Australia's ENERGY FUTURE: 55 BY 35

Electrification & Heat

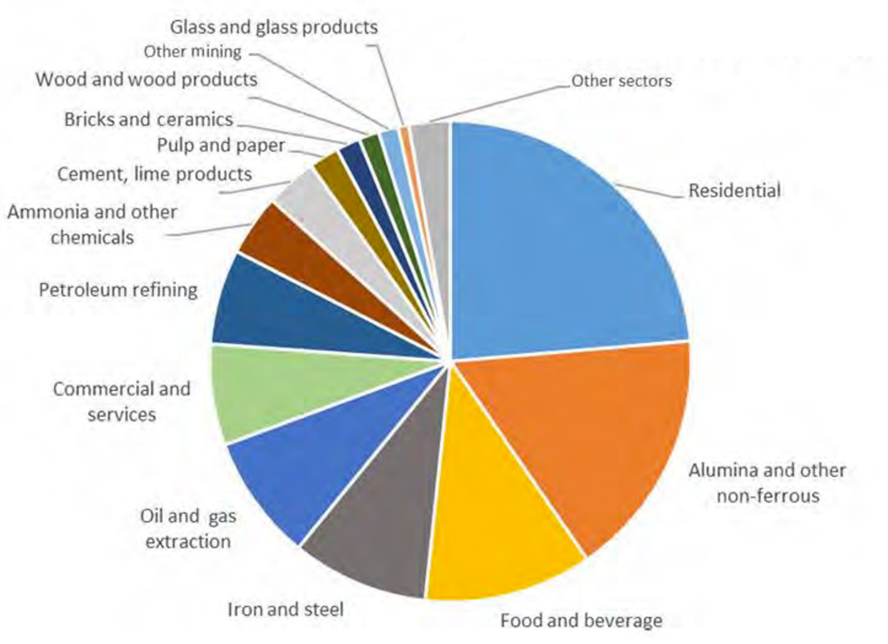
AUSTRALIAN ENERGY COUNCIL

Executive Overview

There are four main ways we use energy: for illumination, for movement, for heat, and to power an ever-growing range of electrical devices and tools. The development of electricity in the 20th century spawned the creation of thousands of new consumer goods: refrigerators, radios and televisions, powered drills to powered toothbrushes, air conditioners and electric fans. Most of these devices are the result of electrification. Three ancient human energy uses – light, movement and heat - have endured for millennia and pre-date electrification. This paper will focus on the current and expanded capacity of low and zero emissions electricity to supply heat in both residential and industrial applications enabling further decarbonisation of these sectors.

When Australia's energy consumption is reallocated according to end-use, rather than fuel or vector, around 1279 PJ per annum or 30 per cent of all energy is used to produce heat, compared to 20 per cent consumed as electricity. Because of thermal losses, this energy produces around 1023 PJ of actual heat. Most of this heat (730 PJ) is consumed by industrial processes: metals refining, processing of food and beverages, production of ammonia, cement, pulp and paper, oil, gas and other chemicals. The remaining heat demand is from households and commercial applications.

Heat market in Australia, by sector 2016-17



Sources: ARENA

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There are two basic uses for heat. The first is amenity based – to heat air and water in buildings for comfort and convenience. The second is industrial – to supply heat for a range of processes from baking bread to making steel. Amenity heat is lower in temperatures required (mostly below 100 degrees C) compared to industrial heat, which can range from around 100 degrees C to more than a thousand degrees.

Electrification of both amenity and industrial heat is closely linked to the plant and equipment used to produce it. Electrification of residential heat requires replacement of long-life assets like water heaters, space heating systems and cooktops. These are major asset changes for households, and, in the case of cooking, can require even more expensive repair or renovation of kitchens. The same applies to retrofitting heating in commercial buildings and in industrial applications.

This means electrification of heat requires two components: the availability of the replacement energy as electricity and considered measures to support the replacement of these major capital assets. Not all industrial uses of heat are easily electrified, particularly high temperature heat which uses gas to achieve very high temperatures needed to trigger chemical reactions. Decarbonisation of these processes may be more suited to replacement fuels like biomethane and hydrogen.

Electricity can be converted into heat using resistance (like an electric kettle or conventional hot water system) or at lower temperatures by using heat pumps, which mechanically extract heat from ambient air and can extract around four to five times the heat from each unit of electrical energy. This means there are opportunities to exploit significant energy cost savings where gas combustion (which can lose 10-40 per cent of heat in the combustion process) can be replaced by electrical heat pumps: residential water and air heating, and in some lower temperature industrial applications.

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Introduction

Heat is used to warm the air in buildings and water for human amenity, and for cooking. It is also used in industrial applications – lower temperature heat is used to make steam and in many food processing industries. Higher temperature heats are required for heavier industries like fabricating metals, papers, and plastics, and then even higher temperatures are required for milling metals and chemical production.

Some of these sources of heat are already derived from electricity. Aluminium smelting specifically requires large amounts of electricity to reduce alumina. Electricity is widely used for some residential and commercial space and hot water heating, and in some cooking and food preparation. It is also used in electric arc furnaces to combine scrap steel and pig iron to make new steel.

The biggest energy source of industrial heat is gas, followed by coal, electricity and some heavy oils. While lower temperature heats can be created by both electricity and gas, gas is more efficient and more capable of producing higher temperatures in some industrial applications. There are broadly two heat markets in Australia: the use of heat for amenity in residential and commercial applications, and the use of heat in industrial applications. The industrial heat market in Australia was around 730 PJ in 2016-17, while the residential and commercial heat market was around 293 PJ.

Electricity can be converted into heat using resistance (like an electric kettle or conventional hot water system). Using this method, a kilowatt hour of electricity converts into 3,600 kilojoules of heat energy. At lower temperatures, this ratio can be improved significantly by using heat pumps, which use electrical motors to extract the heat from ambient air. As a result, heat pumps can improve the conversion ratio from electricity to heat by around four times (by accessing an additional source of heat).

