frontier economics

Pathway to zero emissions for LPG

A Report for Gas Energy Australia and the Australia Gas Industry Trust | 18 January 2023

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Background and objective of report

Frontier Economics has been engaged by Gas Energy Australia (GEA) and the Australian Gas Industry Trust (AGIT) to undertake a study on the pathway for Australia's LPG sector as the economy moves to net zero emissions.

LPG is widely used in Australia by residential, commercial, recreational and industrial customers, particularly in regional and remote areas. Compared to alternative sources of fuel, particularly electricity and other liquid fuels, LPG has been an affordable and lower emitting energy source. As Australia's economy transitions towards net zero emissions, it is clear that the LPG sector will need to change if it is to continue to play a role in meeting the energy needs of Australian households and businesses.

In particular, with the increasing availability of high efficiency electrical appliances, and the expectation that electricity will increasingly be supplied from renewable sources, there are questions about the extent to which the LPG sector can compete with electricity on both emissions reductions and price.

This report considers the pathway to zero for Australia's LPG sector by outlining some of the key technological options by which the LPG sector can deliver low-emissions or zero-emissions gas to its customers and developing a potential transition path by which LPG can achieve zero-emissions by 2050.

We also investigate the competitiveness of LPG for consumers, in comparison with electrification, through case studies that investigate the comparative total costs to customers, and comparative carbon emissions, of remaining with LPG appliances or switching to electrical appliances. These case studies are provided in separate reports provided to GEA and AGIT.

LPG in Australia

Liquefied petroleum gas (LPG) is a high-density fuel that is widely used by residential, commercial, recreational and industrial customers, typically for space heating, water heating, cooking and process heat. LPG consists of propane and/or butane gases. These are relatively easy to liquefy under mild pressurisation, which allows LPG to be easily transported, distributed and stored.

In Australia, the uses of LPG are often broken down into two distinct components – traditional demand and autogas demand.

Autogas was a key driver of the growth in LPG demand throughout the 1980s and 1990s due to the emergence of retail options for LPG-fuelled transport vehicles. However, changes in government policy combined with improved efficiencies of petrol and diesel fuelled vehicles and changes in consumer tastes have seen the LPG-automotive industry begin to decline over the past decade.

Traditional demand refers to the sources of demand for LPG that are not autogas and include sectors such as manufacturing, commercial, residential and agriculture. Total traditional demand has been relatively constant over the previous decade.

The trends for traditional demand vary by state and territory, driven in part by population, climate and local industries. Some jurisdictions have seen growth in traditional demand for LPG since 2008, while other jurisdictions have seen relatively constant or declining demand.

LPG is used in the residential sector in every state and territory, with total volume of LPG used per state reflecting variations in population, climate and the availability of natural gas. Some notable characteristics of the residential sector include:

- Most LPG users in each state are outside capital cities, reflecting the fact that LPG is often a substitute for those isolated from gas networks. LPG is relied on by a large number of households in Australia – around 14% of households, on average, in capital cities and around 29% of households, on average, outside of capital cities.
- Patterns of consumption of LPG across the States and Territories are generally similar.
  - LPG for water heating accounts for the largest proportion of LPG use by households across Australia and has been steadily growing in all jurisdictions.
  - LPG for cooking accounts for the second largest proportion of LPG use by households across Australia and has remained relatively constant over the period since 2008.
  - LPG consumption for space conditioning currently accounts for the smallest proportion of household LPG consumption in all jurisdictions and is declining in all jurisdictions.

With respect to supply, LPG has traditionally been produced in Australia in conjunction with refining of crude oil however the production of LPG from natural gas streams has been steadily increasing.

A notable feature of the supply of LPG in Australia is that despite Australia's consistent status as a net-exporter of LPG, as much as 41% of Australian domestic LPG consumption has been satisfied by imports in recent years. Exports occur from parts of Australia where LPG supply exceeds local demand, and imports occur in parts of Australia where local demand cannot be met be local supply.

LPG and the Transition to Net Zero

The CO2-e emissions intensity of LPG is lower than the emissions intensity of most alternative sources of energy. For example, the emissions intensity of LPG is 67% of the emissions intensity of black coal, 86% of the emissions intensity of diesel, and 32% of the emissions intensity of electricity in the National Electricity Market (based on the current generation mix).[1]

However, total emissions are a function of emissions intensity as well as energy usage, which is determined by the energy efficiency of appliances. Electrical appliances can be significantly more efficient than LPG appliances meaning customers using electricity may use less energy in total than customers using LPG. This efficiency improvement available from electrical appliances can result in lower total emissions from electricity.

[1] The emissions intensities reported in Australia's National Greenhouse Accounts Factors are 60.6 kgCO2e/GJ for LPG, 90.24 kgCO2e/GJ for black coal, 70.20 kgCO2e/GJ for diesel. See: Australian Government, *National Greenhouse Accounts Factors*, August 2021. The emissions intensity for the National Electricity Market reported by AEMO is 188.37 kgCO2e/GJ for electricity. See: AEMO Carbon Dioxide Equivalent Intensity Index: https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/market-operations/settlements-and-payments/settlements/carbon-dioxide-equivalent-intensity-index

Also, it is expected that the emissions intensity of electricity will fall significantly over coming years as the electricity system transitions away from coal generation and gas generation to renewable generation. In order for the LPG sector to remain lower-emitting, the LPG sector will also need to achieve lower emissions over time.

Assuming that the electricity sector achieves the emissions reductions set out under the Step Change and Progressive Change scenarios in the Australian Energy Market Operator's 2022 Integrated System Plan, and accounting for appliance efficiency, the total emissions from customers using electricity will be lower than from the use of conventional LPG (which refers to the mix of propane and/or butane from non-renewable sources that is currently supplied to LPG customers in Australia) sometime in the next 10 to 15 years. When this happens will depend on the rate of reduction in electricity emissions intensity and on the efficiency of the electrical appliances that customers use (higher efficiency electrical appliances result in less electricity use and less emissions, but are more expensive for customers to purchase).

There are many opportunities available to the LPG sector to achieve reductions in the emissions intensity of LPG and, indeed, opportunities for the LPG sector to achieve zero emissions. The two most likely options for reducing emissions and, ultimately, achieving zero emissions, or net-zero emission for the LPG sector are:

- BioLPG: propane produced from renewable feedstocks such as plant and vegetable waste material. BioLPG is chemically identical to conventional LPG and so can act as a 'drop-in' replacement for conventional LPG, which does not require any changes to existing transport and storage infrastructure or appliances. There are many pathways to producing BioLPG. Each of these pathways has the potential to produce bioLPG that has lower emissions than conventional LPG, and potentially to produce bioLPG with zero emissions. The WLPGA has proposed a global pathway to rLPG (bioLPG) satisfying up to 50% of global demand for LPG in 2050 (excluding demand for LPG as a feedstock for the petrochemical sector).
- Renewable Dimethyl Ether (rDME): DME is often described as synthetic LPG. It is chemically similar to propane and butane, so it behaves in much the same way as LPG, including in that it can be transported and stored as a liquid in pressurised cylinders and tanks. rDME can be blended with LPG (whether conventional LPG or bioLPG) at up to 20% by volume in existing appliances. It can also be used as a replacement for LPG, but this would require some changes to appliances. rDME can be produced via numerous processes depending on the feedstock including gasification and catalytic synthesis and electrolysis and catalytic synthesis, both of which can produce rDME that has lower emissions than conventional LPG, and potentially zero emissions.

The LPG sector globally has taken the first steps in transitioning away from conventional LPG towards lower emissions alternatives. However with demand for biodiesel and sustainable aviation fuel (SAF) expected to grow significantly in coming decades, providing the opportunity for associated bioLPG production, and other pathways for the production of bioLPG and rDME being investigated and developed, there is opportunity for significant growth in bioLPG and rDME globally, and in Australia.

Traditional Demand Forecasting and Transition Pathways

In developing a transition path for LPG to reach zero emissions, an important starting point is considering likely demand for LPG until 2050. Given the significant declines in LPG for the autogas market, our forecast of demand for LPG focuses on traditional demand.

We forecast future demand for LPG by extrapolating simple linear trends observed in the historical data for each State and Territory (excluding the Australian Capital Territory).

We note this approach may not capture all of the key drivers of future demand for LPG and there are plausible scenarios in which future demand for LPG could be significantly different from our forecasts. However, the transition path that we develop is not overly sensitive to future demand for LPG and alternative LPG sources remain relevant for higher or lower future demand for LPG.

Traditional demand for LPG is forecast to:

- Increase in Queensland, Tasmania and the Northern Territory
- Decrease in New South Wales, Victoria, Western Australia and South Australia
- Decline moderately in Australia to 2050 from the current level of ~32PJ to ~25.5PJ.

There are many potential technological pathways for the LPG sector to achieve reduced emissions and, ultimately, zero emissions. It is, of course, impossible to be sure of what the future for the LPG sector during the economy's transition to net zero will be, but it is possible to develop credible pathways for the LPG sector in Australia to achieve net zero emissions, or even zero emissions. One such credible pathway includes:

- BioLPG produced as a by-product of renewable diesel or SAF through the hydrotreated vegetable oil (HVO) process
- BioLPG produced as by-product of renewable diesel or SAF through gasification with the Fischer-Tropsch process
- RDME produced from biomass blended with LPG
- RDME produced from renewable energy blended with LPG
- LPG produced through a Power-to-Liquids pathway.

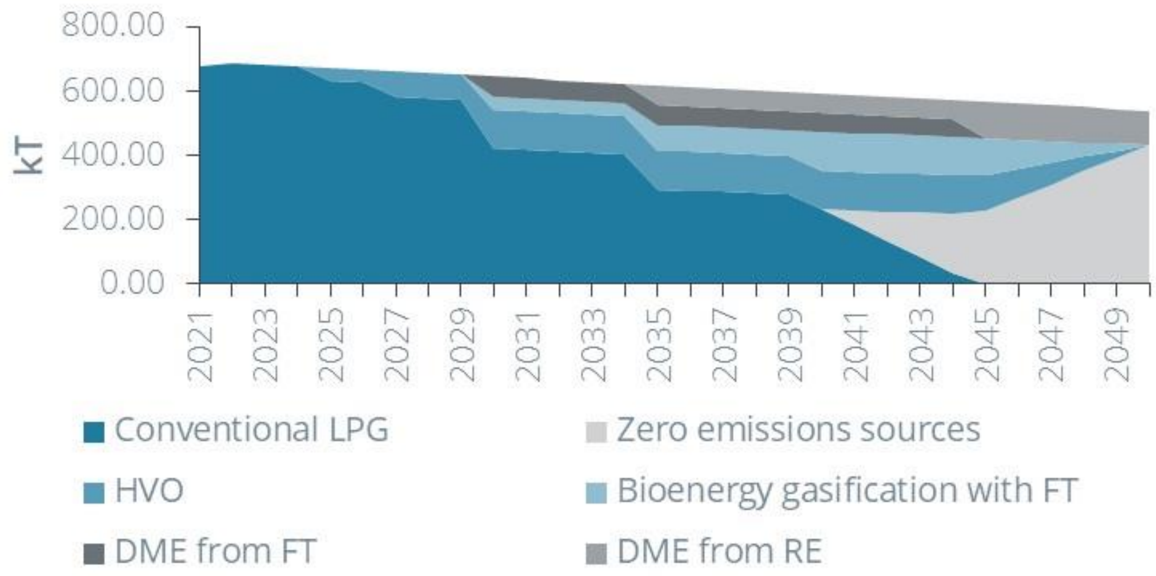
Each of these technologies are at different levels of commercial and technological (discussed in further detail in Section 4.2).

Under the assumed transition pathway, bioLPG from HVO becomes commercially available from 2025, bioLPG from gasification with FT and rDME from biomass from 2030, rDME from green hydrogen from 2035 and LPG from Power-to-Liquids from 2040. The supply of conventional LPG is steadily phased out in favour of these low-emission and zero-emissions alternatives, with conventional LPG no longer consumed by 2045. By 2050, zero emissions sources are the only sources of supply in the market.

This pathway consists of technologies at various states of technological and commercial readiness, as discussed in more detail in the sections that follow. The earlier steps on the pathway – bioLPG produced through HVO of the FT process – are more advanced technologically and commercially, but deliver less reduction in emissions, at least based on current supply chains for these processes. The later steps on the pathway – particularly rDME produced from renewable energy and LPG from Power-to-Liquids – are less well developed but offer the potential to achieve zero emissions. As discussed in Section 3.3, there are many other technologies for decarbonising LPG. If some of the technologies in the pathway that we present do not emerge as commercial options in Australia, there are other technologies that may do so. And, while this pathway ultimately delivers zero emissions, there are also other pathways that would deliver substantial reductions in emissions, which could be consistent with net zero emissions with some offsets.

The assumed transition pathway is illustrated in **Figure 1** and the resulting emissions intensity of LPG is shown in **Figure 2**.

Figure 1: LPG transition pathway



Source: Frontier Economics

Figure 2: Emissions profile from LPG transition pathway

Source: Frontier Economics

1 Introduction

Frontier Economics has been engaged by Gas Energy Australia (GEA) and the Australian Gas Industry Trust (AGIT) to undertake a study on the pathway for Australia's LPG sector as the economy moves to net zero emissions.

1.1 Background

LPG is widely used in Australia by residential, commercial, recreational and industrial customers. Compared to alternative sources of fuel, particularly electricity and other liquid fuels, LPG has been an affordable alternative. LPG has also been lower emitting than alternative sources of fuel.

As Australia's economy transitions towards net zero emissions, however, it is clear that the LPG sector will need to change if it is to continue to play a role in meeting the energy needs of Australian households and businesses. In particular, with the increasing availability of high efficiency electrical appliances, and the expectation that electricity will increasingly be supplied from renewable sources, there are questions about the extent to which the LPG sector can compete with electricity in achieving ongoing emissions reductions while remaining competitively priced for consumers.

1.2 This report

This report considers the pathway for Australia's LPG sector as the economy moves to net zero emissions by outlining some of the key technological options by which the LPG sector can deliver low-emissions or zero-emissions gas to its customers and developing a potential transition path by which LPG can achieve zero-emissions by 2050.

We also investigate the competitiveness of LPG for consumers, in comparison with electrification, through case studies that investigate the comparative total costs to customers, and comparative carbon emissions, of remaining with LPG appliances or switching to electrical appliances. These case studies are provided in separate reports provided to GEA and AGIT.

This report is structured as follows:

- Section 2 details what LPG is, the historical uses and trends in use of LPG in Australia and the characteristics of supply in the Australian market.
- Section 3 discusses the role of the LPG sector as the economy transitions to net zero emissions.
- Section 4 details the method and results of our forecasts of future demand for LPG and sets out a potential transition pathway for LPG to zero emissions.

2 LPG in Australia

This section provides an overview of the historical demand for LPG in Australia, including a breakdown of sectoral demand, state-by-state demand and household demand. This section also provides a brief overview of the historical trends in LPG production, supply and trade in Australia.

2.1 What is LPG?

Liquefied petroleum gas (LPG) is a high-density fuel that is widely used by residential, commercial and industrial customers, typically for space heating, water heating and process heat.

