Australian Gas Infrastructure Group

Using hydrogen to decarbonise natural gas consumption in Victoria is 40 % less expensive than full electrification

Decarbonisation efforts in the energy sector are currently focused largely on electricity. However, over the coming decades natural gas that supplies heat to homes, businesses and industry will also need to be decarbonised.

Australian Gas Infrastructure Group (AGIG) has worked with Deloitte to analyse two pathways to decarbonise Victoria's gas consumption.

- The first pathway, called the Full Electrification case, analyses replacing all natural gas consumption with electricity generated from renewable sources via the replacement of gas appliances with electric appliances, and ultimately decommissioning the gas networks.
- The second pathway, called the Hydrogen Conversion case, analyses conversion of existing natural gas appliances and distribution networks to transport hydrogen produced through electrolysis, utilising electricity generated from renewable sources.
- To enable either pathway to be achieved, the existing electricity sector must also be decarbonised, which has been called the Renewable Electric base case.

The analysis was based on hourly energy consumption data for 2017. It was assumed that all electricity generation was decarbonised instantly at the beginning of the year, along with the completion of all network upgrades, decommissioning, and energy storage installations. In reality, the transition would be completed gradually over several decades. Hence each pathway has been priced on projected 2030 generation costs from the Australian Energy Market Operator (AEMO).

It is important to note that the analysis is for comparative purposes only – that is, the relativity of cost between the two pathways is under consideration. The actual decarbonisation costs for both pathways will benefit from normal “end-of-life“ replacements, further experience-driven cost reductions, digitalisation of the grid operation, demand response and improved efficiency.

- For the Renewable Electric base case, 2017 Victorian electricity consumption was decarbonised by estimating the level of additional renewable generation and storage capacity needed to meet 2017 instantaneous peak electricity demand and annual electricity consumption.

- In Full Electrification, Victorian gas demand was also electrified by estimating the required additional renewable generation and storage above the Renewable Electric case to meet the additional electricity demand as a result of gas consumption being replaced by electricity. The peak electricity demand is adjusted to account for the higher coefficients of performance (COP) of electrical appliances. Electricity distribution and transmission networks are upgraded to meet increased instantaneous peak electricity demand. The natural gas distribution network is decommissioned.
- For Hydrogen Conversion, Victorian gas demand was decarbonised through conversion of natural gas networks to transport hydrogen. Additional renewable generation was required above the Renewable Electric case to produce hydrogen via electrolysis. Inter-seasonal hydrogen storage was also required to give electrolysis the flexibility to match the variability of renewable generation while still meeting seasonal hydrogen demand profiles. Additional investment was required for electrolysis, inter-seasonal hydrogen storage and upgrading the natural gas distribution and transmission networks. There is no investment required for upgrading electricity networks.

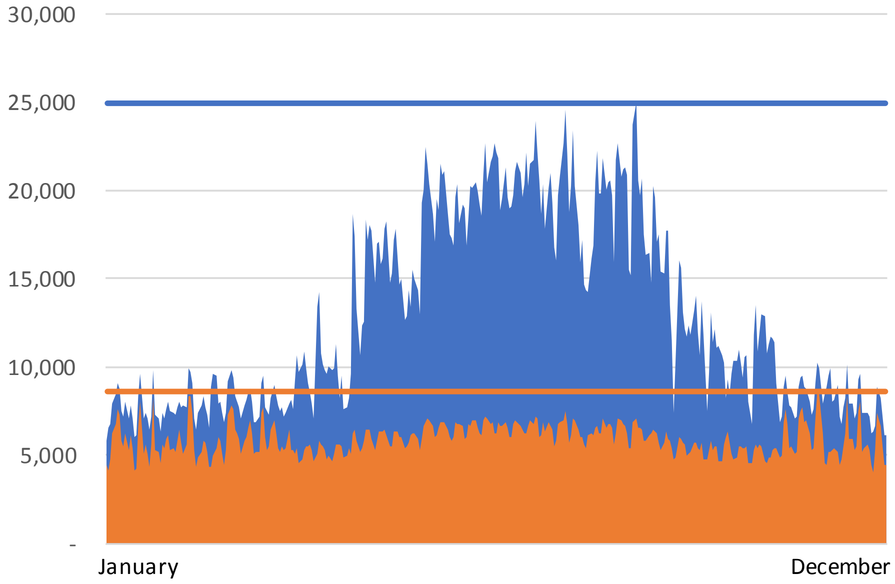
Customer Instantaneous Demand and Total Energy Consumption

