Overview%20-%20April%202021.pdf

Australian Government (2021a) *Budget 2021-22: Budget Overview*, Commonwealth of Australia, Canberra. Available at https://budget.gov.au/2021-22/content/overview.htm

Australian Government (2021b) *Building a More Secure and Resilient Australia* [website]. Available at https://budget.gov.au/2021-22/content/resilient.htm

Australian Renewable Energy Agency (2021) *Over $100 Million to Build Australia's First Large-Scale Hydrogen Plants* [media release], 5 May. Available at https://arena.gov.au/news/over-100-million-to-build-australias-first-large-scale-hydrogen-plants/

Barwon Water (2021) *Renewable Organics Network Colac* [website]. Available at www.barwonwater.vic.gov.au/about-us/major-projects/renewable-organics-networks

Beyond Zero Emissions (2018) *Zero Carbon Industry Plan: Electrifying Industry*, Beyond Zero Emissions, Melbourne. Available at https://bze.org.au/wp-content/uploads/2020/12/electrifying-industry-bze-report-2018.pdf

Bruce S, Temminghoff M, Hayward J, Schmidt E, Munnings C, Palfreyman D and Hartley P (2018) *National Hydrogen Roadmap*, CSIRO. Available at www.csiro.au/en/Do-business/Futures/Reports/Energy-and-Resources/Hydrogen-Roadmap

City of Wyndham (2018) *Quandong Precinct Structure Plan* [website]. Available at https://vpa.vic.gov.au/project/quandong-precinct-structure-plan/

Clarke JM, Grose M, Thatcher M, Hernaman V, Heady C, Round V, Rafter T, Trenham C and Wilson L (2019) *Victorian Climate Projections 2019 Technical Report*, CSIRO, Melbourne. Available at www.climatechange.vic.gov.au/__data/assets/pdf_file/0016/435121/Vic-Climate-Projections-2019-Technical-Report_20200218.pdf

Clean Energy Regulator (2021) *Carbon Capture and Storage* [website]. Available at www.cleanenergyregulator.gov.au/ERF/Pages/Method%20development%20tracker/Carbon-capture-and-storage.aspx

Climate Change Act 2017 (Vic). Available at www.legislation.vic.gov.au/in-force/acts/climate-change-act-2017/005

CO2CRC (2021) *Storage in a Depleted Gas Reservoir* [website]. Available at https://co2crc.com.au/co2research/stage-1/

COAG Energy Council (2019a) *Australia's National Hydrogen Strategy*, Commonwealth of Australia. Available at www.industry.gov.au/sites/default/files/2019-11/australias-national-hydrogen-strategy.pdf

COAG Energy Council (2019b) *Meeting Communique – Friday 22 November 2019*, COAG Energy Council Secretariat, Canberra. Available at https://energyministers.gov.au/sites/prod.energycouncil/files/publications/documents/EC%20-%20Final%20Communique.pdf

Carlu E, Truong T and Kundevski M (2019) *Biogas Opportunities for Australia*, ENEA Consulting. Available at https://arena.gov.au/assets/2019/06/biogas-opportunities-for-australia.pdf

Deloitte Access Economics (2017) *Decarbonising Australia's Gas Distribution Networks*, report prepared for Energy Networks Australia. Available at www.energynetworks.com.au/resources/reports/decarbonising-australias-gas-distribution-networks-deloitte/

Department of Environment, Land, Water and Planning (2017) *About the Gas Sector* [website]. Available at www.energy.vic.gov.au/gas/about-the-gas-sector

Department of Environment, Land, Water and Planning (2020) *Victorian Greenhouse Gas Emissions Report 2018*, State of Victoria. Available at www.climatechange.vic.gov.au/__data/assets/pdf_file/0026/504188/Victorian-Greenhouse-Gas-Emissions-Report-2018a1.pdf

Department of Environment, Land, Water and Planning (2021a) *Cutting Victoria's Emissions 2021-2025: Energy Sector Emissions Reduction Pledge*, State of Victoria. Available at www.climatechange.vic.gov.au/victorian-government-action-on-climate-change/Energy-sector-pledge-accessible.pdf

Department of Environment, Land, Water and Planning (2021b) *Cutting Victoria's Emissions 2021-2025: Land Use, Land Use Change and Forestry Sector Emissions Reduction Pledge*, State of Victoria. Available at www.climatechange.vic.gov.au/victorian-government-action-on-climate-change/LULUCF-sector-pledge-accessible.pdf