Exploiting this conversion efficiency can deliver significant energy cost savings for households and some industrial activities through increased electrification of low temperature heat.

Residential/building heat

Households require heat for three basic activities: to heat the air, water and food (cooking). Air heating (and cooling) consumed around 40 per cent of total residential energy demand in Australia in 2014. Water heating consumed around 23 per cent and cooking around 5 per cent.
The total amount of energy consumed by households was 473.3 PJ in 2019-20. Heat would account for around 321 PJ of this total energy demand. This is energy input, with the amount of heat consumed being lower as a result of energy conversion losses.

Figure 1 *Energy consumed by households by fuel type, 2019-20*

FUEL CONSUMED	PJ
Electricity	217.8
Natural Gas	174.9
Wood	47.1
Solar Energy	18.0
LPG	15.5
	473.3

Sources: Australian Energy Statistics

Several recent studies have estimated the savings that gas households can achieve by switching to electric alternatives. The superior efficiency of electrical appliances significantly outweighs the higher cost of delivered energy. Combustion generally produces efficiency losses. A new gas heater is around 60-70 per cent efficient. Resistive heating is almost 100 per cent efficient, but heat pumps can be 400-500 per cent efficient as they leverage off heat differentials between the inside and outside of a building. An indicative cost saving analysis is presented in Figure 3 below.

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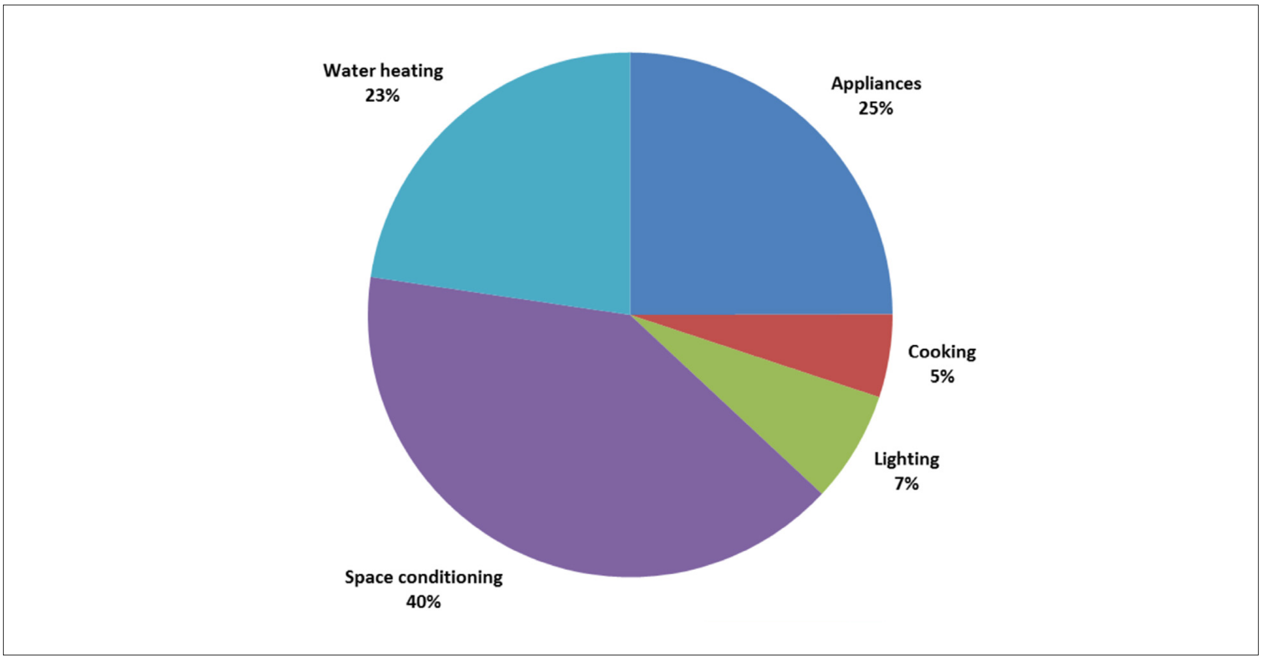
Figure 2 *Share of total residential energy use in Australia, 2014*

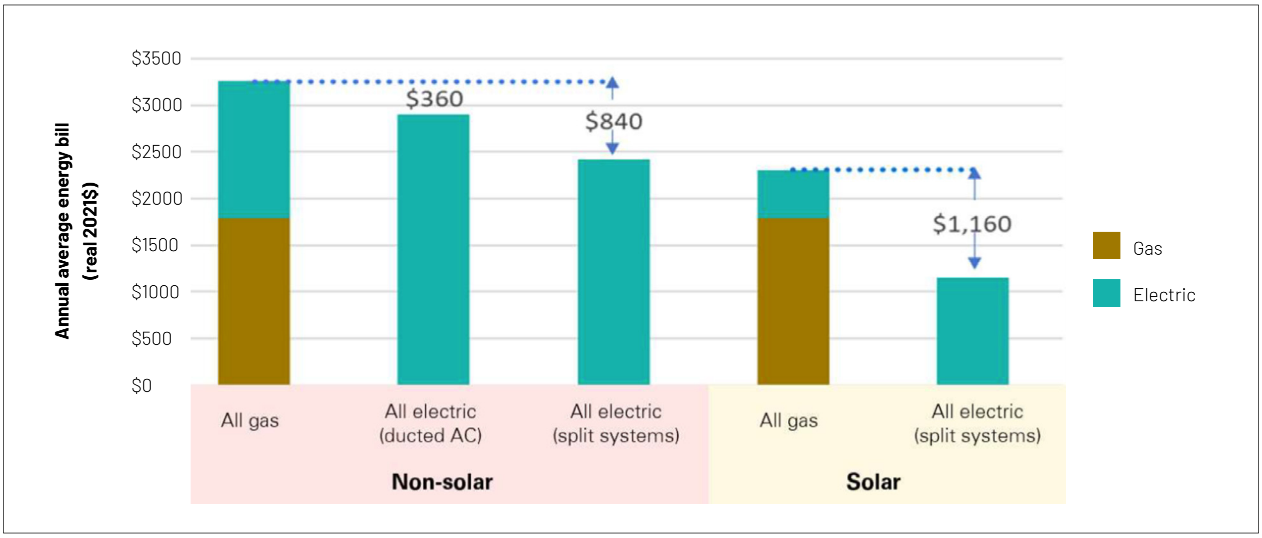


Source: Energy Consult

This analysis indicates that electrification in new builds and appliance replacement at end of life should pay off financially for households. Retrofits will also be cost-effective in many cases. Both gas and electricity bills are a mix of fixed charges and energy charges. So aside from energy efficiency gains, households are only paying one set of fixed charges when they electrify. Notably, Victorians are both the highest residential gas users in Australia and enjoy the lowest prices. So, if electrification pays off there, it should do so in other jurisdictions too.