LPG consists of propane and/or butane gases. These are relatively easy to liquefy under mild pressurisation, which allows LPG to be easily transported, distributed and stored.

Propane and butane can occur naturally with other hydrocarbons in gas and oilfields or can be extracted at oil refineries during the production of other petroleum products. Across most of Australia, LPG consists solely of propane. However, in Western Australia, LPG can vary from 100 per cent propane to a 50/50 mixture of propane and butane.

LPG is supplied to customers in Australia through a network consisting of LPG road tankers, depots for receiving, storing and re-distributing LPG, tanks and cylinders used to store LPG at customers' premises, and trucks for refilling or exchanging tanks and cylinders at customers premises. LPG is also widely available through exchange cylinders, commonly used for barbeques. LPG is used to a greater extent in areas in which natural gas is not available, with the network of LPG infrastructure acting as a 'virtual pipeline' for delivery of LPG to customers.

2.2 Demand for LPG in Australia

LPG emerged as an energy source in Australia in the 1930s, with the industry beginning to take shape by the 1950s as Australia began to 'come of age' industrially[2]. By the early 1970s, Australia was consuming in excess of 20 PJ of LPG energy per year. Nevertheless, with energy consumption in the Australian economy heavily dominated by coal, natural gas and oil products, LPG accounts for a relatively small share of Australia's total energy consumption (49.2 PJ, or 0.8% of all energy consumption nationally, in 2019-20).[3]

Typical uses of LPG include:

- In the home: LPG is used for home and water heating as well as for cooking.
- In businesses: LPG is used for space heating, water heating and cooking by commercial customers, including restaurants and other hospitality venues. LPG is also used as a fuel source for forklifts, scissor lifts and other similar vehicles.
- In industry: LPG can be an essential input for industry, including for power generation, mining, metal processing, food production and for the use of industrial ovens or furnaces.

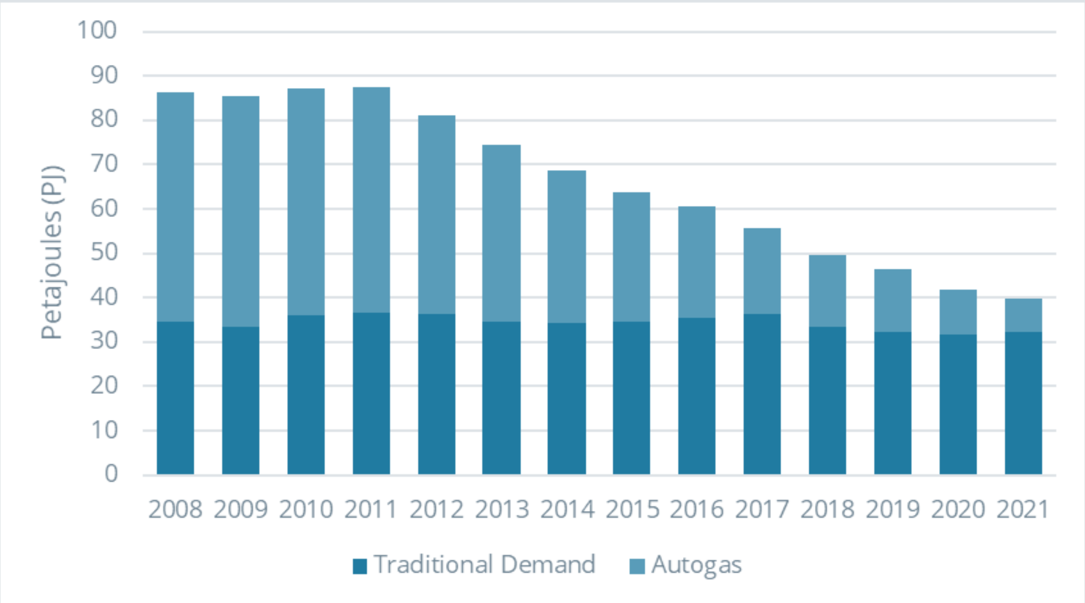
[2] LPG Australia, *50 Years of LPG Australia,* 2005.

[3] Department of Climate Change, Energy, the Environment and Water, *Australian Energy Update 2021*, 2021.

- In agriculture: LPG can be used to power equipment (such as water pumps) as well as for heating (e.g., crop drying, animal rearing and greenhouse heating).
- In transport: LPG can be used as a fuel source for transport.

In Australia, the uses of LPG are often broken down into two distinct components – traditional demand and autogas demand. Historical LPG consumption for traditional demand and autogas demand are shown in **Figure 3**.

Figure 3: LPG consumption Australia, traditional demand and Autogas (calendar year)



Source: Frontier Economics analysis of Gas Energy Australia data

Autogas demand

Autogas was a key driver of the growth in LPG demand throughout the 1980s and 1990s due to the emergence of retail options for LPG-fuelled transport vehicles. By the 1990s, LPG-consumption for road transport was accounting for 40-50% of all LPG consumption nationwide[4]. LPG-conversion of petrol-fuelled vehicles was a relatively easy and inexpensive exercise, with conversion costs ranging between $2000-$4000 in the 2000s and LPG fuelled vehicles widely available for retail purchase[5]. The peak in Autogas consumption came in 2005/06 when 68.4 PJ was consumed, accounting for 62% of all LPG consumption in that year[6].

In 2006, the Federal Government introduced rebates for individuals with LPG-installed systems on their vehicles or who purchased LPG-fuelled vehicles. However, by 2011, excise was levied on LPG vehicle fuel and by 2014 the rebate scheme was scrapped. These changes in government policy combined with improved efficiencies of petrol and diesel fuelled vehicles and changes in

4 Australian Energy Statistics 2021, Table F.

5 NRMA, *The story behind the rise and fall of LPG*, n.d.

6 Australian Energy Statistics 2021, Table F.

consumer tastes have seen the LPG-automotive industry begin to decline over the past decade. 2021 represented the lowest year for the autogas demand since the LPG-fuelled automotive industry was emerging from its infancy.

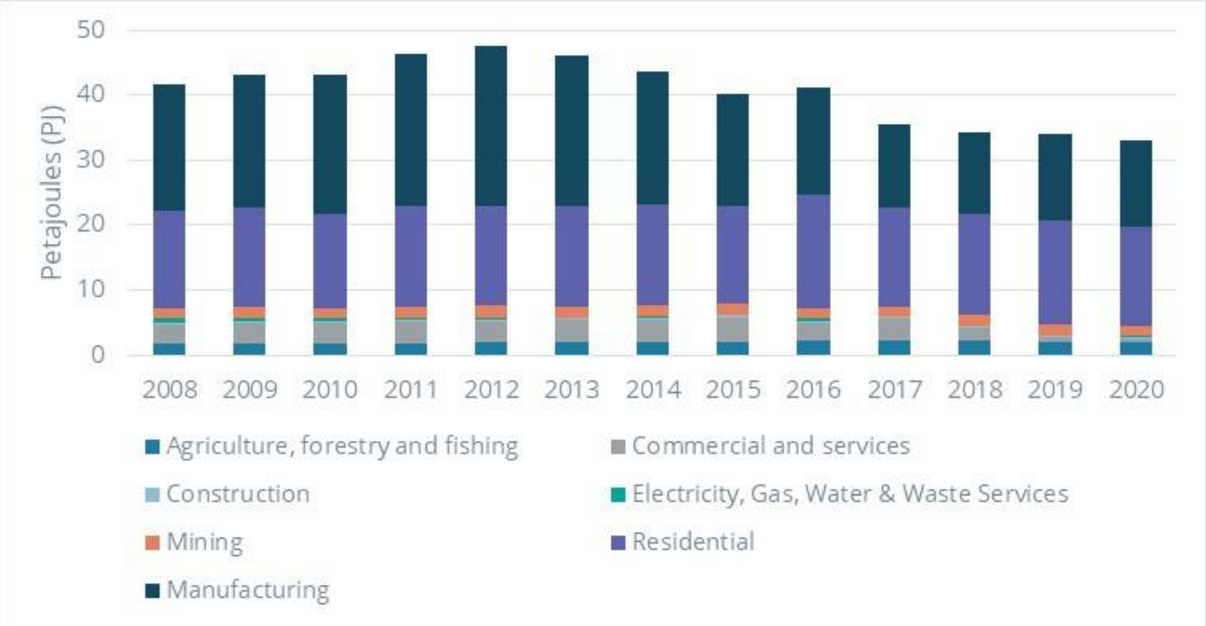
Traditional demand

Traditional demand has followed a different trajectory to that of Autogas. Traditional demand refers to the sources of demand for LPG that are not autogas and include sectors such as manufacturing, residential and agriculture. **Figure 4** shows a breakdown of traditional demand for LPG by sector, with the cumulative total of demand excluding the autogas sector.

There are some discrepancies in total consumption between the Gas Energy Australia data (**Figure 3**) and data from the Department of Climate Change, Energy, the Environment and Water (DCCEEW) (**Figure 4**). For example, total traditional demand in the Gas Energy Australia data is approximately 35 PJ in 2008 whereas in the DCCEEW data it is around 40 PJ. Industry data from 2008 onwards was collected by ACIL Allen for Gas Energy Australia. On 1 January 2018 a legal obligation was introduced to report selected petroleum and other fuel data. These statistics are reported on a monthly basis to the Australian Government, which uses the statistics to monitor Australia's fuel supply security and compliance with our obligations as a member of the International Energy Agency (IEA). The data collected under the reporting scheme eliminated the need for ACIL Allen to conduct a separate survey to collect data for the GEA LPG Supply and Demand Study. As such industry data is a combination of both sources.

Nonetheless, **Figure 4** provides an indication of the breadth of LPG consumption across Australia.

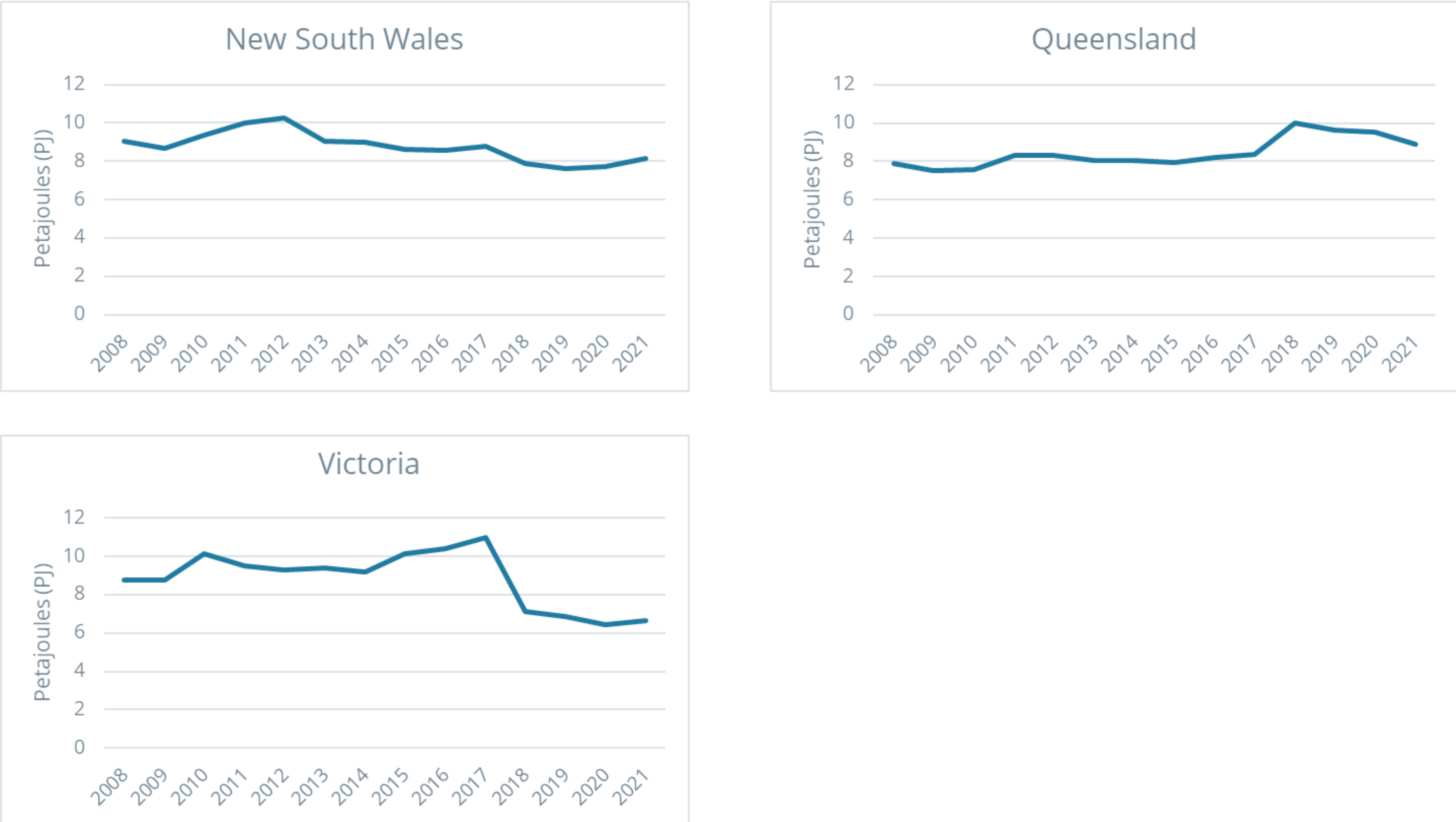
Figure 4: Traditional demand Australia by sector (financial year)

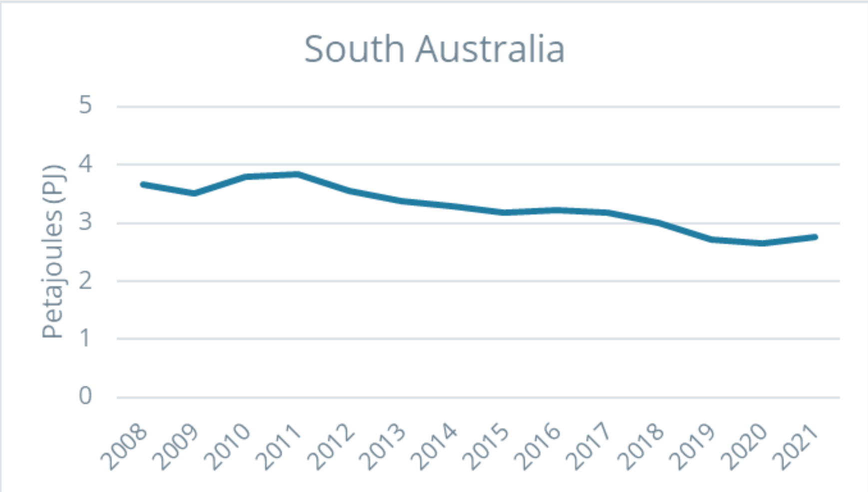


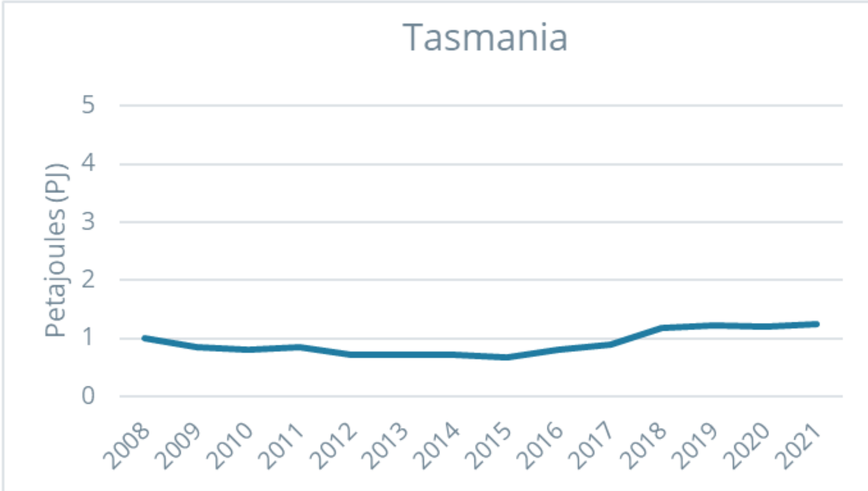
Source: Frontier Economics analysis of DCCEEW Australian Energy Statistics 2021, Table F data