For electricity, consumption data includes all ‘on grid’ consumption and instantaneous demand – that is all electricity that is delivered by transmission and distribution networks to meet the demand of both distribution and transmission connected consumers.

For gas, consumption data includes only gas distributed by the Victorian distribution networks to meet consumer demand. Gas demand of large consumers (such as gas fired power generators and large industrials) that take gas supply directly from the transmission networks has not been included.

The figure below presents the combined daily maximum hourly demand data for electricity and gas – stacked on top of each other. In Victoria, gas consumption is very seasonal, with the majority of gas being consumed in the winter months for heating, with winter instantaneous peak demand of 18,000 MW. Electricity instantaneous peak demand of 9,000 MW occurs during summer, with significantly less inter-seasonal swings compared to gas consumption. The combined maximum demand is 25,000 MW and occurs during winter.

Fig 1: Combined daily maximum hourly demand in MW



25,000 MW combined winter instantaneous peak energy demand

Gas

18,000 MW instantaneous peak demand
36 TWh energy consumption

Electricity

9,000 MW instantaneous peak demand
45 TWh energy consumption

Source: AGIG analysis and AEMO data

Full Electrification and Hydrogen Conversion Cases

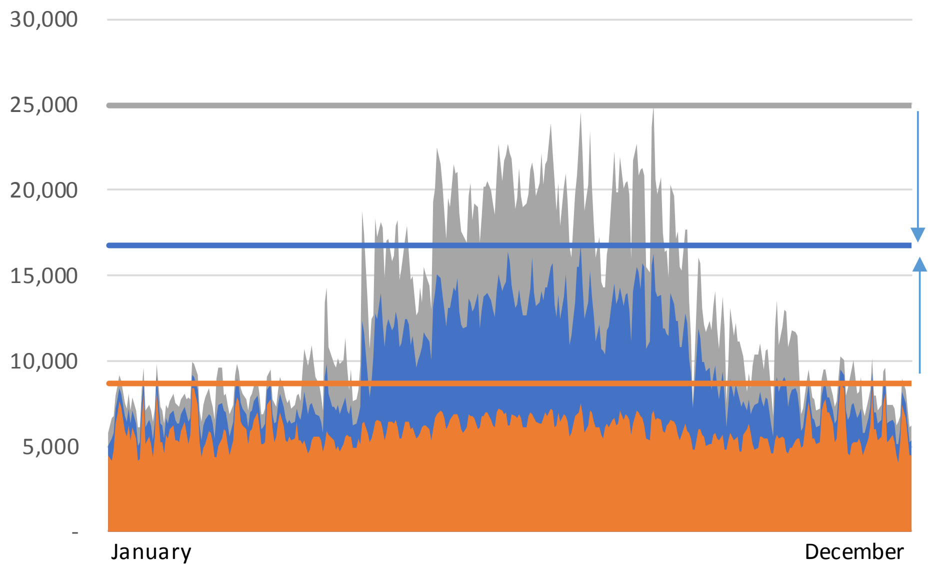
More efficient appliances are used in both cases leading to reductions in peak demand. Key assumptions relating to appliance efficiency and network characteristics are presented in the table below.