However, as the following sections discuss the barriers are not really financial. Governments wishing to drive rapid conversion to electricity will need to consider support policies in a more nuanced way than simply offering subsidies or low cost finance, although these may be helpful.

Figure 3 *Residential energy bill impacts 2022-30*



Source: Victoria's Gas Substitution Roadmap

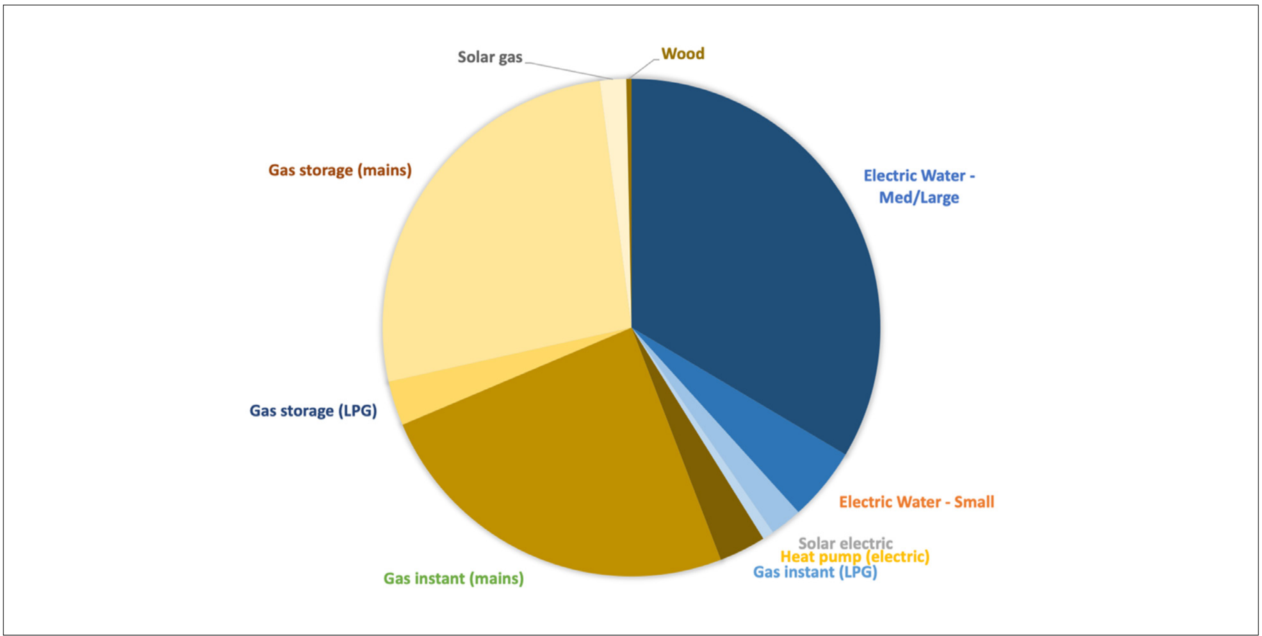
Hot water

A 2015 residential energy baseline study by Energy Consult for the Department of Industry and Science found that gas supplied the majority of energy for water heating in residential Australia. The report estimated Australian households consumed a total of 85.58 PJ to heat water in 2015, with 59 per cent supplied by gas and 41 per cent by electricity.

Residential water heating purchases are typically made during construction, renovations or once every decade. As a result, changing the stock of heating systems is slow and naturally resistant to change. Replacement is often like-for-like as households seek to replace hot water supply as quickly as possible.

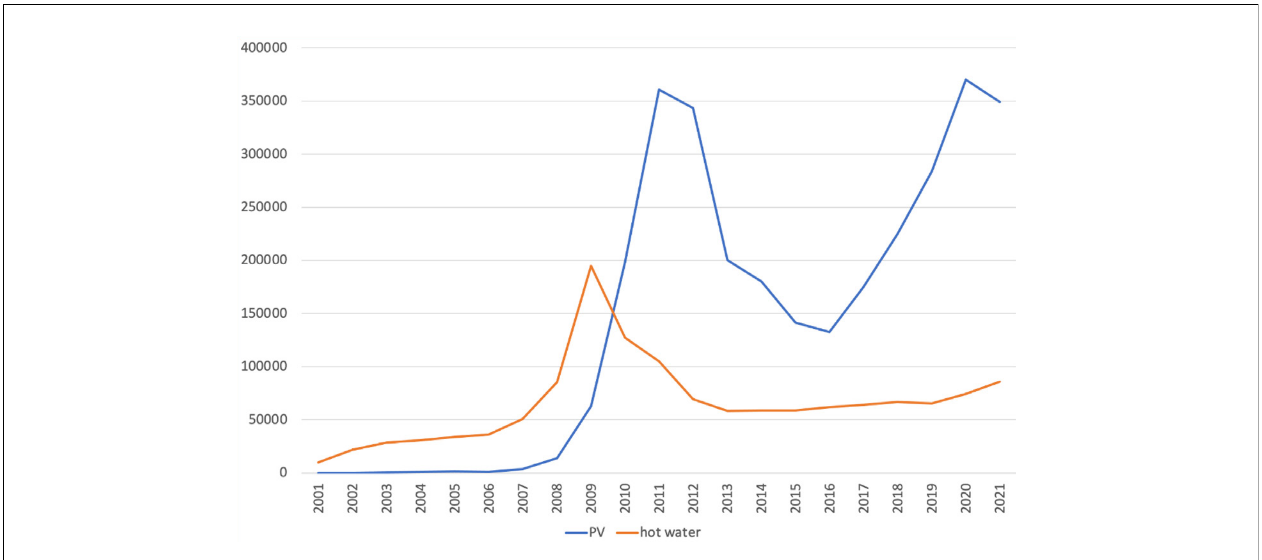
This inertia in the hot water market is reflected in the uptake of solar hot water and heat pumps in Australia. Solar hot water and then heat pumps (which use a heat exchanger to access the heat in the air) became a mainstream commercial product in the 1970s. They were the leading household solar technology of the first decade