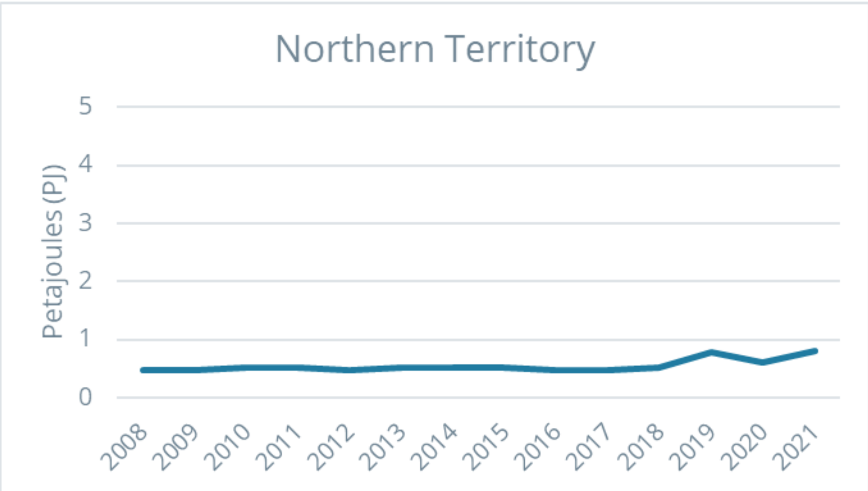
Figure 5 shows traditional demand for LPG for each State and Territory since 2008. The trends for traditional demand vary by State and Territory: some jurisdictions have seen growth in traditional demand for LPG since 2008, while other jurisdictions have seen relatively constant or declining demand.

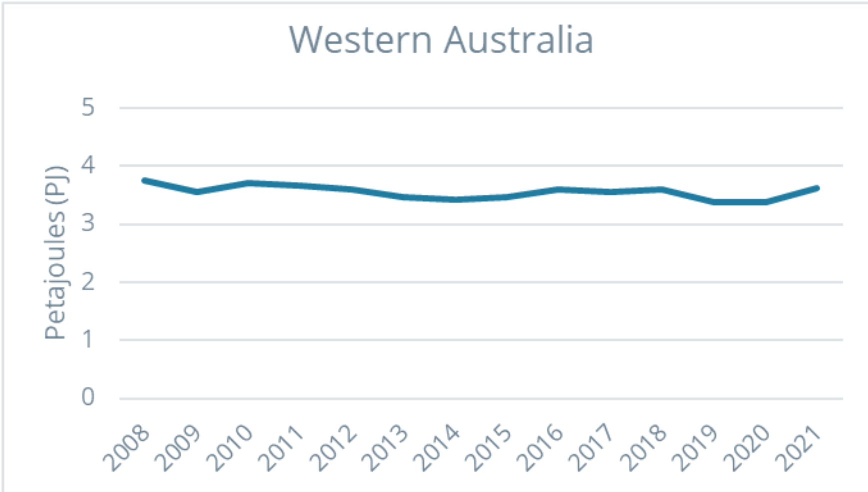
Figure 5: LPG traditional demand by State and Territory (calendar year)









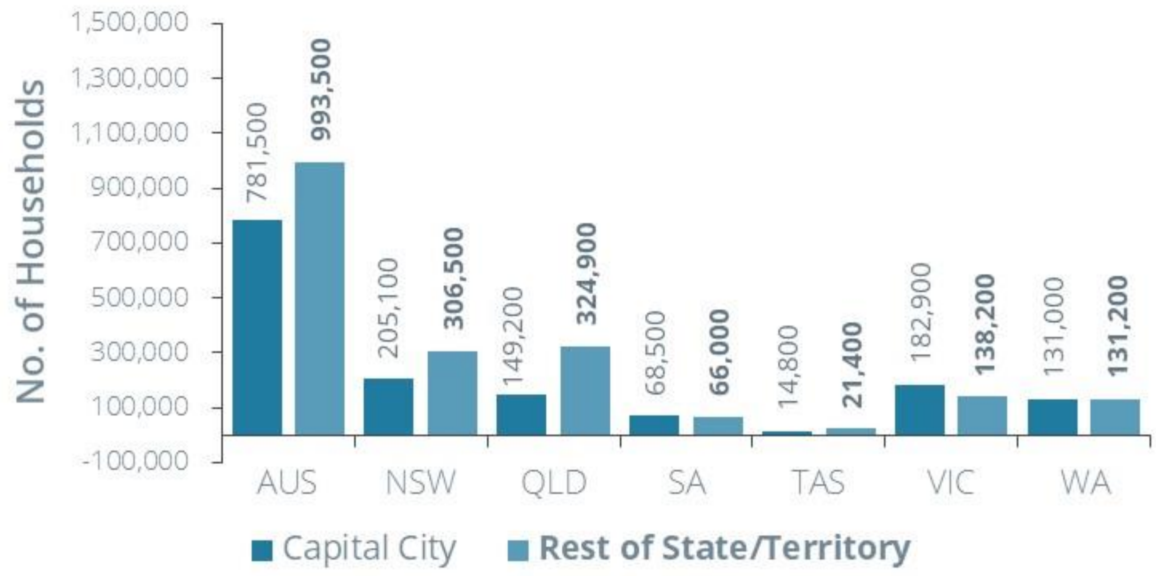


Source: Frontier Economics analysis of Gas Energy Australia data

2.2.1 Residential use of LPG

As discussed in the previous section, LPG is used in the residential sector in every state and territory to varying degrees. There is considerable variation in the total volume of LPG used per state, reflecting variations in population, climate and the extent to which natural gas is available. As detailed in **Figure 6**, most LPG users in each state are outside capital cities. This reflects the fact that LPG is often used as a substitute energy source for those isolated from gas networks. Overall, LPG is relied on by a large number of households in Australia – around 14% of households, on average, in capital cities and around 29% of households, on average, outside of capital cities.

Figure 6: Proportion of households by state with LPG



Source: Frontier Economics analysis of Australian Bureau of Statistics, Environmental Issues: Energy Use and Conservation, Mar 2014 data

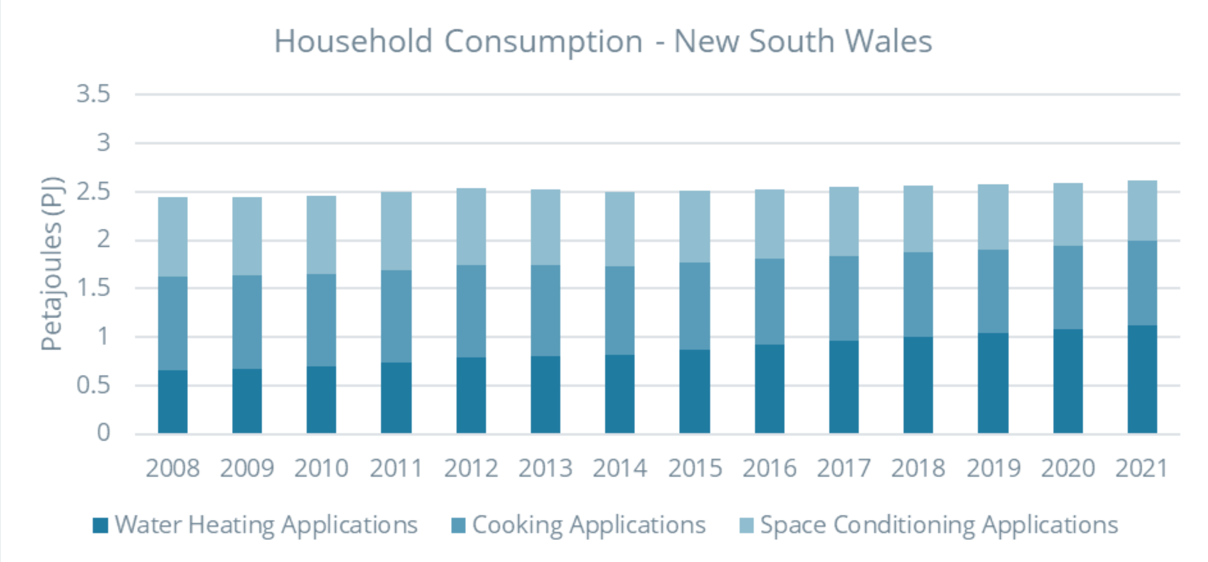
The way that residential customers use LPG is shown in **Figure 7**. Patterns of consumption of LPG across the States and Territories are generally similar.

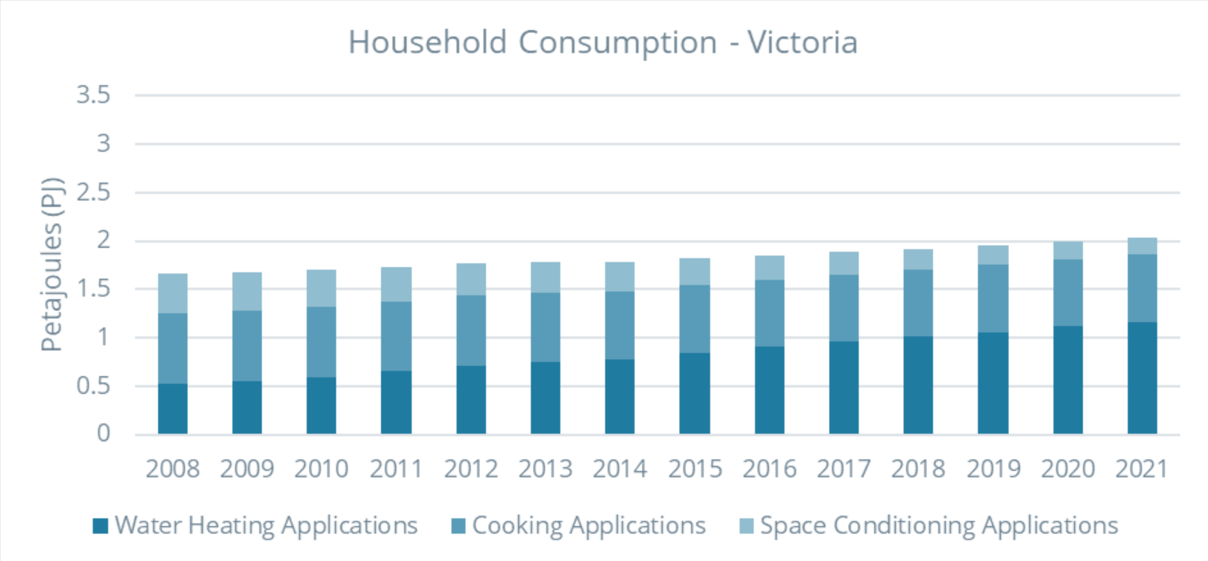
The use of LPG for water heating has been steadily growing in all jurisdictions, and LPG used for water heating accounts for the largest proportion of LPG use by households across Australia.

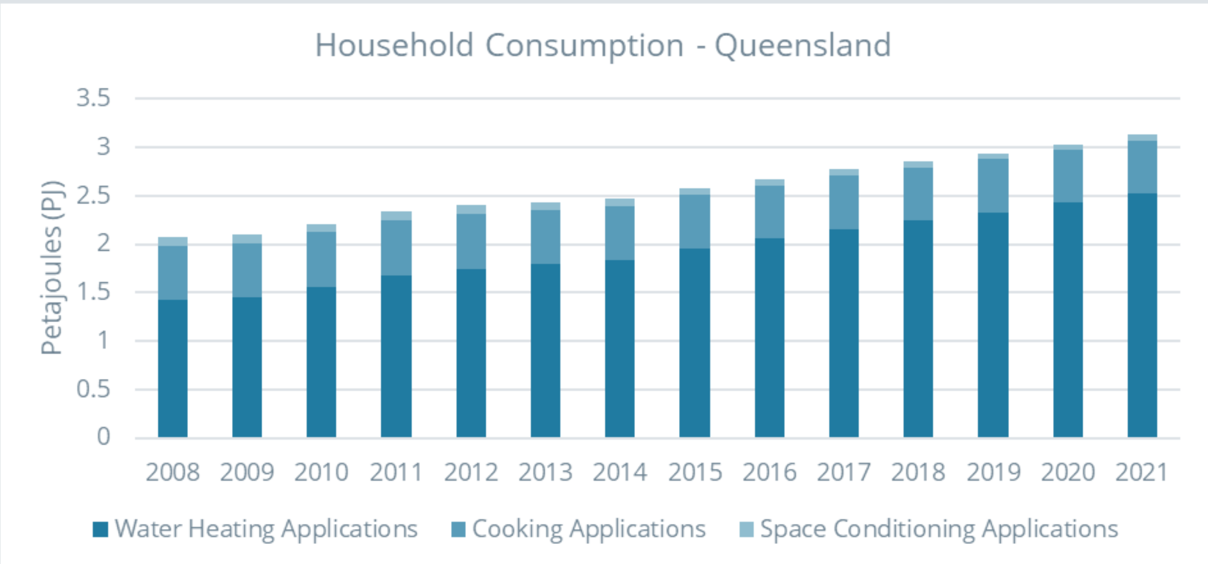
The use of LPG for cooking accounts for the second largest proportion of LPG use by households across Australia and has remained relatively constant over the period since 2008.