Department of Environment, Land, Water and Planning (2021c) *Renewable Hydrogen Industry Development Plan*, State of Victoria. Available at www.energy.vic.gov.au/__data/assets/pdf_file/0021/513345/Victorian-Renewable-Hydrogen-Industry-Development-Plan.pdf

Department of Environment, Land, Water and Planning (2021d) *Victoria's Climate Change Strategy* [website]. Available at www.climatechange.vic.gov.au/victorias-climate-change-strategy

Department of Environment, Land, Water and Planning (2021e) *Victoria's Renewable Energy Targets* [website]. Available at www.energy.vic.gov.au/renewable-energy/victorias-renewable-energy-targets

Department of Environment, Land, Water and Planning (2021f) *Victorian Planning Provisions*, State of Victoria. Available at https://planning-schemes.delwp.vic.gov.au/schemes/vpps/56_09.pdf

Department of Environment, Land, Water and Planning (2021g) *Minimum Rental Standards for Heating* [website]. Available at www.energy.vic.gov.au/energy-efficiency/minimum-rental-standards

Department of Environment, Land, Water and Planning (2021h) *Help Build Victoria's Gas Substitution Roadmap*. Available at https://engage.vic.gov.au/download_file/48288/5619

Department of Industry, Science, Energy and Resources (2020a) *Australian Energy Update 2020, Australian Energy Statistics*, Commonwealth of Australia, Canberra. Available at www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202020%20Energy%20Update%20Report_0.pdf

Department of Industry, Science, Energy and Resources (2020b) *State and Territory Greenhouse Gas Inventories 2018* Commonwealth of Australia. Available at www.industry.gov.au/sites/default/files/2020-05/nga-state-and-territory-greenhouse-gas-inventories-2018.pdf

Department of Industry, Science, Energy and Resources (2021a) *International Climate Change Commitments* [website]. Available at www.industry.gov.au/policies-and-initiatives/australias-climate-change-strategies/international-climate-change-commitments

Department of Industry, Science, Energy and Resources (2021b) *National Gas Infrastructure Plan: Interim Report*, Commonwealth of Australia. Available at www.energy.gov.au/sites/default/files/National%20Gas%20Infrastructure%20Plan%20-%20Interim%20Report.pdf

Department of Industry, Science, Energy and Resources (2021c) *Offshore Oil and Gas Decommissioning: Enhanced Framework* [website], https://consult.industry.gov.au/offshore-resources-branch/offshore-decom/

DORIS Engineering (2021) *Net Zero Emission Scenario Analysis*, report prepared for Infrastructure Victoria

Earth Resources (2021) *About the Project* [website]. Available at https://earthresources.vic.gov.au/projects/carbonnet-project/about-the-project

Energy Consumers Australia (2021) *A Future Energy Vision. Consumer Expectations Research: Household Findings*, Energy Consumers Australia. Available at https://energyconsumersaustralia.com.au/wp-content/uploads/Future-Energy-Vision-Research-2020-Household-Findings-for-ACCC.pdf

Energy Networks Association (2021) *Britain's Hydrogen Network Plan*, Energy Networks Association. Available at www.energynetworks.org/industry-hub/resource-library/britains-hydrogen-network-plan.pdf

Environment Victoria (2021) *Briefing Paper: Demand Side Measures Overlooked in Victorian Gas Shortfall Estimates*, Environment Victoria. Available at https://environmentvictoria.org.au/2021/03/26/briefing-paper-demand-side-measures-overlooked-in-victorian-gas-shortfall-estimates/

Eurostat (2020) *Energy Consumption in Households 2018*, Eurostat. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households

Forcey T (2015) *Switching Off Gas - An Examination of Declining Gas Demand in Eastern Australia*, Melbourne Energy Institute, Melbourne, https://energy.unimelb.edu.au/__data/assets/pdf_file/0007/1993309/switching-off-gas-an-examination-of-declining-gas-demand-in-eastern-australia.pdf

Fyfe C, Telfar-Barnard L, Howden-Chapman P and Douwes J (2020) 'Association Between Home Insulation and Hospital Admission Rates: Retrospective cohort study using linked data from a national intervention programme', *BMJ*, 371:m4571. Available at www.bmj.com/content/371/bmj.m4571

Geological Survey of Victoria (2020) *Victorian Gas Program Progress Report No 5*, Department of Jobs, Precincts and Regions, State of Victoria, Melbourne. Available at https://earthresources.vic.gov.au/__data/assets/pdf_file/0020/613091/VGP_PR05-161926-Low-res.pdf