Figure 4 *Share of residential water heating by fuel type, 2015*



Source: Energy Consult

Figure 5 *Solar hot water vs rooftop solar PV, installations per annum 2001-21*



Source: Clean Energy Regulator

of this century, before being overtaken by rooftop solar PV. The annual install rate has stabilised below 1 per cent of total households per annum. Solar hot water uses the heat from solar radiation, which is distinct from solar PV panels which convert photons of light into electricity using the photovoltaic effect.

The value of the higher capital cost of solar hot water systems may be challenged by the continued increase in rooftop solar PV generation, which is already creating significant oversupply of electricity during the day, reflected in low or negative wholesale spot prices. Using this near-free solar PV electricity to heat conventional water tanks may be cheaper than using solar hot water systems and may provide useful, grid-stabilising demand for electricity during the middle of the day.

Increasing electrification of residential hot water will require a more strategic approach to system replacement, in particular for existing dwellings. Households could be required to pre-order or purchase replacement hot water systems or be given sufficient incentive to change over their hot water system ahead of its eventual failure.

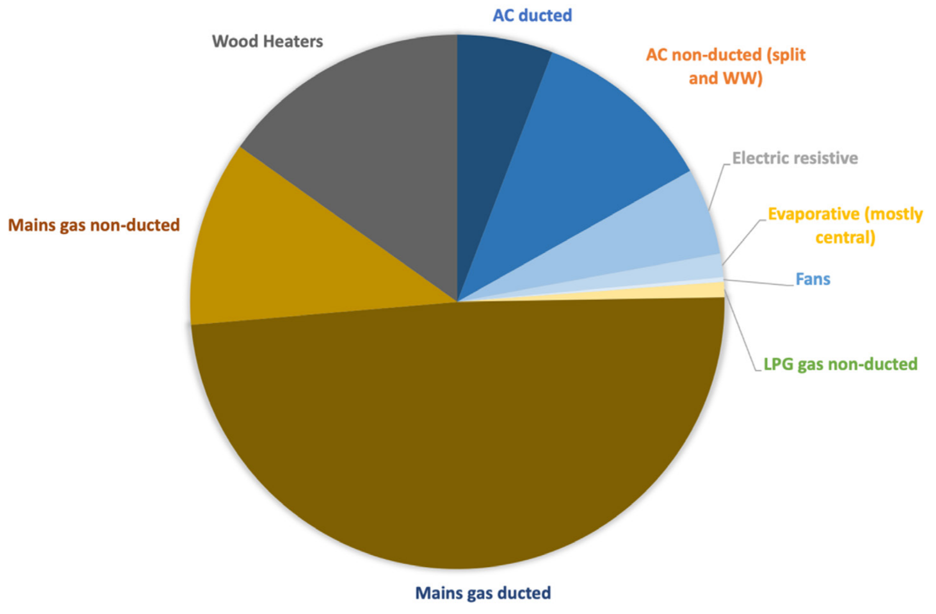
While heat pumps can operate so long as there is sufficient heat in the air, rooftop solar hot water systems are operating at the same time as rooftop solar PV. If daytime electricity prices remain low, this does challenge the value of having two "competing" solar technologies heating water at the same time. Presumably one should be cheaper than the other.

Heating air

Electricity supplies around 24 per cent of the energy used to heat Australian homes, while gas provides around 61 per cent. Wood, which is carbon neutral but contributes to particulate matter pollution, provides the remaining 15 per cent. The pathway to increase electricity used for heating is increased as the percentage of households with reverse cycle air conditioners increases. In 2014 it was estimated between 64 per cent and three out of every four Australian households had an air conditioner, up from 25 per cent in the 1990s.

Based on these trends it would appear likely that electrification of residential heating will gradually increase over time with increased penetration of reverse cycle air conditioners. The other driver would be if the cost to households of heating their home with electricity is materially different to gas (and wood). Over time, prices are likely to accelerate behaviour towards the cheaper technology.

Figure 6 *Residential share of air heating in Australia by fuel type, 2015*



Source: Energy Consult

Cooking

Residential cooking accounts for only around 5 per cent of total household energy demand. Around 53 per cent of cooking heat was supplied by electricity, while 47 per cent was fuelled by gas. Like other residential heat consumption, the fuel type is a function of the type of cooktop and oven installed in each household. These appliances have long operating lives and may only be naturally replaced every 10-20 years or purchased in new builds and renovations. They also tend to display a consumer inertia towards like-for-like replacement. Households would need either regulation, incentives to promote fuel switching or material price differential in fuel costs to encourage increased electrification. If cooking is the only use of reticulated gas, the fixed charges alone will make it significantly more expensive than electric options.