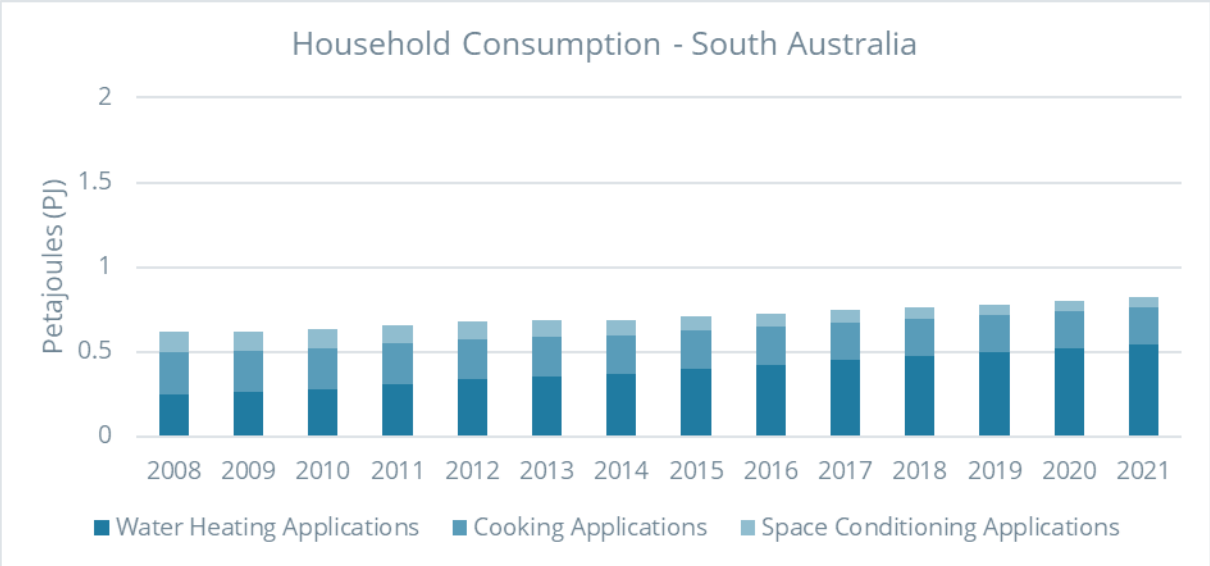
LPG consumption for space conditioning currently accounts for the smallest proportion of total household LPG consumption in all jurisdictions. The total LPG consumption for space conditioning is declining in all jurisdictions.

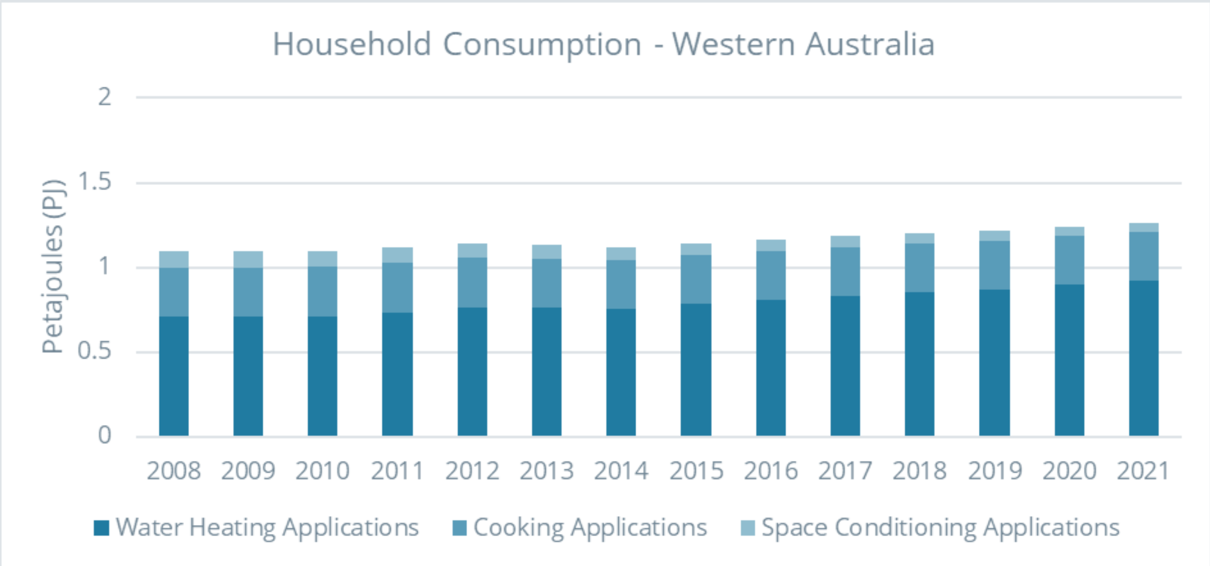
Figure 7: Household LPG consumption by State and Territory (calendar year)

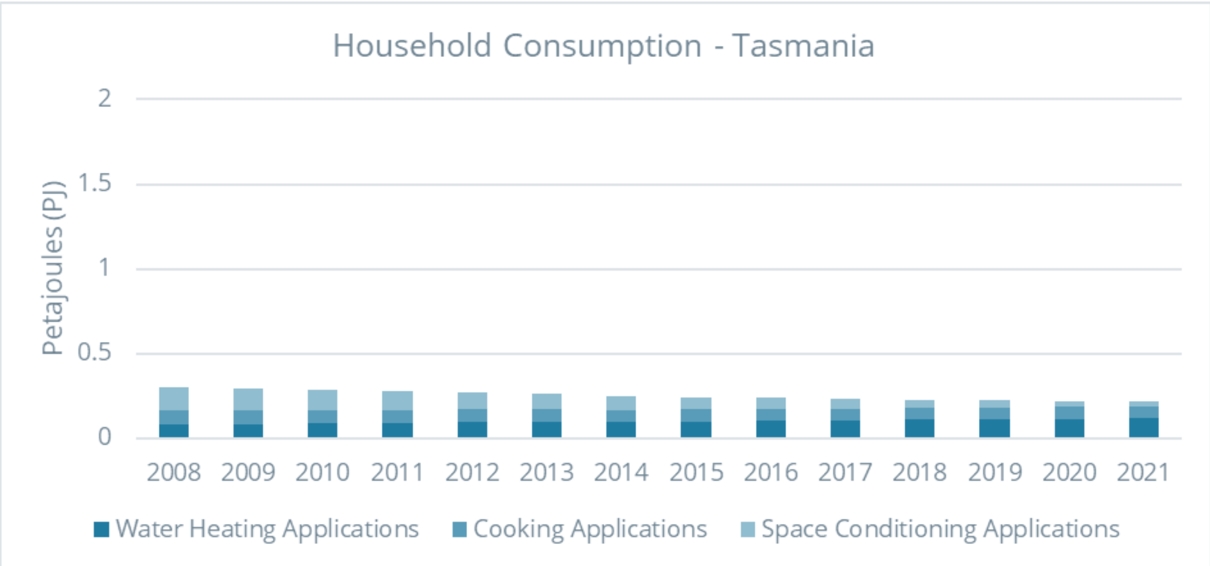


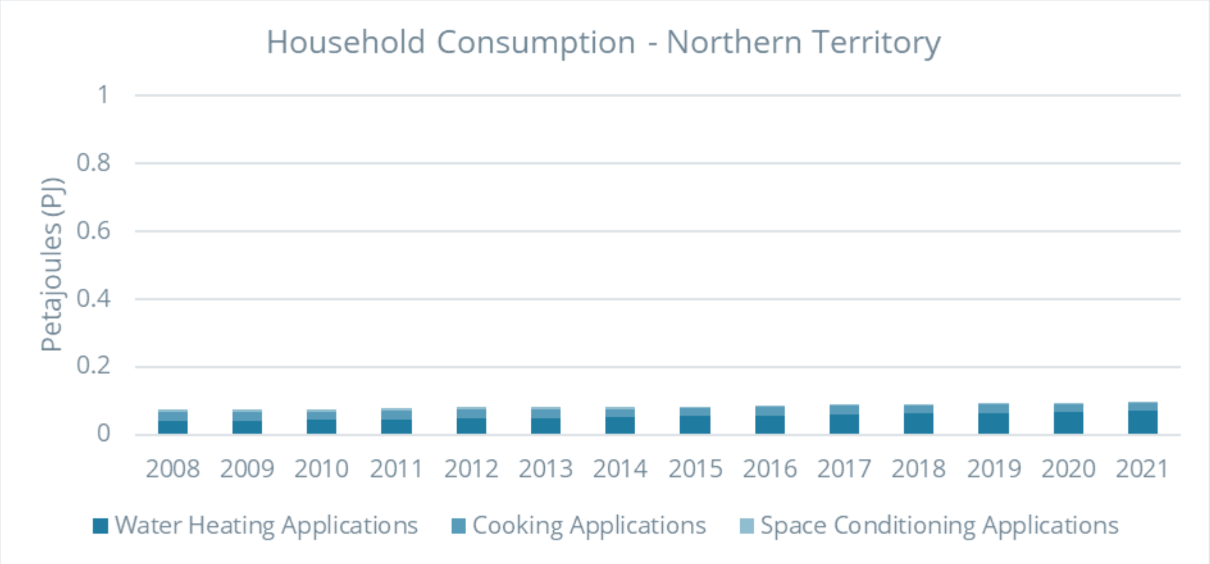





Household Consumption - South Australia
Petajoules (PJ)
2
1.5
1
0.5
0
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Water Heating Applications
Cooking Applications
Space Conditioning Applications


Household Consumption - Western Australia
Petajoules (PJ)
2
1.5
1
0.5
0
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Water Heating Applications
Cooking Applications
Space Conditioning Applications


Household Consumption - Tasmania
Petajoules (PJ)
2
1.5
1
0.5
0
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Water Heating Applications
Cooking Applications
Space Conditioning Applications



Source: Frontier Economics analysis of 2021 Residential Baseline Study data

2.3 Supply of LPG in Australia

There are multiple methods by which LPG can be produced, including via natural gas processing, crude oil refining and the treatment of renewable and waste products to create alternative, renewable sources of LPG. The vast majority of LPG production globally is tied to the production and processing of natural gas and crude oil, accounting for approximately 60% and 40% respectively of global LPG production.[7]

When extracting natural gas out of the ground, several other natural gas liquids are extracted, including butane, isobutane and propane. These liquids are separated from the unprocessed gas stream and processed into marketable LPG. A similar process is undertaken with respect to oil refining. At several points along the oil refining process LPG is produced. As a consequence, LPG supply is often a function of the production of natural gas and crude oil and is subject to fluctuations in demand for and supply of these commodities.

In the Australian context, LPG has traditionally been produced in conjunction with the refining of crude oil. However, the proportion of LPG produced from natural gas streams has steadily been increasing.[8]

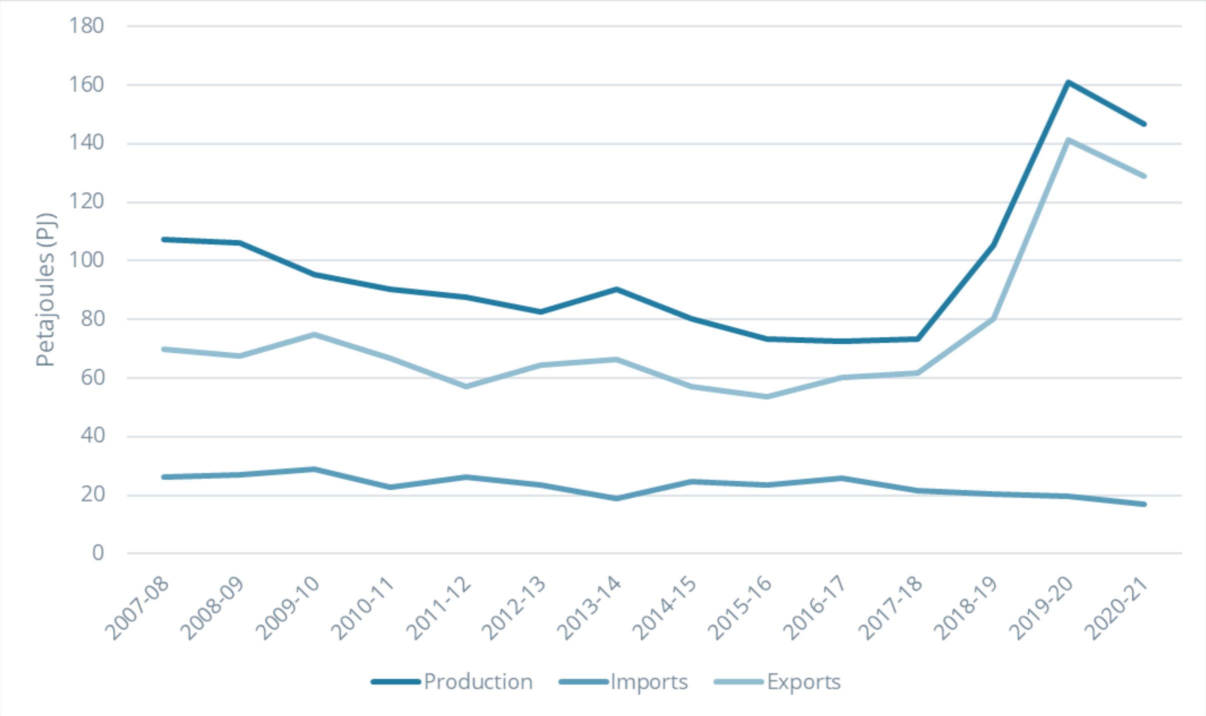
A notable feature of the supply of LPG in Australia is that despite Australia's consistent status as a net-exporter of LPG, as much as 41% of Australian domestic LPG consumption has been satisfied by imports in recent years (**Figure 8**).

As **Figure 8** shows, Australia exports a relatively high proportion of domestic production, contributing to its status as a net-exporter of LPG. Between 2000/01 and 2019/20, approximately 70% of all LPG produced domestically was exported. Exports occur from parts of Australia where LPG supply exceeds local demand, and imports occur in parts of Australia where local demand cannot be met be local supply.

7 World Liquid Petroleum Gas Association, *Where does LPG come from?* n.d.

8 Gas Energy Australia, *LPG Supply and Demand Study – 2017 Calendar Year*, 2018.

Figure 8: Australia LPG production, import and export (financial year)



Source: Frontier Economics analysis of DCCEEW Australian Energy Statistics 2021, Table J data

3 LPG and the Transition to Net Zero

To date, LPG has been a lower emitting energy source than many alternative sources of energy. As we discuss in this section, the CO2-e emissions intensity of LPG is lower than most alternatives.

Nevertheless, the emissions from the LPG sector will need to fall over time as part of a transition to net zero emissions. There are many opportunities available to the LPG sector to achieve reductions in the emissions intensity of LPG and, indeed, opportunities for the LPG sector to achieve zero emissions. This section provides an overview of the key pathways and feedstocks.