Geoscience Australia (n.d.), *Hydrogen* [website]. Available at www.ga.gov.au/scientific-topics/energy/resources/hydrogen

Ginninderry (2021) *Home Energy Solutions* [website]. Available at https://ginninderry.com/home-energy-solutions/

Global CCS Institute (2020) *Global Status of CCS 2020*, Global Carbon Capture and Storage Institute, Melbourne. Available at www.globalccsinstitute.com/wp-content/uploads/2020/12/Global-Status-of-CCS-Report-2020_FINAL_December11.pdf

GPA Engineering (2019) *Hydrogen Impacts on Downstream Installations and Appliances*, report prepared for COAG Energy Council and South Australia Government. Available at www.coagenergycouncil.gov.au/sites/prod.energycouncil/files/publications/documents/

HESC (2020) *About HESC* [website]. Available at https://hydrogenenergysupplychain.com/about-hesc/

IEA Bioenergy (2018) *Country Reports, Australia - 2018 Update: Bioenergy Policies and Status Implementation*, IEA Bioenergy. Available at www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_Australia_final.pdf

Infrastructure Australia (2019) *Australian Infrastructure Audit 2019*, Infrastructure Australia. Available at www.infrastructureaustralia.gov.au/sites/default/files/2019-08/Australian%20Infrastructure%20Audit%202019%20-%207.%20Energy.pdf

Infrastructure Victoria (2021) *Gas Infrastructure Advice - Literature Review*

International Energy Agency (2018) *Energy Efficiency 2018*, International Energy Agency. Available at www.iea.org/reports/energy-efficiency-2018

International Energy Agency (2019) *The Future of Hydrogen*, International Energy Agency. Available at www.iea.org/reports/the-future-of-hydrogen

International Energy Agency (2021) *Net Zero by 2050: A Roadmap for the Global Energy Sector*, International Energy Agency, Paris. Available at https://iea.blob.core.windows.net/assets/4719e321-6d3d-41a2-bd6b-461ad2f850a8/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf

Longden T, Beck F, Jotzo F, Andrews R, Mousami P (2021) *'Clean' Hydrogen? An Analysis of the Emissions and Costs of Fossil Fuel Based Versus Renewable Electricity Based Hydrogen*, CCEP Working Paper 21-03, ZCEAP Working Paper ZCWP02-21, The Australian National University, Canberra. Available at https://iceds.anu.edu.au/files/2020%2003%2025%20-%20ZCEAP%20-%20CCEP%20Working%20Paper%20-%20Clean%20hydrogen%20emissions%20and%20costs_0_0.pdf

Macdonald Smith A. (2021) 'Gorgon CCS Headaches to Increase Emissions Bill', *Australian Financial Review*, 14 January. Available at www.afr.com/companies/energy/gorgon-ccs-headaches-to-increase-emissions-bill-20210114-p56u0l

Northmore Gordon (2020) *Victorian Gas Market – Demand Side Measures to Avoid Forecast Supply Shortfall*, report prepared for Environment Victoria, Northmore Gordon, Cremorne. Available at http://environmentvictoria.org.au/wp-content/uploads/2020/06/Vic-Gas-Market-Demand-Side-Study-Final-Report-1.pdf

OECD (2015) *The Economic Consequences of Climate Change*, OECD Publishing, Paris. Available at https://doi.org/10.1787/9789264235410-en.

Plante L, Browning J, Aitken G, Inman M, and Nace T Global (2020) *Gas Bubble 2020*, Global Energy Monitor. Available at https://globalenergymonitor.org/wp-content/uploads/2020/07/GasBubble_2020_r3.pdf

Plumbing Regulations 2018. Available at www.legislation.vic.gov.au/in-force/statutory-rules/plumbing-regulations-2018/003

Powell D (2020) *Focus on Blue Hydrogen*, Gaffney Cline. Available at www.gaffneycline.com/sites/g/files/cozyhq681/files/2020-08/Focus%20on%20Blue%20Hydrogen.pdf

Premier of Victoria (2021a) *Enshrining Victoria's Ban On Fracking Forever* [media release], 5 March. Available at www.premier.vic.gov.au/enshrining-victorias-ban-fracking-forever

Premier of Victoria (2021b) *Gas Proposal Ruled Out Due to Environmental Impacts* [media release], 30 March. Available at www.premier.vic.gov.au/gas-proposal-ruled-out-due-environmental-impacts