Commercial heat

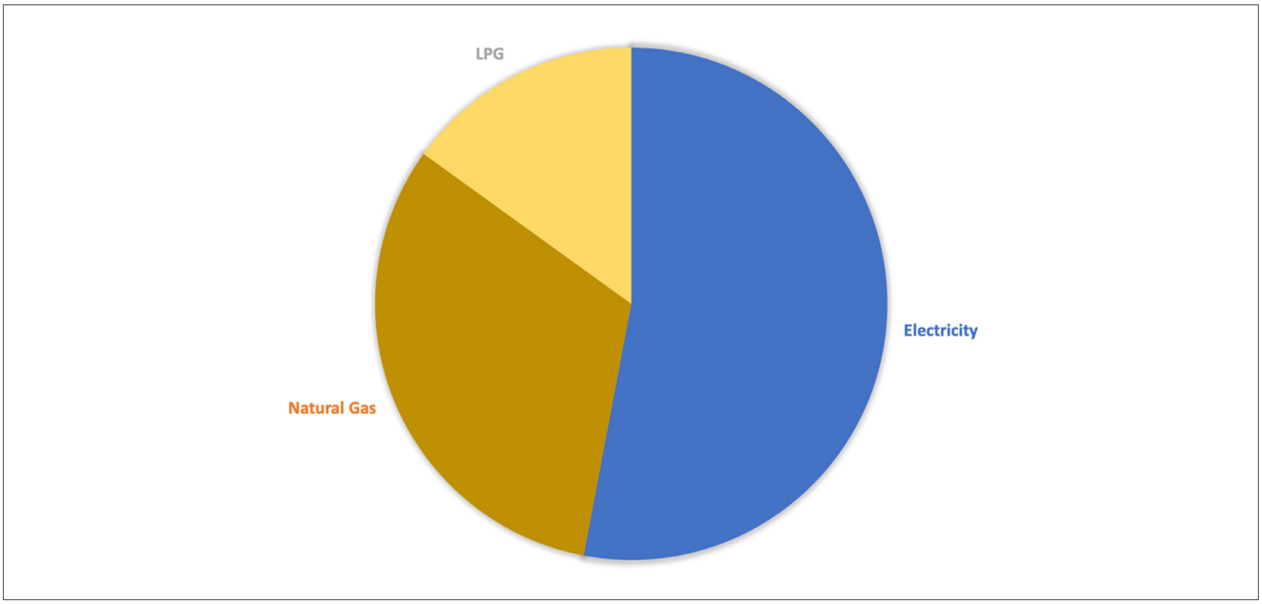
The commercial and services sector consumed around 321PJ of energy in 2019-20. This sector includes offices, accommodation, retail, healthcare and education. The Australian Energy Statistics identified electricity constituted around 73 per cent of energy consumed in this sector. Commercial buildings use heat in a similar way to residential buildings: for heating and cooling, heating water and cooking.

Commercial and services energy consumers face similar opportunities and challenges to residential users to electrify their energy use. The fuel consumption is a function of the type of long-life capital assets (air conditioners, heating systems, water heating and cooking) that are installed. These businesses will require commercial incentives to electrify gas fuelled systems. Some very specific activities like commercial kitchens may be particularly resistant to electrification because of the organoleptic and functional properties of cooking with gas. In these cases, decarbonisation may be easier to achieve with tailored solutions, like substituting natural gas with biomethane.

Other options

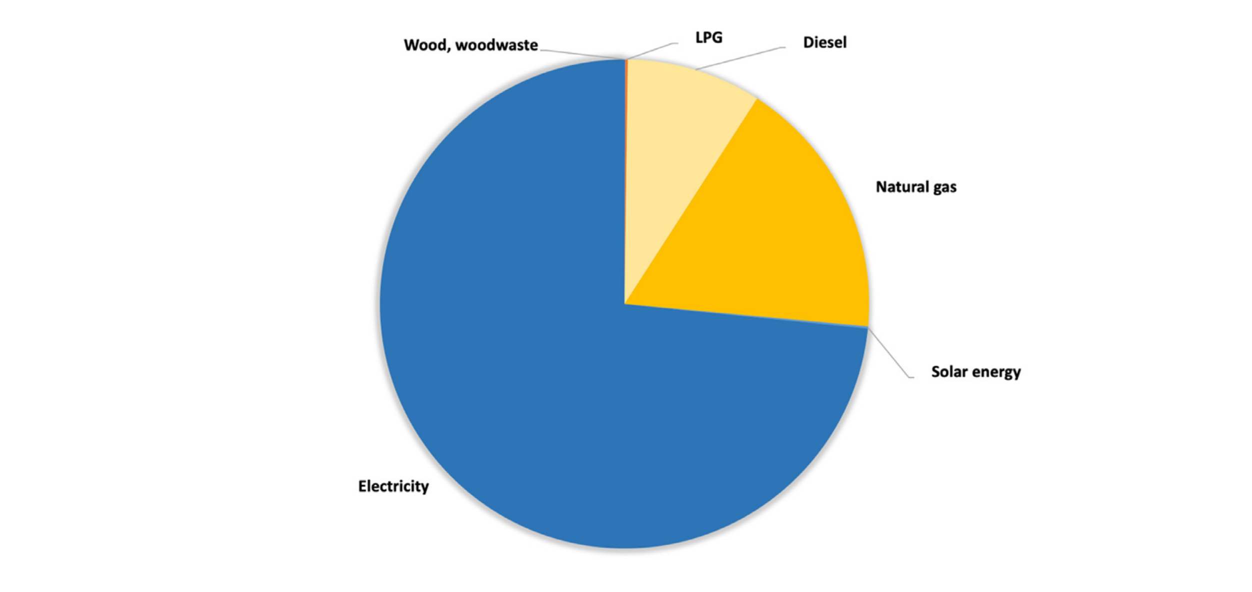
There is no costless way to decarbonise residential and commercial heat use. As noted above, electrification offers lower running costs to offset the capital costs of appliance change. Biomethane may find a niche role, but supply is likely to be constrained well below the level needed to substitute fully for reticulated natural gas. The other option is hydrogen. Hydrogen blending is being trialled in several gas networks. This may offer marginal emissions reduction with little if any impact on users' amenity, given that it will be capped at a limit so that it doesn't affect the operation of existing appliances. However, blending limits of 10-15 per cent mean that this approach cannot get us to net zero. Full conversion of networks and appliances to hydrogen is a different scale of challenge and cost. Hydrogen opportunities and challenges will be explored in more detail in a later paper in this series.