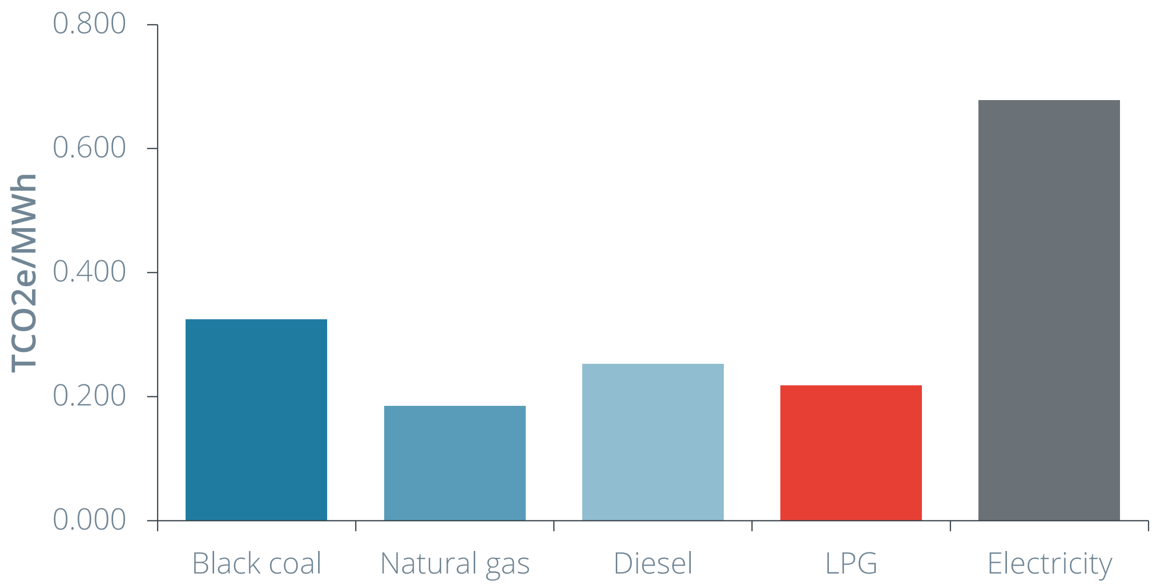
3.1 Conventional LPG has been lower-emitting than alternatives

Conventional LPG has been a relatively low carbon emitting form of energy, compared with alternative sources of energy. Depending on the customer, the alternatives to LPG might include electricity, diesel or coal (or natural gas as a long-term potential option, although it is typically not available in areas where customers use LPG).

The emissions intensity of these different forms of energy are shown in **Figure 9**. It is clear from **Figure 9** that the emissions intensity of LPG is lower than the likely alternatives for existing users of LPG, so that the emissions resulting from the use of a MWh of LPG are lower than the emissions resulting from the use of a MWh of these other forms of energy. The emissions intensity of LPG is:

- 67% of the emissions intensity of black coal,
- 86% of the emissions intensity of diesel, and
- 32% of the emissions intensity of electricity.

Figure 9: Emissions intensity



Source: Australian Government, National Greenhouse Accounts Factors, August 2021; AEMO, Carbon Dioxide Equivalent Intensity Index.

However, emissions *intensity* is not the only determinant of the emissions associated with using energy. The amount of energy used also matters. This is determined by the energy efficiency of appliances. This is particularly important when comparing LPG emissions with electricity emissions, because electrical appliances can be significantly more efficient than LPG appliances. This means that customers using electricity may use less energy in total than customers using LPG.

Given that the emissions intensity of LPG is currently less than a third of the emissions intensity of electricity, in order for the emissions from using electricity to be lower than the emissions from using LPG, it would need to be the case that, on average, electrical appliances are more than 3 times more efficient than LPG appliances.

For some customers and some uses this may be the case. For instance, for residential customers electrical heat pumps used for space heating can be 3 times more efficient than gas heating.[9] For other appliances, however, the difference in efficiency between electrical appliances and LPG appliances will be much less. For instance, an electrical panel heater used for space heating is only around 20% more efficient than gas heating.[10] For commercial and industrial customers, the relative efficiency of LPG and electricity will depend on whether heat pumps are a feasible alternative to appliances using LPG; where heat pumps are feasible, electrical appliances can be significantly more efficient.

If we assume, on average, that electrical appliances that replace LPG appliances are 2 times more efficient, this suggests that, currently, the total emissions from using LPG are 64% of the total emissions from using electricity.

9 See, for instance: GHD Advisory and ACIL Allen, *Economic and Technical Modelling of the ACT Electricity Network*, Strategic Report, EPSDD, 26 April 2022; appliances specifications.

10 See, for instance: GHD Advisory and ACIL Allen, *Economic and Technical Modelling of the ACT Electricity Network*, Strategic Report, EPSDD, 26 April 2022; appliances specifications.

In short, at existing emissions intensities for LPG and other alternative fuels, total emissions are likely lower as a result of customers using LPG.

3.2 Emissions from the LPG sector will need to fall over time

While conventional LPG may have been lower-emitting than alternatives, it is nevertheless the case that emissions from the LPG sector will need to fall over time as part of a transition to net zero emissions. Even with a relatively low emissions intensity, and relatively small total consumption compared to other forms of energy, it is hard to see that continued use of conventional LPG is consistent with achieving net zero emissions by 2050.

An important comparison for LPG emissions is electricity emissions; after all, it is likely that customers will increasingly see electricity as the best alternative to continued use of LPG.

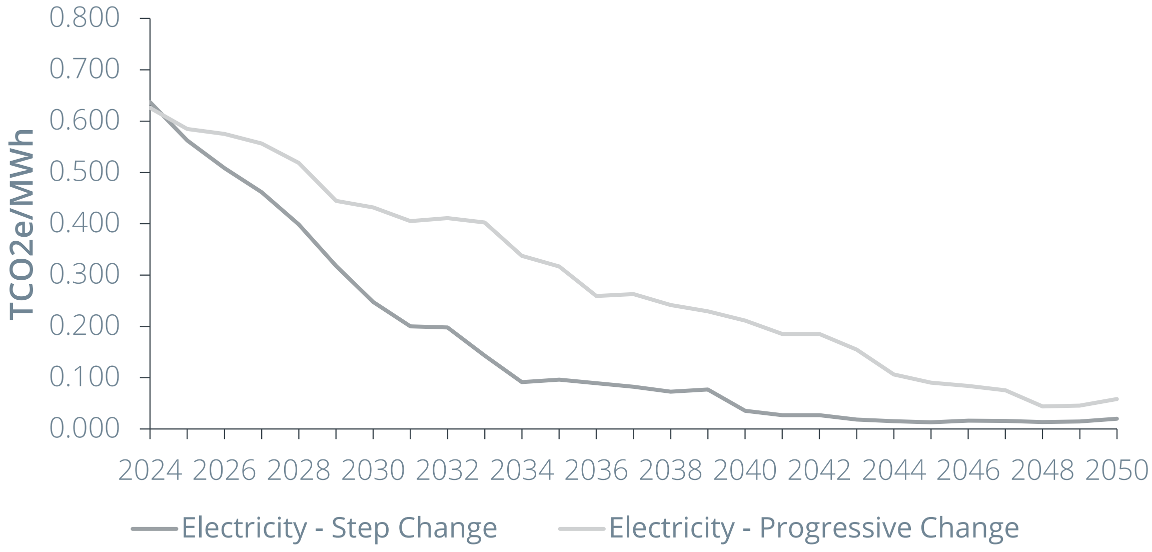
It is expected that the emissions intensity of electricity will fall significantly over coming years. This will occur as the electricity system transitions away from coal generation and gas generation to renewable generation. In order for the LPG sector to be lower-emitting, the LPG sector will also need to achieve lower emissions over time.

For electricity, AEMO forecasts these reductions in emissions intensity for electricity in the National Electricity Market (NEM) in its Integrated System Plan (ISP). The forecast emissions intensity for electricity in the NEM, from AEMO's 2022 ISP, is shown in **Figure 10**. The forecast emissions intensities are shown for two scenarios – the Step Change scenario, which has been identified by stakeholders as the most likely scenario in the long-term, and the Progressive Change scenario, which has been identified by stakeholders as likely in the short-term.

Assuming that the electricity sector does achieve these reductions in emissions intensity, the emissions intensity of electricity will be lower than the emissions intensity of conventional LPG before 2050.

Furthermore, once accounting for the relative efficiency of electrical appliances and LPG appliances, the total emissions from customers using electricity will be lower than from the use of conventional LPG sometime in the next 10 to 15 years. When this occurs depends on the rate of reduction in electricity emissions intensity and on the efficiency of the electrical appliances available to, and chosen by, customers. The relative emissions of electrical appliances and LPG appliances is considered in more detail in the case studies we have undertaken that investigate the comparative total costs to customers, and comparative carbon emissions, of remaining with LPG appliances or switching to electrical appliances. These case studies are provided in separate reports provided to GEA and AGIT.

Figure 10: Forecast emissions intensity for electricity



Source: AEMO 2022 ISP

3.3 There are alternatives to conventional LPG that have lower emissions

There are many opportunities available to the LPG sector to achieve reductions in the emissions intensity of LPG and, indeed, opportunities for the LPG sector to achieve zero emissions.

The two most likely options for reducing emissions and, ultimately, achieving zero emissions, for the LPG sector are:

- **BioLPG**, which is propane produced from renewable feedstocks such as plant and vegetable waste material. BioLPG is also sometimes also referred to as bio-propane or as renewable LPG (rLPG). BioLPG is chemically identical to conventional LPG and so can act as a 'drop-in' replacement for conventional LPG, which does not require any changes to existing transport and storage infrastructure or appliances. Emissions from BioLPG can be as much as 80% lower than conventional LPG.
- **Renewable Dimethyl Ether (rDME)**. DME is often described as synthetic LPG. It is chemically similar to propane and butane, so it behaves the same way as LPG, including in that it can be transported and stored as a liquid in pressurised cylinders and tanks. DME can be blended with LPG at up to 20% by volume in existing appliances. It can also be used as a replacement for LPG, but this would require some changes to appliances. There are options for producing rDME, which has lower emissions than DME.

These two options are discussed in more detail in the sections that follow.

3.3.1 BioLPG

There are many pathways to producing bioLPG. Each of these pathways has the potential to produce bioLPG that has lower emissions than conventional LPG, and potentially zero emissions.

The key pathways have been summarised by WLPGA as:

- **Hydrotreating** – also known as the hydrotreated vegetable oil (HVO) pathway, hydrotreating involves the conversion of vegetable oils to biodiesel, sustainable aviation fuels (SAF) or other liquid hydrocarbons. The primary feed of vegetable oil is combined with a secondary feed of hydrogen in a hydrotreating process. The process yields biodiesel as the primary product, with LPG production of 5-10% of the output regularly identified.[11] HVO has been identified as a 'first generation' replacement for conventional LPG.[12]

- **Gasification and Fischer-Tropsch** – also known as gasification with FT, this pathway involves the production of syngas and then the conversion of that syngas into liquid hydrocarbons. Syngas is a mixture of hydrogen, carbon monoxide and carbon dioxide that is produced from organic carbon through a thermochemical process at high temperature in an environment with a specific mixture of oxygen or steam. The Fischer-Tropsch process is a collection of chemical reactions that converts syngas into liquid hydrocarbons. The feedstock for this gasification with FT can be municipal solid waste, food waste, crop residues, wastewater and manure. The process would generally target biodiesel or SAF, with LPG production of 8% of the output identified.[13] Gasification with FT has been identified as a 'second generation' replacement for conventional LPG.[14]

- **Gasification and methanation** – like gasification with FT, this pathway involves the production of syngas from bioenergy feedstock and the conversion of this syngas to liquid fuels. The methanation process involves the reaction of hydrogen and carbon dioxide in syngas at high temperature and high pressure to produce water and hydrocarbons.

- **Oligomerisation** – is a process for converting methane into higher hydrocarbons, including LPG. Oligomerisation of biomethane can be used to produce bioLPG.

- **Digestion** – involves the digestion of organic matter in the absence of oxygen to produce biogas. Biogas can then be processed through an FT process to produce higher hydrocarbons, including propane and butane. A range of waste streams and agricultural products can be used.

- **Pyrolysis** –is similar to gasification in that it involves heating biomass in a controlled environment, but the temperatures for pyrolysis are lower and the main output is fast pyrolysis bio-oil (FPBO) rather than syngas. FPBO then needs to be hydrotreated to produce liquid fuels, including LPG.

- **Fermentation** – involves using microorganisms for fermentation of sugars to produce bio-based isobutene, which can be a component of LPG.

- **Power-to-X** – involves producing hydrogen from electrolysis powered by renewable energy, and then synthesising that hydrogen with carbon dioxide (for instance, using at FT process) to produce liquid hydrocarbons, including LPG.

11 Worley, *Pathway to 70/100% renewable LPG*, Report for LPG Association of NZ, 26 March 2021, page 24 and NNFCC, *Biopropane: Feedstocks, Feasibility and our Future Pathway*, Prepared for Liquid Gas UK, September 2019, page 31.

12 Worley, *Pathway to 70/100% renewable LPG*, Report for LPG Association of NZ, 26 March 2021.

13 Worley, *Pathway to 70/100% renewable LPG*, Report for LPG Association of NZ, 26 March 2021, page 27.

14 Worley, *Pathway to 70/100% renewable LPG*, Report for LPG Association of NZ, 26 March 2021.

BioLPG is already enjoying commercial use across a range of applications. **Box 2** details some examples of these uses.

Box 1: Bio-LPG consumption - Europe

Europe is by far the largest consumer of HVO in the world presently and it is forecast that demand for HVO will only continue to grow throughout the 2020s. A high proportion of demand is driven by the transport sector, with bio-LPG being made available at petrol stations and bioLPG vehicles operating in a number of jurisdictions.

Bio-LPG is also increasingly being made available for purchase in cylinders for a range of off-grid leisure activities as well as industrial heating. In partnership with SHV Energy, Circle K in Sweden since mid-2020 has provided 100% bioLPG cylinders across all its stores.

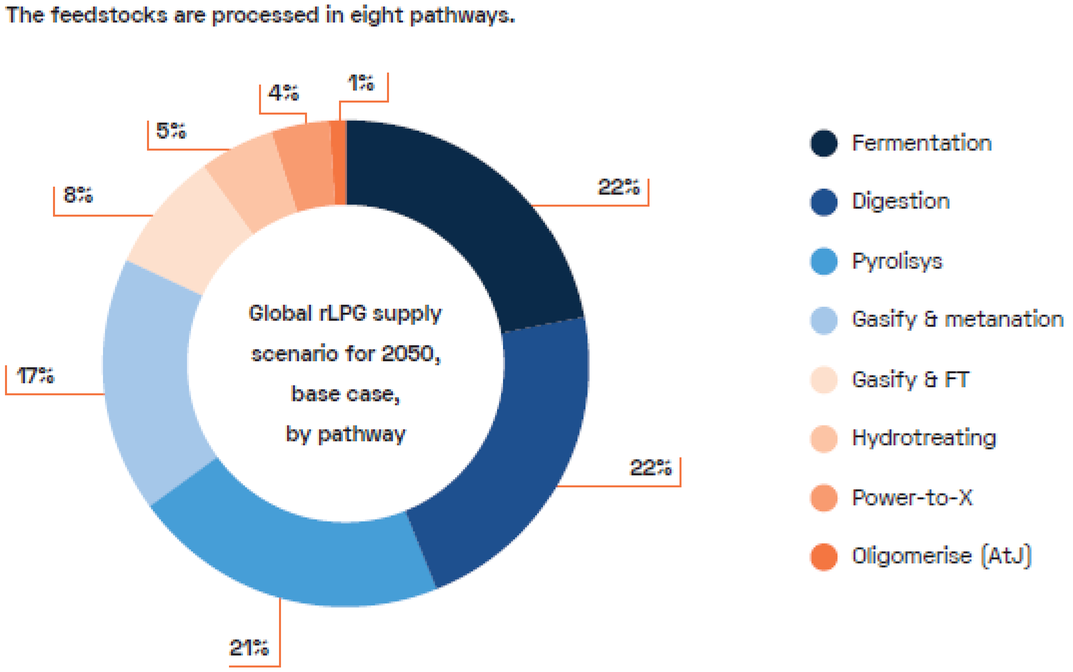
Rural and regional homes and hospitality venues across the UK and Ireland are also increasingly adopting bio-LPG for use in their kitchens as well as for water heating and space conditioning functions. Examples include Montalto Estate and BrookLodge & Macreddin Village in Ireland.