Table 1: Appliance and network impact on gas equivalent energy consumption

	Full Electrification	Hydrogen Conversion
Appliance efficiency	**Residential and commercial segment** • Average COP of 4 for ducted reverse cycle heating (100% take up) • Average COP of 3 for heat pump hot water (14% customer take up – those with higher consumption) • Heating and hot water appliance COP reduces to 2, at temperatures of 4 degrees C and below • All other converted appliances (e.g. cooktops) COP 1 for electric equivalent **Industrial segment** • Average COP of 1.2 on all consumption	**Residential segment** • Large customers (those with higher consumption - 14% in numbers) will invest in gas (hydrogen) powered reverse cycle heating, with average COP of 2 • No reduction in COP due to colder temperatures (waste heat from gas motor utilised) **Commercial segment** • 100% take up of gas (hydrogen) powered reverse cycle heating, with average COP of 3 • No reduction in COP due to colder temperatures (waste heat from gas motor utilised) **All segments** • All other hydrogen converted appliances efficiency is unchanged
Gas storage	• No intraday peak shaving / inter-seasonal gas storage benefits	• No Change

For the Full Electrification case, the figure below presents the combined daily maximum hourly demand for electricity and gas equivalent consumption– stacked on top of each other. Both the total energy consumed and combined maximum peak demand are lower as a result of assumed appliance efficiency. However, the total instantaneous electricity peak generation and customer demand increases to 17,000 MW (from 9,000 MW) as a result of gas consumption being met by electricity. The Full Electrification case also loses the benefits of intraday peak-shaving and inter-seasonal storage provided by the existing gas transmission and distribution networks and storage facilities.

Fig 2: Combined daily maximum hourly demand in MW – Full Electrification case



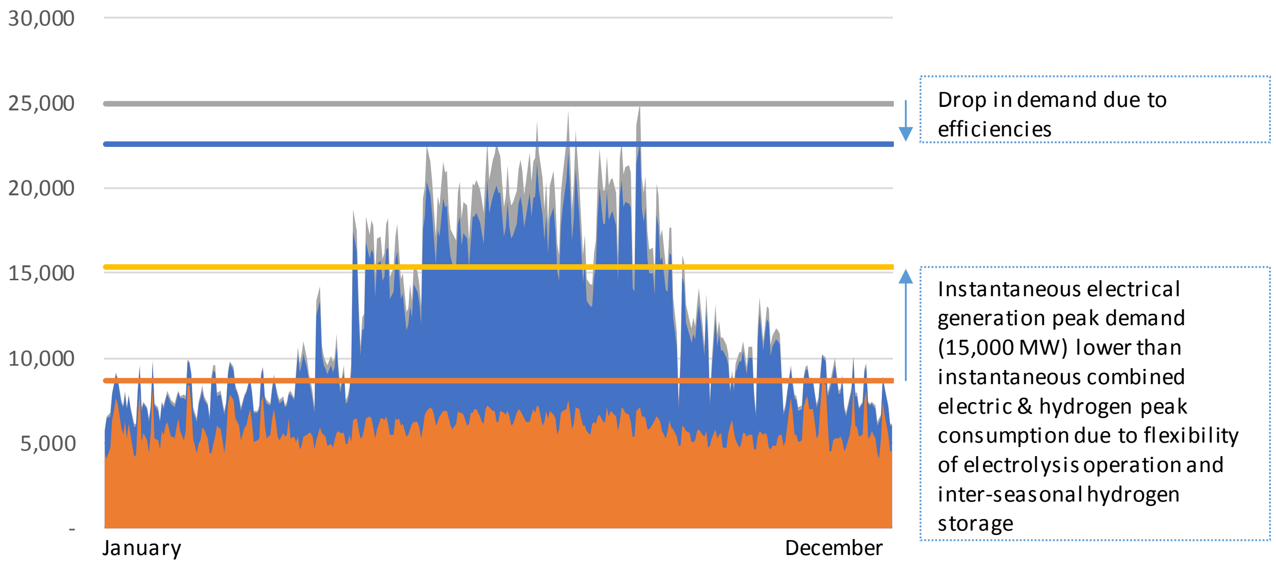
Drop in peak instantaneous energy demand due to efficiencies

Higher **17,000 MW** combined winter instantaneous electricity peak demand

Source: AGIG analysis and AEMO data

For the Hydrogen Conversion case, both the total energy consumption and combined maximum peak demand are lower than 2017 values as a result of slight gains to appliance efficiency assumed upon changeover during conversion of gas to hydrogen. However, due to the operational flexibility of electrolysis and long term hydrogen storage, the increase in instantaneous electricity peak generation demand (now 15,000 MW) is 2000 MW lower compared to that in the Full Electrification case. Customer peak demand on the electricity networks remains at 9,000 MW. This is shown below.