Figure 7 *Household energy consumption for cooking by fuel type, 2015*



Source: Energy Consult

Figure 8 *Share of energy consumed, commercial and services, Australia, 2019-20*



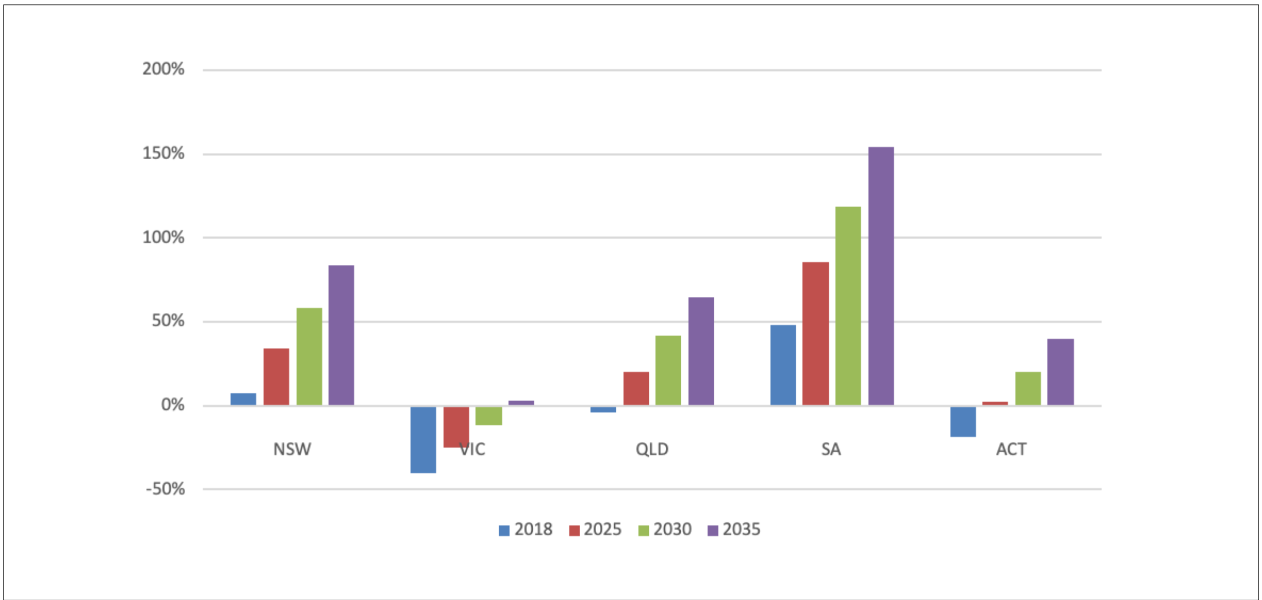
Source: Australian energy statistics, Table F

Summary

Residential heat presents a major opportunity for electrification in Australia. However, it is not a simple transformation. Household heat consumption is disaggregated and dependent on organised switching of long-life assets like heaters and hot water heaters. This will require sufficient electricity network capacity (noting further demand increases anticipated for electrification of vehicles). However, hot water heating, can be targeted at low demand periods (now typically the middle of the day, due to rooftop solar).

It will also require active policy intervention from governments to accelerate this asset changeover, otherwise households will, logically, tend to continue with like-for-like replacement of assets.

Figure 9 *Domestic emissions from using gas appliances instead of electricity, as a share of electricity emissions*



Source: Wood, T. and Dundas, G., 2020, Flame out: The future of natural gas, Grattan Institute

Increased electrification of household energy use is possible and desirable. Interim modelling for Victoria's Gas Substitution Roadmap suggests electrification of household heating with split system air conditioners could deliver typical energy savings of $840 a year, increasing to $1,160 with solar PV augmentation. Emissions reductions are also significant in most jurisdictions and, importantly, will grow over time as electricity grids continue to decarbonise.

This analysis underestimates the rate of emissions intensity reduction in the NEM, notably in Victoria and NSW where several coal plants have brought froward their retirement since the Grattan report was published. Higher savings could be realised by households choosing GreenPower.

Some of the energy supplied by gas could and is likely to be electrified over the coming decades through natural attrition (increased reverse cycle air conditioner penetration rates, increased uptake of rooftop solar PV or heat pumps, popularity of induction cooktops). These gains can be augmented by government policies and initiatives to accelerate the change out of the relevant stock of plant and equipment.

The barriers to residential electrification include households being offered like-for-like replacement of existing systems as the fastest and most convenient replacement. This decision is often reinforced by suppliers and tradespersons. There can also be additional costs in replacing or repairing flooring and benchtops, and more efficient electric options often have a higher up-front cost (although this is recovered in the first year of use). These barriers can be removed by effective government support and skills training.

Because of the natural inertia in the key appliances that determine fuel use, accelerating household electrification will require policy measures that specifically target electrification, interrupting asset lives and targeting change overs. An alternative incentive is exposing household consumers to sufficient fuel cost differentials to accelerate electrification. However, the commodity cost of gas is under 50 per cent of a typical residential gas bill, so there would need to be a very material increase – whether through changes in the market price as supply and demand evolve or through pricing the externality of carbon dioxide.

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Industrial heat

According to the International Energy Agency, industrial heat makes up two thirds of global industrial energy demand and almost one-fifth of global energy consumption. Most industrial heat is derived from direct combustion of fossil fuels. Electrification of industrial heat will be critical to reduce emissions by replacing fossil fuel combustion with renewable generated electricity.

Heat is required to drive some industrial scale chemical reactions like the reduction of alumina and iron ore, the cracking of methane molecules for oil and gas extraction and to drive industrial chemistry involved in the production of ammonia, cement and other chemical products, as well as the more "conventional" heat needed to bake bricks and bread, cook, and process foods and beverages.