Bio-LPG has also emerged as an important energy source in the industrial sector. For example, La-Roche-Posay in France became the first industrial site in France to use bio-LPG in 2018. Since 2019, the facility now emits no greenhouse gas emissions, with the switch to bioLPG representing the last step towards carbon neutrality.

Source: Frontier Economics

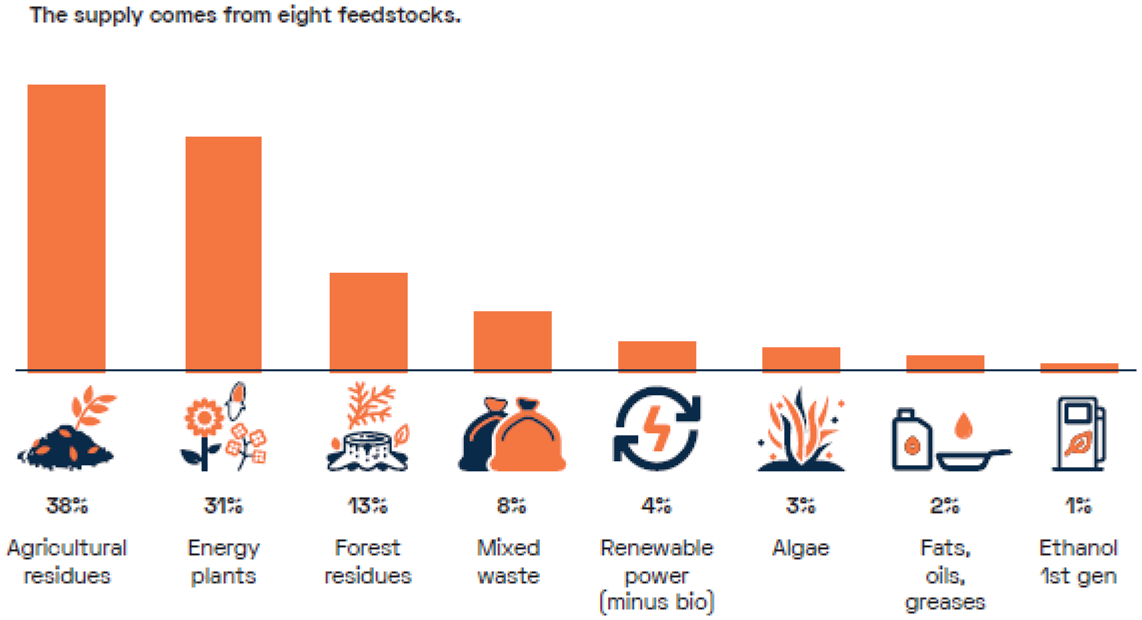
The WLPGA has proposed a global pathway to rLPG satisfying up to 50% of global demand for LPG in 2050 (excluding demand for LPG as a feedstock for the petrochemical sector) that consists of the mix of pathways as shown in **Figure 11**. The mix of feedstocks required for these pathways is shown in **Figure 12**.

Figure 11: Overview of pathways to rLPG



Source: WLPGA, Global rLPG Pathways to 2050: A Scenario of Future Supply.

Figure 12: Overview of feedstocks for rLPG



Source: WLPGA, Global rLPG Pathways to 2050: A Scenario of Future Supply.

3.3.2 Renewable DME

RDME is a methanol derived, single molecule that can be produced from a wide range of bioenergy and renewable feedstocks.

RDME is chemically similar to propane and butane and is easily transported as liquid in pressurised containers like conventional LPG. RDME can be blended with conventional LPG or bioLPG at up to 20 percent for domestic heating and cooking applications with no modifications required.[15]

RDME can be produced via numerous processes depending on the feedstock. Methods include:

- Gasification and catalytic synthesis. DME is produced from syngas through two steps: methanol synthesis from syngas via hydrogenation and the water-gas shift, followed by the dehydration of methanol to produce DME. RDME is produced when the syngas is produced from bioenergy feedstocks.
- Electrolysis and catalytic synthesis. RDME is produced using a similar process to gasification and catalytic synthesis, except methanol is produced from carbon dioxide and hydrogen from electrolysis powered by renewable energy.

Each of these pathways has the potential to produce rDME that has lower emissions than conventional LPG, and potentially zero emissions.

RDME is already commercially available in the United States as discussed in **Box 2**.

Box 2: RDME in the United States

A world first project, from mid-2021 Oberon Fuels began producing rDME in California. RDME is now commercially available for consumption in the United States, with retailers such as Suburban Propane making rDME available to consumers in certain areas in 2022.

Source: Frontier Economics

3.3.3 Pathways to replacing conventional LPG

To date, the LPG sector globally has taken the first steps in transitioning away from conventional LPG towards lower emissions or zero emissions alternatives.

BioLPG is produced and blended with conventional LPG in Europe, though in small volumes as a new sector. This has primarily occurred as a result of support for biodiesel and SAF, with bioLPG being produced alongside these products through the HVO process.

15 Worley, *Pathway to 70/100% renewable LPG*, 2021; SHV Energy and International DME Association, *Renewable DME Factsheet,* n.d.

With demand for biodiesel and SAF expected to grow significantly in coming decades, and other pathways for the production of bioLPG and rDME being investigated and developed, there is opportunity for significant growth in bioLPG and rDME globally, and in Australia.

In order for the LPG sector to continue to meet the needs of its customers as economies transition to net zero, it will be necessary that the pathways for the production of bioLPG and rDME can deliver the emissions reductions required to meet a net zero target at a cost that is competitive with alternative pathways for decarbonisation, such as electrification. We consider the emissions reductions potential, and the cost implications, of a possible pathway for the LPG sector in Australia in Section 4.

4 Traditional Demand Forecast and Transition Pathways

In developing a transition path for LPG to achieve zero emissions, an important starting point is considering likely demand for LPG until 2050. Given the significant declines in LPG for the autogas market, our forecast of demand for LPG focuses on traditional demand.

As discussed in Section 2.2, traditional demand for LPG occurs across a range of sectors in the Australian economy. The following sections set out the forecasts for traditional demand in Australia up to 2050 that we use in developing a transition path. The following sections also describe a transition path for the LPG industry to meet this demand with new low emissions and renewable alternatives to conventional LPG.

4.1 Forecasting future traditional demand

We forecast future demand for LPG by extrapolating simple linear trends observed in the historical data. This provides a forecast of LPG consumption for each State and Territory (excluding the Australian Capital Territory). We use the same approach for forecasting demand for each jurisdiction, with the exception of the period over which we determine the historical linear trend:

- In most instances, we calculate the historical linear trend based on the full time series of data from 2008 to 2021 to determine the trend.
- However, for each of South Australia, Tasmania and the Northern Territory there appears to be structural breaks in the historical data. For these jurisdictions we use the data from 2018 to 2021 to determine the trend.

We recognise that the use of this simple trend extrapolation approach to demand forecasting may not capture all of the key drivers of future demand for LPG. There are plausible scenarios in which future demand for LPG could be significantly different from our forecasts. However, the transition path that we discuss is not overly sensitive to future demand for LPG, and the alternatives to conventional LPG that we have identified as part of that transition path can remain relevant for higher or lower future demand for LPG.

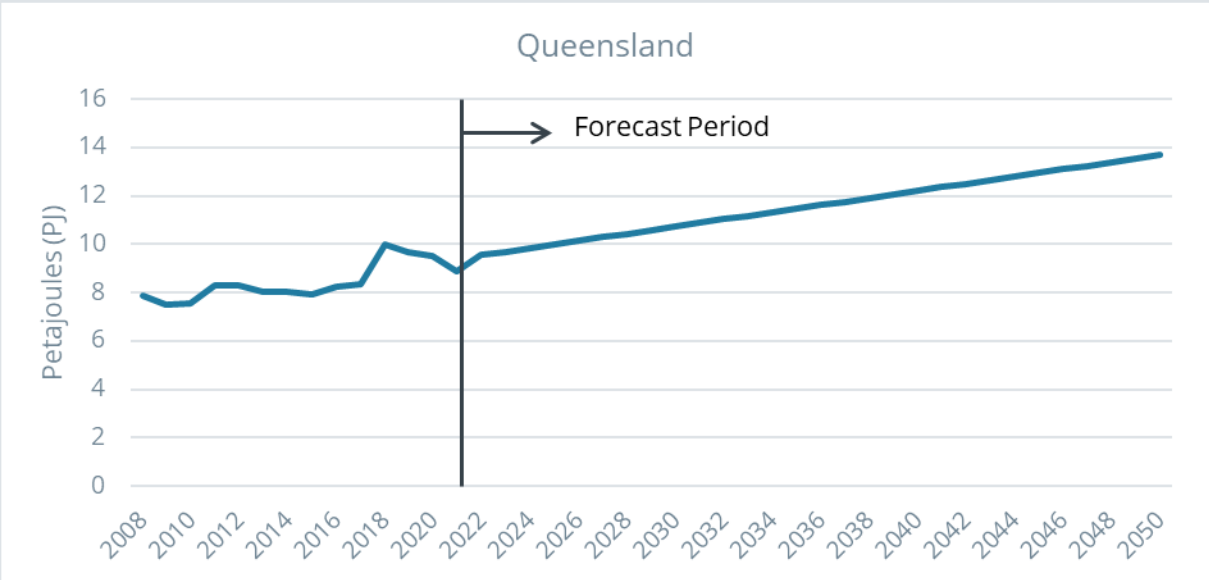
For the early stages of the transition path, this is because bioLPG is produced as an output of processes primarily targeting biodiesel and SAF. Given the small size of the LPG market in Australia relative to the markets for biodiesel and SAF (which may include targeting export markets) the level of demand for bioLPG is unlikely to be a constraint.

For the latter stages of the transition path, this is also because the inputs into LPG from power-to-liquids or rDME from renewable energy will be small relative to the scale of these sectors in Australia. For instance, amount of renewable generation that would be required to produce rDME from LPG from power-to-liquids will be a small fraction of the amount of renewable generation that will be needed to convert the electricity system to renewable sources and to either replace the natural gas system with hydrogen or electrification. For context, Australian LPG demand is currently less than 5 percent of Australian natural gas demand and less than

5 percent of Australian electricity demand, and forecast to fall, while gas demand (excluding electrification) and electricity demand increase.

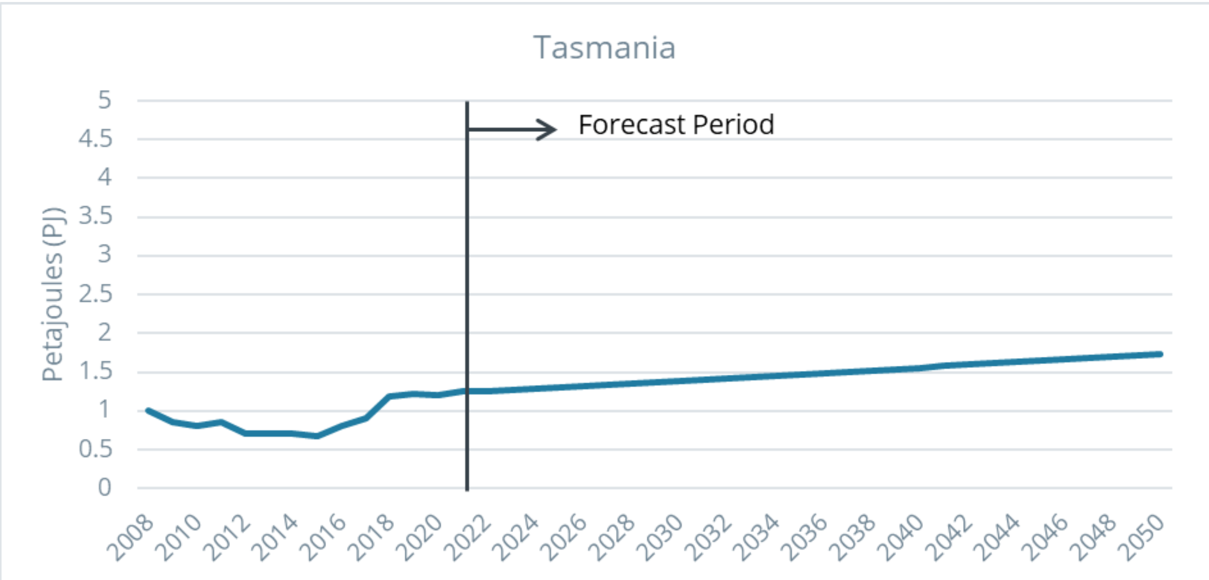
A feature of the resulting forecasts is the heterogeneity present between states. Traditional demand for LPG is forecast to increase in Queensland, Tasmania and the Northern Territory, based on the observed historical trends in these jurisdictions (see **Figure 13** through **Figure 15**).