Fig 3: Combined daily maximum hourly demand in MW – Hydrogen Conversion case



Drop in demand due to efficiencies

Instantaneous electrical generation peak demand (15,000 MW) lower than instantaneous combined electric & hydrogen peak consumption due to flexibility of electrolysis operation and inter-seasonal hydrogen storage

Source: AGIG analysis and AEMO data

Renewable Electricity Generation and Storage

Meeting the additional renewable electricity demand described above will require significant additional generation and storage, as presented in the table below.

Table 2: Victorian renewable electricity generation and storage[1]

	Renewable Electric base case	Full Electrification	Hydrogen Conversion
	Peak power (MW)	Peak power (MW)	Peak power (MW)
Existing wind	1,412	1,412	1,412
Existing hydro	2,306	2,306	2,306
Existing renewable generation	**3,718**	**3,718**	**3,718**
New solar	4,000	8,335	6,000
New wind	4,551	9,265	13,265
New biomass	500	500	500
New CST (6 hours energy storage)	1,000	1,000	1,000
TOTAL renewable generation	**13,769**	**22,818**	**24,483**
Battery storage (2 hours energy storage)	3,218	5,390	2,402
Snowy 2.0 (175 GWh energy storage, 50% allocated to Victoria)[2]	1,000	1,000	1,000
Tasmanian pumped hydro (130 GWh energy storage)[3]	N/A	4,840	N/A
TOTAL short and long term storage	**4,218**	**11,230**	**3,402**
TOTAL additional generation and storage	**14,269**	**30,330**	**24,167**

Source: Australian Gas Infrastructure Group analysis and Deloitte energy market modelling.

Energy storage is an important consideration in 100 percent renewable generation scenarios predominantly based on intermittent wind and solar generation technologies. In any given year, there are likely to be several prolonged periods where wind generation is extremely low. For example, in 2017 there were 126 periods greater than eight hours in length (40% of the year in total) when wind generation was less than 20% of nameplate generation availability, and 90 periods (20% of the year in total) when wind generation was less than 10 percent nameplate availability.[4]

In all modelling cases, storage requirements have been sized to meet both the instantaneous peak electricity demand, and the electricity consumption during sustained periods of low wind generation. As a representative example of such a sustained low wind generation period, the modelling considered a period of 190 hours, from 7:00pm on the 8th of May to 5:00pm on the 16th of May, 2017. During this timeframe, from actual 2017 Victorian wind

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[1] In all modelled cases, Victoria is a net importer of energy from other states through existing interconnection. The additional renewable generation built in those states that contributes to Victoria has not been included in Table 2, but has been accounted for in the total cost comparison.

[2] Snowy Hydro website

[3] Hydro Tasmania, Battery of the Nation – Tasmanian pumped hydro in Australia's future electricity market, Concept Study Knowledge sharing report, April 2018

[4] Derived from AEMO NEM generation data

generation data, average wind generation was only 6 percent of nameplate maximum peak generation availability.

During this period wind generation in New South Wales and South Australia was also at similarly low levels, resulting in these states unable to transfer electricity to Victoria through interconnectors (in an all renewable generation scenario).

It is in these sustained low wind generation periods that long term energy storage is required to meet electricity consumption and avoid sustained and significant customer demand curtailment. The calculated storage requirements to meet electricity consumption during the example period, and avoid the requirement for curtailment, are summarised below for each modelling case.

Renewable Electric base case

In the Renewable Electric case, 13,769 MW of renewable generation, 4,218 MW of instantaneous peak storage, and 110 GWh of long term energy storage (met by Snowy 2.0’s 175 GWh) is required to meet instantaneous peak demand, annual electricity consumption, and cater for long periods of low wind generation.