Figure 10 *Industrial heat consumption by sector and temperature*

SECTOR	PJ/YEAR <150°C	PJ/YEAR 150–250°C	PJ/YEAR 250–800°C	PJ/YEAR >800°C
Alumina and other non-ferrous	0.0	85.5	0.0	85.5
Food and beverage	45.0	53.1	17.2	0.0
Iron and steel	0.0	0.0	0.0	93.9
Oil and gas extraction	0.0	77.8	8.6	0.0
Petroleum refining	6.5	26.1	26.1	6.5
Ammonia and other chemicals	0.0	0.0	4.2	38.0
Cement, lime products	0.0	5.0	1.6	28.5
Pulp and paper	2.5	3.7	14.4	0.0
Commercial and services	5.4	12.6	0.0	0.0
Bricks and ceramics	0.0	0.0	1.7	14.9
Wood and wood products	3.3	2.2	8.4	0.0
Other mining	2.3	3.0	3.0	5.3
Glass and glass products	0.0	0.0	0.7	6.6
Textile, clothing and footware	0.3	1.8	3.2	0.0
Other hydrocarbon products	0.5	1.5	1.5	1.5
Other non metallic mineral	0.4	1.3	1.3	1.3
Solvents, lubricants, greases and bitumen	0.4	1.1	1.1	1.1
Agriculture, forestry and fishing	1.3	1.7	0.0	0.0
Construction	0.8	1.9	0.0	0.0
Machinery and equipment	0.1	0.9	1.5	0.0
Fabricated metal products	0.0	0.5	1.4	0.4
Water and sewerage	0.4	0.9	0.0	0.1
Other manmufacturing	0.0	0.3	0.3	0.0

Source: ARENA

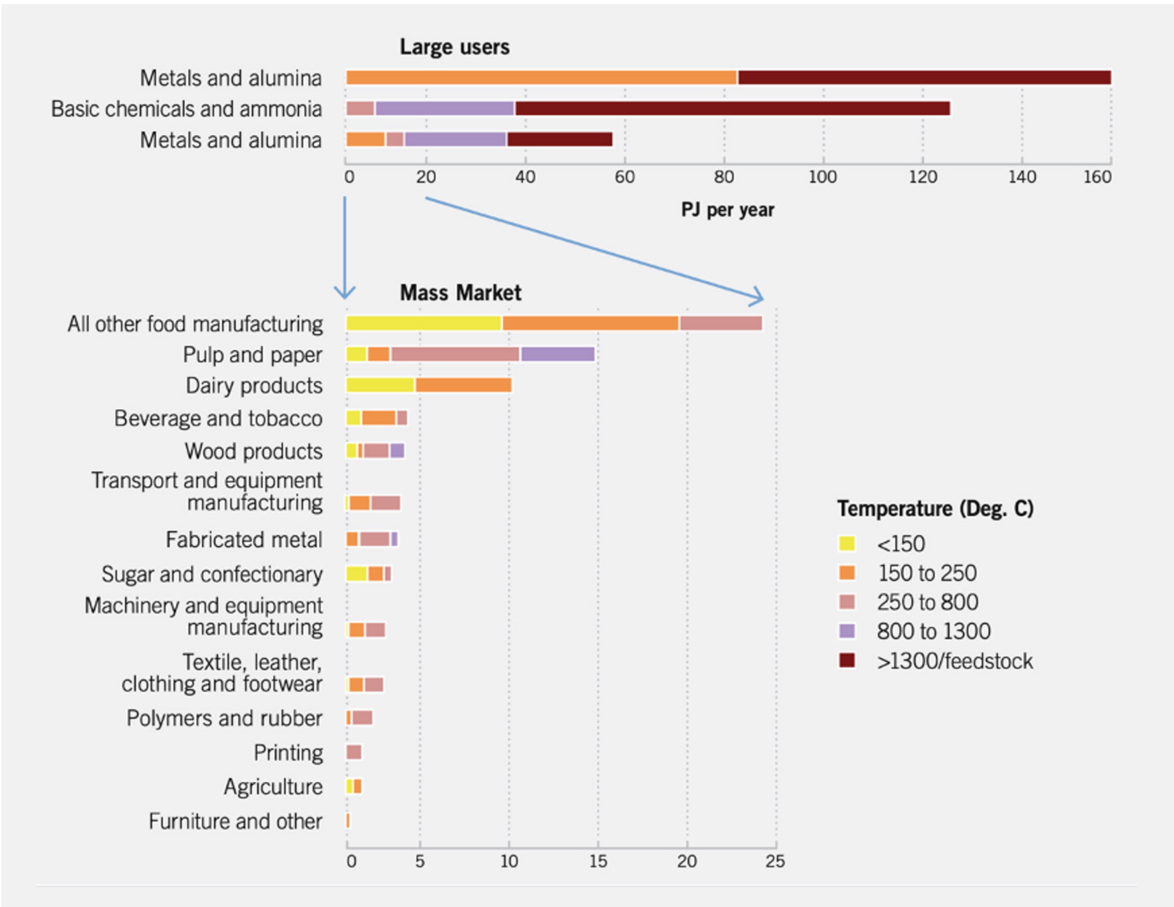
The temperatures of industrial heat required ranges from steam-based heat (100 degrees C) for food and some other applications, up to temperatures in excess of 800 degrees C for metals processing, ammonia, cement and brick kilns. The capacity for electrification of these processes is impacted by high temperatures. Lower temperature industrial heat is more easily electrified than creating the extreme temperatures needed for specific chemical reactions.

A report on electrification of industrial heat for the Australian Renewable Energy Agency (ARENA) identified the different temperatures for major industrial heat consuming sectors.

Most of these high temperatures are achieved using gas as fuel, because it is able to be combusted on site and deliver this heat directly into the targeted process. Industrial gas consumers that require high temperatures in their industrial processes currently have limited options to decarbonise. Green hydrogen or biomethane may provide an alternative zero emissions option in the future. Lower temperature industrial activities (below 250 degrees) may have more zero emissions options using green electricity and steam.