Figure 13: Forecast traditional demand for LPG in Queensland (calendar year)



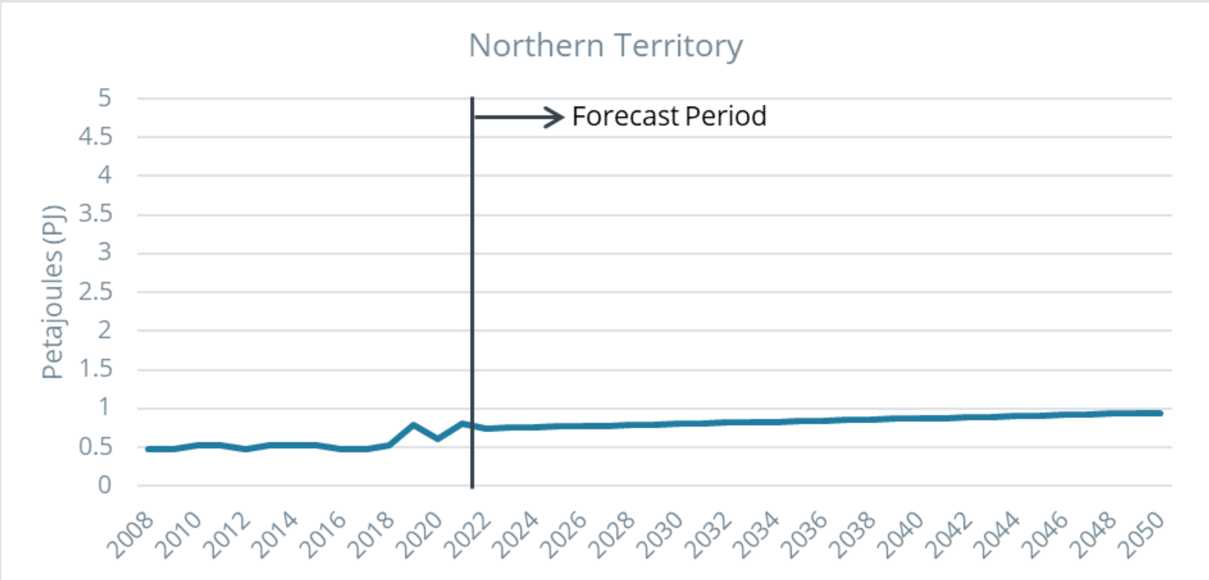
Source: Frontier Economics analysis of Gas Energy Australia data

Figure 14: Forecast traditional demand for LPG in Tasmania (calendar year)



Source: Frontier Economics analysis of Gas Energy Australia data

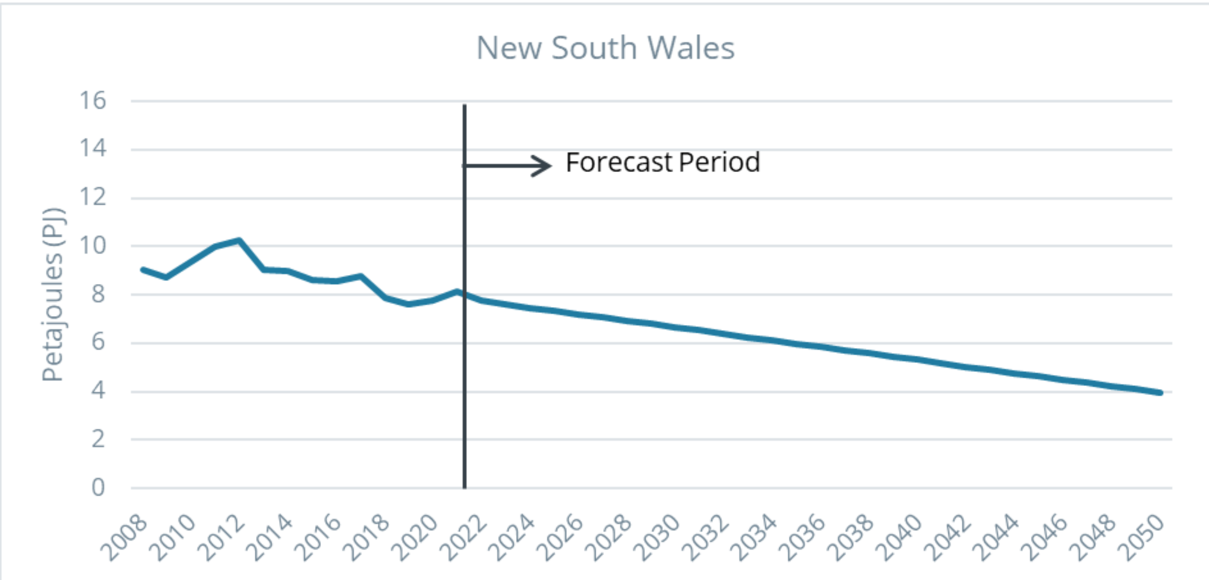
Figure 15: Forecast traditional demand for LPG the Northern Territory (calendar year)



Source: Frontier Economics analysis of Gas Energy Australia data

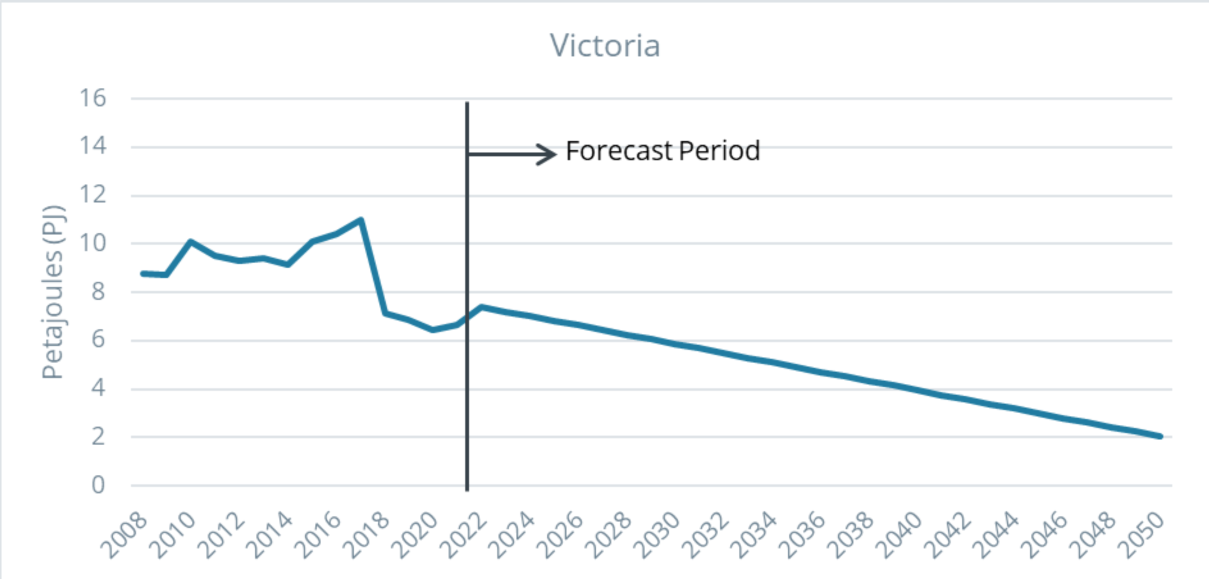
Conversely, traditional demand in each of New South Wales, Victoria, Western Australia and South Australia is forecast to decline over the modelling period. South Australia in particular is forecast to experience a material decline in traditional LPG demand, with total traditional LPG consumption forecast to be ~0.3PJ in 2050 (see **Figure 16** through **Figure 19**).

Figure 16: Forecast traditional demand for LPG in New South Wales (calendar year)



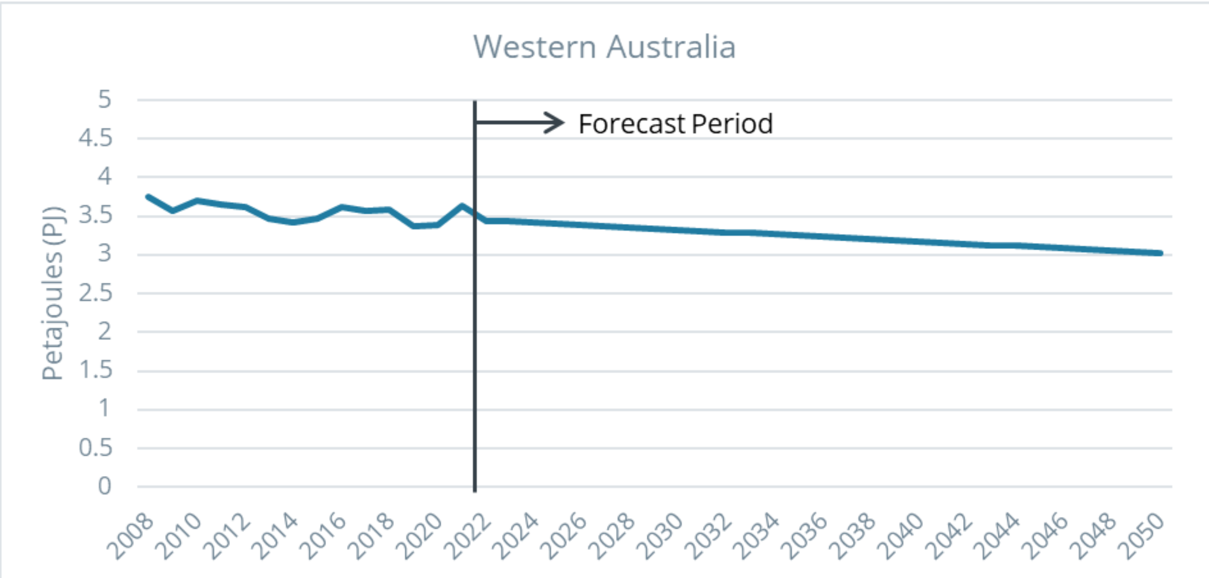
Source: Frontier Economics analysis of Gas Energy Australia data

Figure 17: Forecast traditional demand for LPG in Victoria (calendar year)



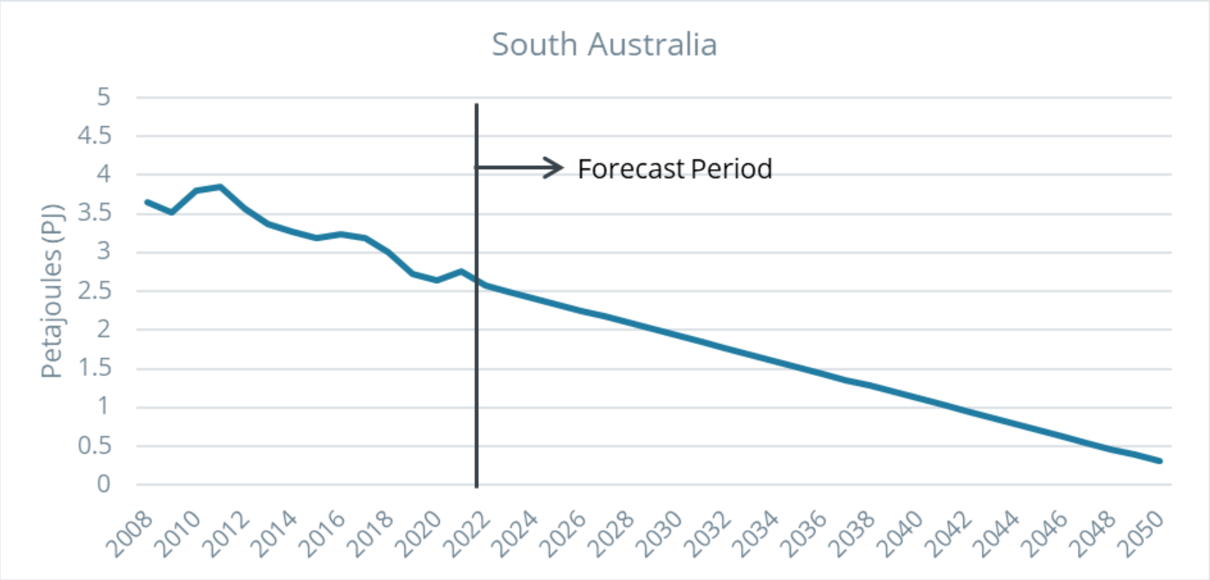
Source: Frontier Economics analysis of Gas Energy Australia data

Figure 18: Forecast traditional demand for LPG in Western Australia (calendar year)



Source: Frontier Economics analysis of Gas Energy Australia data

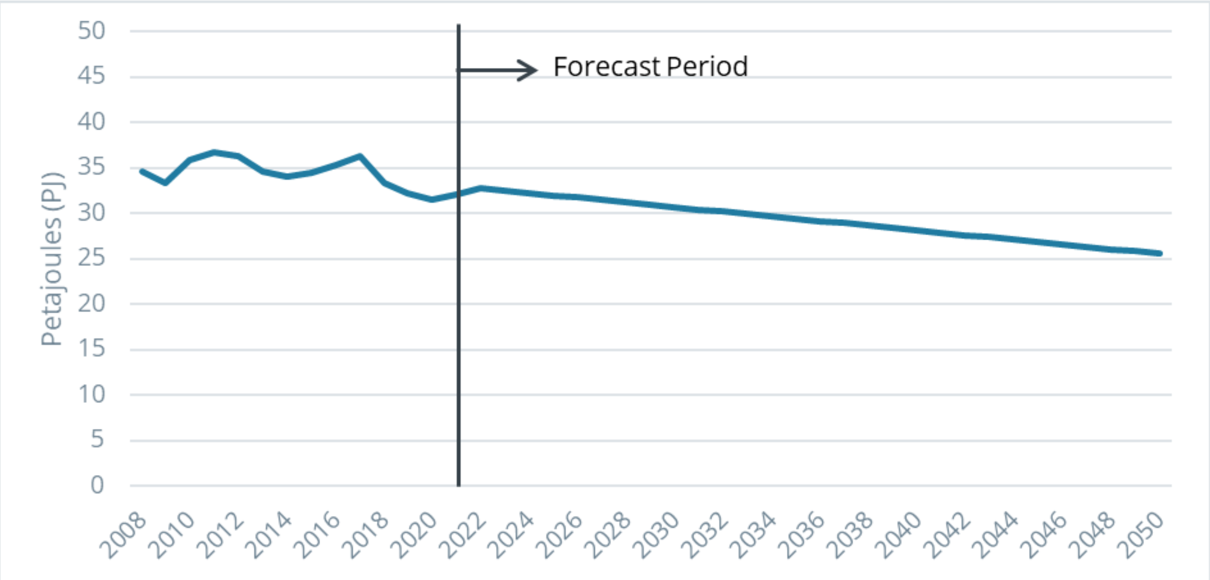
Figure 19: Forecast traditional demand for LPG in South Australia (calendar year)



Source: Frontier Economics analysis of Gas Energy Australia data

Summing the forecasts for each jurisdiction provides a forecast for Australia as a whole, which suggests that traditional demand for LPG in Australia will decline slightly over the modelling period, falling from current level of ~32PJ to ~25.5PJ by 2050 (see **Figure 20**).

Figure 20: Forecast traditional demand for LPG in Australia up (calendar year)



Source: Frontier Economics analysis of Gas Energy Australia data

4.2 Potential LPG transition in Australia

As discussed in Section 3.3 there are many pathways to producing bioLPG and renewable LPG. Each of these pathways has the potential to produce an alternative to LPG that has lower emissions than conventional LPG, and potentially zero emissions.

This gives rise to many potential technological pathways for the LPG sector to achieve reduced emissions and zero emissions. It is, of course, impossible to be sure of what the future for the LPG sector during the transition to net zero will be, but it is possible to develop credible pathways for the LPG sector in Australia to achieve reduced emissions and zero emissions. We present one such credible pathway below, consisting of:

- BioLPG produced as a by-product of renewable diesel or SAF through the hydrotreated vegetable oil (HVO) process
- BioLPG produced as by-product of renewable diesel or SAF through gasification with the Fischer-Tropsch process
- RDME produced from biomass blended
- RDME produced from renewable energy blended
- LPG produced through a Power-to-Liquids pathway.

This pathway consists of technologies at various states of technological and commercial readiness, as discussed in more detail in the sections that follow. The earlier steps on the pathway – bioLPG produced through HVO of the FT process – are more advanced technologically and commercially, but deliver less reduction in emissions, at least based on current supply chains for these processes. The later steps on the pathway – particularly rDME produced from renewable energy and LPG from Power-to-Liquids – are less well developed but offer the potential to achieve zero emissions. As discussed in Section 3.3, there are many other technologies for decarbonising LPG. If some of the technologies in the pathway that we present do not emerge as commercial options in Australia, there are other technologies that may do so. And, while this pathway ultimately delivers zero emissions, there are also other pathways that would deliver substantial reductions in emissions, which could be consistent with net zero emissions with some offsets.

In the section below we discuss each the role of each of these technologies in the pathway we have developed.