Full Electrification Case

In the Full Electrification case 22,818 MW of renewable generation, 11,230 MW of instantaneous peak storage and 305 GWh of long term energy storage (provided by Snowy 2.0 and Tasmanian pumped hydro) is required to meet instantaneous peak demand, annual electricity consumption and periods of low wind generation.

Compared to the Renewable Electric case, this case requires significantly more investment in both short term and long term storage and a significant overbuild in solar to cater for the higher overall energy needed during periods of sustained low wind generation.

Hydrogen Conversion Case

In the Hydrogen Conversion case 24,483 MW of renewable generation, 175 GWh of long term energy storage (provided by Snowy 2.0) and 2,402 MW of instantaneous peak storage is required to meet instantaneous peak electrical demand, annual electricity consumption and periods of low wind generation.

Compared to the Full Electrification case, both long term and instantaneous electrical storage requirements are greatly reduced. This is due to the flexibility of electrolysis coupled with long term hydrogen storage, which is able to maximise the utilisation of variable wind generation output to meet the seasonal gas demand profile.

Appliance Upgrades

In both the Full Electrification and the Hydrogen Conversion pathways, gas consumers would be required to change their current natural gas appliances to either electrical appliances or hydrogen compatible appliances. Any major infrastructure replacement program would be guided and supported by government policy and implemented over a gradual period of time. Hence, consumers and appliance manufacturers would have sufficient notice to minimise the cost of appliance changeover.

- In the Full Electrification pathway, consumers would be signalled to change their gas appliances for electric appliances when their existing gas appliances reach end of life. All remaining gas consumers would be required to change their appliances at the time of gas network decommissioning
- The Hydrogen Conversion pathway would commence with blending of hydrogen with natural gas, requiring no change to the majority of current gas appliances. Full conversion to 100% hydrogen would be planned over time such that consumers are signalled to buy new gas appliances that are easily convertible to 100% hydrogen when their existing appliances reach end of life. All remaining incompatible gas appliances would be replaced at the time of 100% hydrogen conversion.

Therefore the cost of appliance changeover is not considered material.

Victorian Electricity Distribution and Transmission Network

In the Full Electrification pathway, significant investment will be required to upgrade the Victorian electricity distribution and transmission network. This is because as current gas consumption is switched over to electricity, instantaneous peak demand increases from 9,000 MW in summer to 17,000 MW in winter, an increase of over 90 percent. In calculating this increase in instantaneous peak demand, the relative higher efficiencies of electric appliances has been factored in.

In estimating the total cost to upgrade the Victorian electricity distribution and transmission networks, the current gross historic value of distribution assets[5] has been used to estimate the additional investment required to meet the increase in peak electricity demand. The present value (PV) of additional annual operating costs (OPEX) based on 1% on asset investment are included.

From the total additional electricity network costs (upgrade costs plus PV of incremental OPEX), the present value of avoided operating costs on gas networks[6] has been deducted.

Electrolysis and Long Term Hydrogen Storage

In the Hydrogen Conversion pathway, 7,000 MW of electrolysis is required to generate sufficient hydrogen to meet consumer demand. The cost of electrolysis has been based on benchmarks sourced from the CSIRO Hydrogen Roadmap Report.[7]

Long term storage of 12 TWh has been based on the cost of storage in salt caverns – benchmarks obtained from the CSIRO Hydrogen Roadmap Report.

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[5] Data obtained from network company RIN submissions to the Australian Energy Regulator

[6] Annual operating cost data sourced from company Post Tax Revenue Models published on the AER website

[7] CSIRO National Hydrogen Roadmap to be launched in August 2018

Gas Networks

In the Full Electrification pathway, the current Victorian gas distribution network would have to be decommissioned. This cost comprises mainly of decommissioning services and mains and satisfying licence requirements to remove transmission pipeline assets.

In the Hydrogen Conversion pathway, a conversion process analogous to that employed to convert gas networks from town gas to natural gas in the past, would be implemented to systematically isolate and convert sections of the gas distribution network to 100% hydrogen. Conversion would be extensively planned and could take about 10 to 15 years.