Prime Minister of Australia (2020) *Gas-Fired Recovery* [media release], 15 September. Available at www.pm.gov.au/media/gas-fired-recovery

Quicke A and Bennett E (2020) *Climate of the Nation 2020*, The Australia Institute, Canberra. Available at https://australiainstitute.org.au/wp-content/uploads/2020/12/Climate-of-the-Nation-2020-cover-WEB.pdf

Rewaste (2021) *About ReWaste* [website]. Available at www.rewaste.com.au

Sandri O, Holdsworth S, Hayes J, O'Shea B, Krosch D and Chester L (2020) *RP2.2-01: Regulatory Mapping for Future Fuels*, Future Fuels CRC. Available at www.futurefuelscrc.com/project/regulatory-mapping-for-future-fuels-rp2-2-01/

Shell (2020) *Quest CCS Facility Captures and Stores Five Million Tonnes of CO2 Ahead of Fifth Anniversary* [media release], 10 July. Available at www.shell.ca/en_ca/media/news-and-media-releases/news-releases-2020/quest-ccs-facility-captures-and-stores-five-million-tonnes.html

Solar Victoria (2021) *Energy Efficient Heating and Cooling* [website]. Available at www.solar.vic.gov.au/heaters

Sustainability Victoria (2019) *Comprehensive Energy Efficiency Retrofits to Existing Victorian Houses*, Sustainability Victoria, Melbourne. Available at https://assets.sustainability.vic.gov.au/susvic/Report-Energy-Comprehensive-Energy-Efficiency-Retrofits-to-Existing-Victorian-Houses-PDF.pdf

Sustainability Victoria (2021) *Home insulation* [website]. Available at www.sustainability.vic.gov.au/energy-efficiency-and-reducing-emissions/building-or-renovating/insulation

UK Government (2021) *Rigorous New Targets for Green Building Revolution* [media release], 19 January. Available at www.gov.uk/government/news/rigorous-new-targets-for-green-building-revolution

Victorian Energy Efficiency Target Act 2007. Available at www.legislation.vic.gov.au/in-force/acts/victorian-energy-efficiency-target-act-2007/016

Victorian Parliamentary Debates (2016) Legislative Assembly, Fifty-Eight Parliament, First Session, 23 November, page 4549. Available at https://hansard.parliament.vic.gov.au/search/?LDMS=Y&IW_FIELD_ADVANCE_PHRASE=be+now+read+a+second+time&IW_FIELD_IN_SpeechTitle=Climate+Change+Bill+2016&IW_FIELD_IN_HOUSENAME=ASSEMBLY&IW_FIELD_IN_ACTIVITYTYPE=Second+Reading&IW_FIELD_IN_SittingYear=2016&IW_DATABASE=*

Viva Energy Australia (2021) *Approvals Process and Scoping Requirements* [website]. Available at www.vivaenergy.com.au/energy-hub/gas-terminal-project/approvals-process-and-ees/approvals-process-and-scoping-requirements

Wood T and Dundas G (2020) *Flame Out: The Future of Natural Gas*, Grattan Institute. Available at https://grattan.edu.au/wp-content/uploads/2020/11/Flame-out-Grattan-report.pdf

Wood T and Ha J (2021) *Go for Net Zero*, Grattan Institute. Available at https://grattan.edu.au/wp-content/uploads/2021/04/Go-for-net-zero-Grattan-Report.pdf

World Health Organization (2018) *WHO Housing and Health Guidelines*, World Health Organization, Geneva. Available at https://apps.who.int/iris/bitstream/handle/10665/276001/9789241550376-eng.pdf?ua=1.

About us

Infrastructure Victoria is an independent advisory body, which began operating on 1 October 2015 under the *Infrastructure Victoria Act 2015*.

Infrastructure Victoria has three main functions:

- preparing a 30-year infrastructure strategy for Victoria, which is refreshed every three to five years
- providing written advice
  to government on specific infrastructure matters
- publishing original research on infrastructure-related issues

Infrastructure Victoria also supports the development of sectoral infrastructure plans by government departments and agencies.

The aim of Infrastructure Victoria is to take a long-term, evidence-based view of infrastructure planning and raise the level of community debate about infrastructure provision.

Infrastructure Victoria does not directly oversee or fund infrastructure projects.

Printed by Infrastructure Victoria

June 2021

This document is also available in PDF and accessible Word format at www.infrastructurevictoria.com.au

ISBN 978-1-925632-69-9 (**pdf/online/MS word**)