4.2.1 BioLPG produced through the hydrotreated vegetable oil (HVO) process

The HVO process is currently producing bioLPG at commercial scale, and HVO for the production of biodiesel is well established in Europe, as discussed in **Box 3**.

As discussed in Section 3.3, there are a number of projects operating globally that produce biodiesel and/or SAF through the HVO process, which also produce bioLPG as a by-product.

The readiness level of the HVO process for producing biodiesel and/or SAF has been rated as follows:[16]

16 European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

- On the Technology Readiness Level, HVO has been rated as **TRL 9**, which is the highest rating and corresponds to an actual system proven in operational environments.
- On the Commercial Readiness Level, HVO has been rated as **CRL 6**, which is the highest rating and corresponds to the 'bankable' grade asset class. For this asset class, market and technology risks do not drive investment decisions.

Box 3: European HVO production

As of 2021, pure HVO is available in nine European countries: Belgium, Denmark, Finland, Estonia, Latvia, Lithuania, the Netherlands, Norway and Sweden. For off-road purposes it is also available in Germany, the UK and Switzerland.

In 2019, approximately 1.9 million tonnes of HVO was consumed across Europe where the biggest consumers were France, Norway, Spain and Sweden.

Standalone HVO production capacity is presently around 3.5 million tonnes across Europe, with new production plants and capacities proposed and forecast, this figure is expected to rise. The Netherlands currently has the largest HVO production plant (Neste, Rotterdam) with new production plants also proposed in the coming years in France, Italy, Sweden and Finland.

Co-processed HVO is also prevalent across the continent with a current production capacity of around 1.8 million tonnes (the majority of which is concentrated in Spain).

In Australia, it would be expected that bioLPG from the HVO process would come as a by-product of production of biodiesel and/or SAF, as is the case globally. Production and use of biodiesel and SAF are likely to increase as part of the transition to net zero as transport industries seek to lower their emissions.

There are a number of sizeable biodiesel and SAF projects at some stage of planning in Australia, including:

- **Sherdar Australia Bio Refinery**: Sherdar Australia is currently proposing to develop Australia's first biodiesel refinery and storage plant. There is currently no location for the project, however the proposal would cost $600 million, and the site would be able to produce 500,000 tonnes per year of biodiesel and SAF upon completion. Proposed feedstocks for production at the site include animal fats, seed oil and waste greases.[17]
- **BP renewable fuel and green hydrogen project (WA)**: BP is currently proposing to establish a renewable fuel and green hydrogen site in the Kwinana industrial site in Western Australia. The project would involve repurposing a fuel import site to produce 8,000-10,000 barrels of biodiesel and SAF per day from products such as waste oil, tallow and used cooking oil.[18]

17 Brelsford, *Plans launched for Australia's first renewable diesel, storage complex,* Oil & Gas Journal, 2021.

18 Lewis, *BP targeting renewable fuels and green hydrogen future for former Australian refinery*, Upstream Energy Explained, 2022.

- **Oceania Biofuels Project, Gladstone QLD**: Gladstone, Queensland was selected as the site in April 2022 for a $500 million biodiesel and SAF refinery. The project proposes to use locally sourced tallow, canola and used cooking oil to produce 350 million litres of SAF and biodiesel per year. Construction is planned to begin in 2023 and operations by 2025 [19].

A key consideration for the development of bioLPG production in Australia is the availability of viable and sustainable feedstocks. Australia has a significant bioenergy resource potential however there is presently a lack of clarity and data pertaining to the extent and sustainability of Australia's feedstock resources.[20]

BioLPG produced from HVO can be produced with materially lower emissions than conventional LPG. We have assumed that emissions from bioLPG produced from HVO are initially 69% lower than those from conventional LPG, increasing to 85% lower than those from conventional LPG by 2050.[21] These assumed emissions reductions are based on estimates of emissions reductions from production of biodiesel from HVO. Most of the remaining emissions are from the production and conditioning of feedstock for HVO plant. It can be expected that the emissions intensity of these processes will also fall over time as part of a broader transition of the economy to net zero emissions.

The transition pathway that we have developed assumes that bioLPG will be available (at a rate of 9% of the total product) from 3 HVO plant developed in Australia over the period 2025 to 2030. We have assumed that each of these 3 HVO plants are of the average size of the three projects discussed above: the Sherdar Australia Bio Refinery, the BP project at Kwinana and the Oceania Biofuels Project.

4.2.2 BioLPG produced through gasification with the Fischer-Tropsch process

Both gasification and FT processes are well-established commercial processes when using fossil fuels such as coal and natural gas. However, gasification from biomass is much less developed. Most facilities that gasify biomass use the resulting syngas for heat and power because of the high syngas purity required in FT processes.[22]

Gasification with FT opens up opportunities to use a broader range of feedstocks, with the process in use or proposed for municipal solid waste streams and for forestry products.

The gasification and FT process for the production of biofuels is at the early stage of commercial trials. There are several plants operating, or in planning, globally, including:

- In May 2022, Fulcrum Bioenergy started operations at the Sierra BioFuels Plant, which they say is the world's first commercial-scale plant converting landfill waste into transportation fuels. Fulcrum Energy claim on 80% reduction in carbon emissions compared to production of conventional jet fuel. Fulcrum Energy is also developing a number of other larger plants, two in the United States and one in England.

19 Oceania Biofuels, *Our Australian Project*, 2022, https://oceaniabiofuels.com.au/port-of-gladstone/

20 Australian Renewable Energy Agency, *Australia's Bioenergy Roadmap*, 2021.

21 Based on emissions estimates from European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

22 NNFCC, *Biopropane: Feedstocks, Feasibility and our Future Pathway*, Prepared for Liquid Gas UK, September 2019, page 33.

- BayouFuels is planning a plant in the United States that will process forestry products through a gasification and FT process to develop SAF.

The readiness level of the gasification with FT process for producing biodiesel and/or SAF has been rated as follows:[23]

- On the Technology Readiness Level, gasification with FT has been rated as **TRL 8**, which corresponds to the system being complete and qualified.
- On the Commercial Readiness Level, gasification with FT has been rated as **CRL 2**, which corresponds to small scale commercial trials, first of a kind projects funded by equity and government project support, with the commercial proposition backed by evidence of verifiable data typically not in the public domain.

In Australia, it would be expected that bioLPG from the gasification and FT process would come as a by-product of production of biodiesel and/or SAF, as is the case globally. Production and use of biodiesel and SAF are likely to increase as part of the broader transition to net zero emissions as transport industries seek to lower their emissions.

BioLPG produced from gasification and FT can be produced with materially lower emissions than conventional LPG. We have assumed that emissions from bioLPG produced from HVO are 85% lower than those from conventional LPG by 2050.[24] These assumed emissions reductions are based on estimates of emissions reductions from production of biodiesel from gasification and FT. Most of the remaining emissions are from the transport of feedstock to the gasification plant. It can be expected that the emissions intensity of these processes will also fall over time as part of a transition to net zero emissions.

The transition pathway that we have developed assumes that bioLPG will be from 3 gasification with FT plant developed in Australia over the period 2030 to 2040. We have assumed that each of these 3 HVO plant are of the same size as the HVO plant we assume will be developed between 2025 and 2030.

4.2.3 RDME produced from biomass

RDME from biomass is at the early stages of commercial development. There are several plants operating, or in planning, globally, including:

- In June 2021, Oberon Fuels began production of the first RDME in the United States. The Oberon Fuels plant in California converted waste methanol into RDME. Suburban Propane is now selling a mix of propane and rDME to customers in California.
- Oberon Fuels has also developed a Modular Conversion System. Using feedstocks including animal and food waste, wastewater treatment, landfills and natural gas, the system converts methane to partially renewable DME. The plants are designed to be modular and established in remote and industrial regions to access CO2 and biogas waste. Standard plants are sized to produce 2.7-9.0 ktpa of DME (from 15,000 to 25,000 cows), which is 1.7-5.6 ktpa renewable LPG equivalent.

23 European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

24 Based on emissions estimates from European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

- In the United Kingdom, Dimeta has announced the location of its first commercial rDME plant, at Teesworks. The plant will produce rDME from non-recyclable waste. Dimeta plans to produce 50,000 tonnes/year of rDME.

The readiness level of the rDME from biomass process has been rated as follows:[25]

- On the Technology Readiness Level, rDME from biomass has been rated as **TRL 8**, which corresponds to the system being complete and qualified.
- On the Commercial Readiness Level, rDME from biomass has been rated as **CRL 2**, which corresponds to small scale commercial trials, first of a kind projects funded by equity and government project support, with the commercial proposition backed by evidence of verifiable data typically not in the public domain.

RDME from biomass can be produced with materially lower emissions than conventional LPG. We have assumed that emissions from rDME from biomass are 85% lower than those from conventional LPG by 2050.[26] Most of the remaining emissions are from the transport of feedstock to the plant. It can be expected that the emissions intensity of these processes will also fall over time as part of a broader transition to net zero emissions.

The transition pathway that we have developed assumes that rDME from biomass will be blended with LPG at a rate of 10%, starting in 2030 and ending in 2045 (at which point we assume that rDME from green hydrogen replaces rDME from biomass).

4.2.4 RDME blended from green hydrogen

RDME from green hydrogen is less advanced than RDME from biomass, although the component parts are operating elsewhere. For instance, there are power to methanol plants in Iceland and Switzerland, and conventional DME is currently produced from methanol.

In Australia, ABEL Energy's[27] Bell Bay Powerfuels Project plans to produce green hydrogen, methanol and 100% rDME. The project aims to use some of the 70,000 tonnes per year of green methanol to produce rDME for blending with conventional LPG, with the ultimate aim to supply renewable DME/LPG blends to households and industry.[28]

The readiness level of the rDME from green hydrogen has been rated as follows:[29]

- On the Technology Readiness Level, rDME from green hydrogen has been rated as **TRL 9**, which is the highest rating and corresponds to an actual system proven in operational environments.
- On the Commercial Readiness Level, rDME from green hydrogen has been rated as **CRL 3**, which corresponds to commercial scale up, occurring driven by specific policy and emerging debt finance.

25 European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

26 Based on emissions estimates from European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

27 With support from the Tasmanian Government.

28 Gas Energy Australia, *GEA Response to the Tasmanian Future Gas Strategy – Discussion Paper*, 2022; ABEL Energy, *Bell Bay Powerfuels Project*, n.d. https://www.abelenergy.com.au/our-projects

29 European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

RDME from green hydrogen can be produced with materially lower emissions than conventional LPG. We have assumed that emissions from rDME from biomass are 98% lower than those from conventional LPG by 2050.[30]

The transition pathway that we have developed assumes that rDME from green hydrogen will be blended with LPG at a rate of 10%, starting in 2035 and increasing to 20% starting in 2045.

4.2.5 LPG produced through a Power-to-Liquids pathway

Power-to-Liquids is currently at an earlier stage of development than the other technologies in the pathway that we have developed.

The readiness level of the LPG from power-to-liquids process has been rated as follows:[31]

- On the Technology Readiness Level, LPG from power-to-liquids has been rated as **TRL 6**, which corresponds to prototype system verified, with the prototype demonstrated in an operational environment.
- On the Commercial Readiness Level, LPG from power-to-liquids has been rated as **CRL 1**, which corresponds to hypothetical commercial proposition, with commerciality untested or unproven.

LPG from Power-to-Liquids can be produced at zero emissions.[32]

The transition pathway that we have developed assumes that LPG from Power-to-Liquids will become available in 2040, and by 2050 will form 80% of the product provided by the LPG sector (with the remaining 20% being rDME from green hydrogen).

Of course it is these latter stages of the pathway that are least clear. It may be that one or the other of rDME from green hydrogen or LPG produced through a Power-to-Liquids pathway are, ultimately, not commercially available in Australia. If this is the case, there are a number of other technological options that can deliver a pathway to zero emissions, or net zero emissions, for the LPG sector.

4.3 Outcomes from the assumed transition pathway

Under the assumed transition pathway, bioLPG from HVO becomes available from 2025, bio-LPG from gasification with FT and rDME from biomass from 2030, rDME from green hydrogen from 2035 LPG from Power-to-Liquids from 2040. **Figure 21** illustrates the respective contributions of each energy source to meeting demand under this scenario.

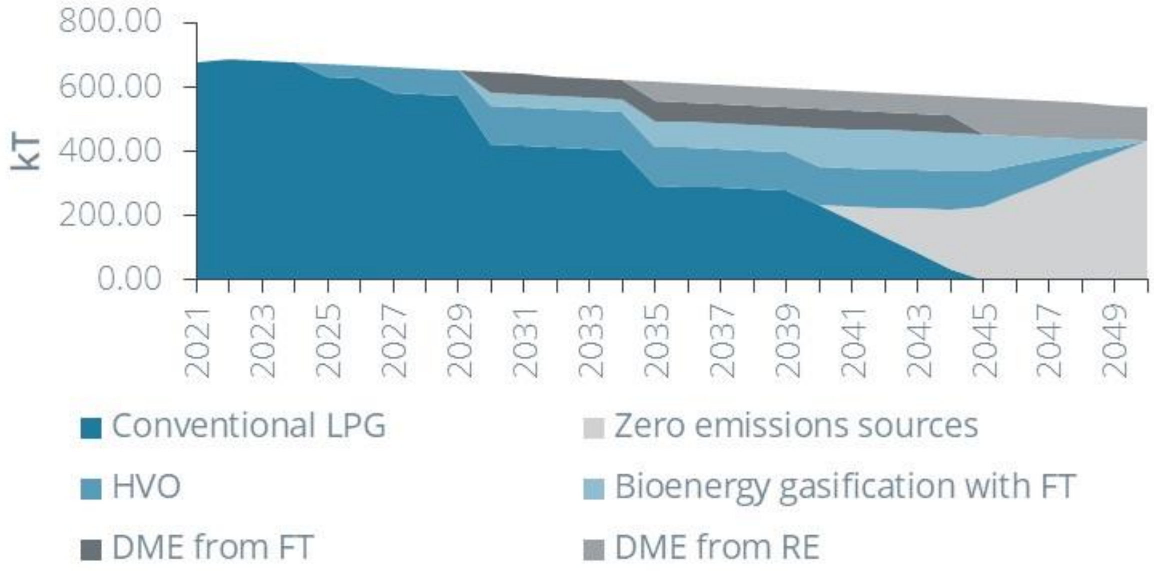
As we can see from **Figure 21**, the supply of conventional LPG is steadily phased out in favour of these low-emission and zero-emission alternatives. Conventional LPG supply is phased out entirely by 2045. By 2050, zero emissions sources are the only sources of supply still in the market.

30 Based on emissions estimates from European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

31 European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

32 Based on emissions estimates from European Commission JRC Science for Policy Report, *JEC Well-to-Tank report v5*, 2020.

Figure 21: LPG transition pathway



Source: Frontier Economics

The transition from conventional LPG to alternatives has significant implications for emissions. As seen in **Figure 22**, beginning from 2025 the emissions intensity of LPG begins to fall, with ongoing further ongoing reductions achieved until zero emissions in 2050. The reductions in total emissions are slightly more pronounced, as a result of the forecast reduction in total demand for LPG in Australia.

Figure 22: Emissions profile from LPG transition pathway

Source: Frontier Economics

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