In most cases this is not a simple process and may require new plant and equipment and reorganisation of processes. But it is possible there may be an erosion of gas demand for these industrial applications over the next decade as some companies switch to non-gas zero emissions low temperature heat sources (renewable electricity, solar thermal, geothermal).

Figure 11 *Industrial gas consumption by temperature*



Source: ARENA

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The cost of heat

The cost of supplying heat includes the cost of the energy and the infrastructure needed to deliver it. Gas delivers its energy directly as heat (with combustion losses), while electricity is converted into heat. A megawatt hour (MWh) of electricity converts into 3.6 GJ of energy. This means if a MWh costs $50, it converts into heat directly at a cost of $13.90 per GJ. Where heat pumps can be used, this heat cost is much lower: around $3 per GJ. The delivered cost of gas heat depends on the scale of combustion loses, which vary from process to process, but typically can add $1-$4 per GJ on top of the delivered gas price.

The desirability of electrification is influenced by the relative cost of gas and electricity. According to the ACCC, LNG netback prices range from $6-$20 per GJ, with short term price spikes nearly double this. Average spot electricity prices typically range from $35-$85 per MWh. Both gas and electricity customers also pay transmission and retail supply costs in addition to these fuel costs.

Because heat demand is linked to long life assets, the cost differential of using electricity or gas to supply heat will be assessed by most businesses from a long-term perspective. Under different scenarios and contracting arrangements, different energy vectors may be able to exploit advantages. A price on emissions would materially advantage renewable electricity over gas.

Low temperature industrial heat

Low temperature industrial processes include heat used in food and beverage manufacturing. Heat is used to make hot water, sterilising, drying, pasteurisation, steaming, boiling and cooking, baking, cleaning and brewing. Most of these temperatures range from 60 degrees C to 200 degrees C, although some baking processes can require temperatures up to 400 degrees. Most of these processes are fuelled by gas heat (outside of the sugar industry, which uses bagasse). Outside of sugar, the amount of heat used in the food and beverage industry is around 75 PJ per annum, consumed over hundreds of sites and thousands of different industrial processes and machines.

There are numerous electric powered heating technologies which could replace gas for these lower temperatures. These include:

- heat pumps / vapour recompression
- electromagnetic heating (induction, dielectric, infrared, ultraviolet)
- resistance (ohmic) heating
- electric arc heating
- High temperature industrial heat

Higher temperature industrial processes are more challenging for direct electrification as the application of heat requires combustion from a fuel (coke ovens, blast furnaces, cement kilns, alumina refining), while some fuels (coal in blast furnaces, gas in ammonia) also serve as a feedstock to the process. Gas is also preferred in some high temperature applications like brick kilns both because of the high temperatures needed and the temperature control operators have over the firing of the kilns.

Low emissions options

There is a small but growing range of alternatives to produce high temperature heat for industrial applications.

Electrification: High temperature electric furnaces for cement production are being developed by Vattenfall and Cemeta. Electrification of ultra-high temperatures may be possible for some applications using a plasma arc furnace, which can generate temperatures higher than 5000°C.

Biomethane: Biogas is produced from the anaerobic digestion of organic matter. There is a large variety of organic resources, including agricultural waste, industrial waste, and waste-water treatment. Biogas can then be upgraded to biomethane, which is a direct zero carbon substitute for natural gas. Scale constraints mean it can only partially replace the demand for gas, and its higher cost means biomethane may seek higher value add applications than heat supply. ARENA has estimated the annual biogas potential for Australia to 371PJ which would represent close to 9% of Australia's total energy consumption. While most gas for heat application is supplied through reticulated gas networks, biomethane can also be supplied via tankers (or even bottles for small-scale use) as liquified or compressed gas (LRNG/CRNG).

Hydrogen: Green hydrogen can be used both a source of high temperature heat and as a feedstock in some processes, like ammonia production. Given the high cost of moving hydrogen, it is likely to be produced from electrolysers on most industrial sites.

Key sectors

Alumina: Australia has six alumina refineries which require temperatures above 800 degrees C. These high temperature processes could be fuelled with renewable hydrogen.

Ammonia: Ammonia is a very large user of natural gas. There are already trials to use renewable hydrogen to replace natural gas as a feedstock, which would address the largest energy input for this process.

Steel: Green steel technology is under development in Europe, using hydrogen to replace coal as an energy source and feedstock. Electric arc furnaces are already used in scrap steel reprocessing and can be operated flexibly to take advantage of cheap renewable electricity.

Cement: The process of manufacturing cement produces emissions. The high temperature kilns could be fuelled by biomethane or green hydrogen.

Pulp and paper: Australia's pulp and paper industry already uses waste biomass to help heat for steam and hot water. This sector could exploit low cost green electricity for its heat needs.

Summary

The opportunities to electrify and decarbonise industrial heat depend on the temperatures and processes. Lower temperature industrial heat, particularly that used in food processing, can exploit the same efficiency benefits of heat pumps as residential dwellings. Like households, the changeover of these commercial assets is not cheap. Businesses will look to exploit efficiency gains and cost savings if they are warranted by the replacement costs.

Higher industrial heat is based around high capital cost, long life assets. The replacement of high temperature, long life capital assets like blast furnaces and alumina refineries occurs every 15-20 years for steel and longer for alumina. These businesses will use these capital replacement cycles to upgrade to the best available/cost effective technologies at the time.

Because there are not the clear cost savings delivered by heat pump heat, the relative cost of electricity and gas will be a significant factor in these commercial decisions.

There is an emerging suite of high temperature heat technologies under development, with the objective of being able to switch to zero-emissions replacement options in the future.

This includes using green hydrogen in steel reduction, to fuel cement kilns and alumina refineries and to replace gas as a feedstock for ammonia production. Green hydrogen is effectively a derivative of green electricity.

Efficient electricity system design will be critical to making electricity as cheap as possible as the grid decarbonises. Demonstrating the ability to sustain supply of low-cost electricity will be one of the key enablers of accelerated electrification of industrial heat.

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