Through the ongoing mains replacement program,[8] where old cast iron pipes are being replaced by polyethylene pipes (that are capable of distributing hydrogen), the distribution network would be hydrogen ready by 2035. Although conversion can begin much earlier to convert sections of the distribution network that have already been fully converted to polyethylene pipes. The main costs of conversion comprise of isolating and purging of natural gas, project management, customer engagement and minor enhancements.

The Hydrogen Conversion case requires a new transmission network that would transport hydrogen from renewable energy zones where hydrogen would be produced via electrolysis.

Total Cost Comparison

The total costs of each pathway are presented in the figure below. The base costs of converting the current electricity demand to renewables is included in each of the pathways.

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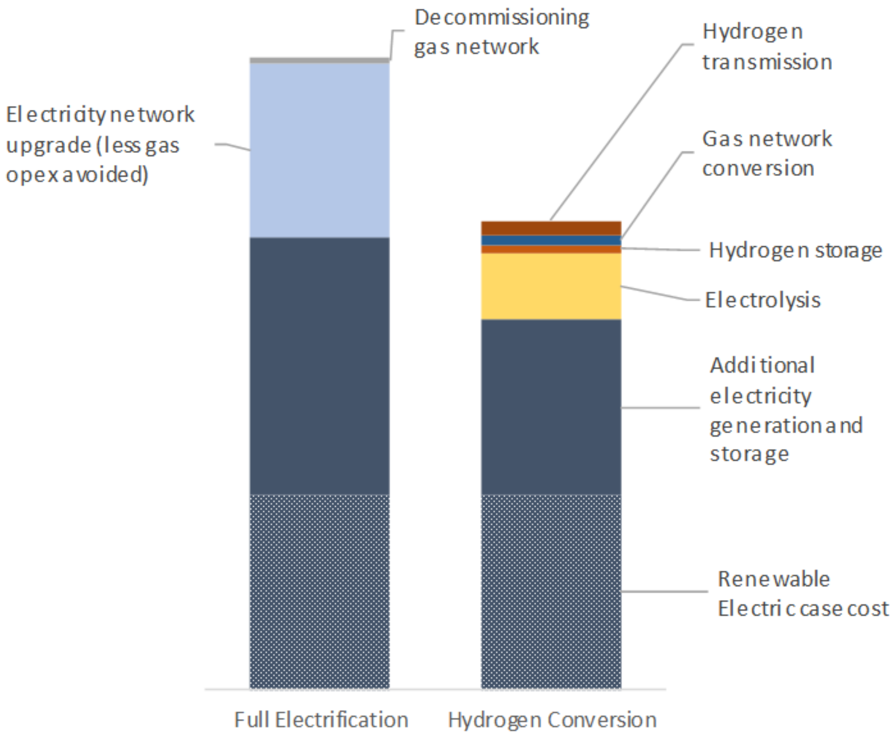
[8] End of life replacement program currently being undertaken by distribution companies to replace low pressure cast iron mains

Fig 4: Relative cost comparison of decarbonisation pathways



Source: Australian Gas Infrastructure Group analysis and Deloitte energy market model.

To decarbonise gas consumption in Victoria, the Hydrogen pathway is 40% less expensive than Full Electrification.

In Summary

The analysis presented has made several simplifying assumptions to reduce the complexity of the analysis. However, the results suggest that there is considerable merit in further investigating the Hydrogen Conversion decarbonisation pathway.[9]

The Hydrogen Conversion pathway also has the benefit, through the widespread deployment of electrolysis, of adding flexible load to the electricity system that can respond to peaks and troughs in both renewable electricity generation and consumer demand. This provides a means to get greater value out of the required ‘overbuild’ of renewable energy generation by using energy excess to consumer demands.

The cost of the Hydrogen Conversion pathway has the potential to be reduced via further optimising storage and production costs in conjunction with the potential domestic transport and export markets for hydrogen.

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[9] For example, AGIG with support from the South Australian government, is demonstrating a power-to-gas project where hydrogen will be produced from a 1.25 MW electrolyser and blended into the gas distribution network in Tonsley, SA.