beyond ZERO emissions

Zero Carbon Industry Plan

# Electrifying Industry

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Published by Beyond Zero Emissions Inc.
Ross House
Suite 4.7, 247 Flinders Lane
Melbourne Victoria 3000

First published September 2018



This document is available for download from http://bze.org.au

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# Contributors & acknowledgments


## Donations

This research was supported by:
Hamer Family Fund
Lenko Family Foundation
Lord Mayor's Charitable Foundation
Mullum Trust
NR Peace and Justice Fund
Pace Foundation
Pixel Seed
Robin Friday

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Stuart Sneyd, Outotec
Timothy Walmsley, Brno University of Technology
Veronika Wilk, Austrian Institute of Technology

## Organisations

C-Tech Innovation
FlowPower
Furnace Engineering
GLP Renewables
International Energy Agency

## Graphic Design

Cari Gray
Sonja Loader-Jurac

## Report production sponsored by

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# Key Messages

## How things stand:

1. Manufacturers' use of fossil fuels causes **8% of Australia's greenhouse gas emissions** – as much as our entire car fleet and more than the state of South Australia.
2. Australian manufacturers are struggling to remain competitive due to **rising energy costs.** Many businesses' gas and electricity bills have doubled in the last two years, and the days of cheap gas in Australia are over for good.
3. Australian manufacturing is inefficient, consuming **more energy per dollar of output** than any other developed country.
4. Australia's manufacturing sector is in long-term decline, with nearly **one in five manufacturing jobs disappearing** in the last 10 years.
5. Businesses wedded to **high-carbon strategies are at risk** from the global transition to a low-carbon economy.

## Australia's opportunity:

1. Renewable energy is affordable and reliable now. Many businesses are already paying **20 to 50% less** for electricity by switching to renewables.
2. Renewable energy could be **30 to 50% cheape**r in just 10 years. In some places this could make electricity cheaper than gas.
3. With Australia's unparalleled resources in solar and wind energy, we could electrify all industrial processes. This would eliminate **6 to 8% of national greenhouse gas emissions,** and relieve industry of its dependence on gas.
4. Electricity is a versatile form of energy that can be used to **power any industrial heat process.** By switching to electrical heating we can **halve the energy required** to produce many goods, while reducing costs and increasing production speed.
5. The next wave of industrial revolution is coming – **the zero-carbon economy.** Electrifying industry would **increase the competitiveness of Australian manufacturing** by reducing costs and producing zero-carbon goods.
6. Electrifying industry would enable Australia to **become a world leader** in energy-intensive, zero-carbon manufacturing, such as:
    - becoming the first country to produce emissions-free steel without coal
    - exporting renewable ammonia – a zero-carbon fuel
    - zero-carbon production of energy-intensive materials such as carbon fibre.
7. Renewable electricity could power a vibrant industry in r**ecycling materials including plastic, glass and paper.**
8. Thousands of factories across Australia could save money on energy today, by **replacing their gas-fired boilers with industrial heat pumps.**
9. The manufacturing sector drives innovation, exports and creates high-quality jobs. Governments should help Australian manufacturers capitalise on the zero-carbon opportunity with **ambitious industrial policy.**

# Executive Summary

## Australian manufacturing's next wave of opportunity

Wherever you are now, chances are you're using the products of industry. Materials like metal, glass, paper and plastic allow us to make an endless array of goods that enrich our lives. But when you pour a can of beer, open a jar, read a book or buy a plastic drink bottle – how often do you think about the energy used to make them?

Transforming the materials we dig up or grow, into the products we use every day, requires enormous amounts of heat. Right now in Australia, thousands of factories – from breweries to steel-works to biscuit makers – are burning fossil fuels to generate this heat. Manufacturers' need for heat causes 8% of Australian greenhouse gas emissions[i] – as much as our entire car fleet and more than the state of South Australia.

While fossil fuels have powered industry since the industrial revolution, a new low-carbon industrial transformation is coming. This change is vital if we are to limit the impacts of dangerous climate change. With this change, new industries will be created and existing industries transformed.

This report shows how Australian manufacturing can not only survive but thrive in the next wave of industrial revolution - the zero-carbon economy powered by renewable electricity. The focus of this report is the adaptation of industrial processes which are not yet electrified.

### Australia's new energy advantage

In a low-carbon world, Australia has a unique advantage – unparalleled resources in solar and wind energy. As Beyond Zero Emissions showed in our 2015 report, *Renewable Energy Superpower*, Australia is in the enviable position of having the natural resources to generate far more renewable electricity than we could ever need.

Australia can use this abundance of renewable electricity to develop a clean, efficient manufacturing sector, adapted to the needs of the 21st century – and we can do it right now.

Few people are aware of the compelling case for electrifying industry. That's because it rests on very recent developments which have disrupted a long-standing reality. For many years natural gas in Australia was cheaper than in most other countries. Electricity was not just more expensive, but more polluting, being generated in dirty, inefficient coal-fired power stations.

Since Australia became a major exporter of gas, domestic prices have doubled, and gas will never be cheap here again. Meanwhile the cost of clean, renewable electricity has plummeted, reaching a level where any manufacturer can now switch to renewables and save money in the process.

Leading companies of all sizes are signing power purchase agreements to secure low-cost electricity from solar and wind, typically paying 20 to 50% less than the standard market price. Through these deals they secure long-term price assurance, eliminating the risk from fluctuating energy prices. Hundreds of other companies are installing rooftop solar panels or even building their own renewable energy plants off-site.

Renewable technologies are mature enough to power even the most energy-hungry manufacturers. Both of Australia's steel-makers, BlueScope and Liberty One Steel, are turning to renewables as a way of lowering costs. Sun Metals in Queensland is building a massive 124 MW solar farm to help safeguard the future of its zinc refinery.

While this shift has only just begun, already half of Australian businesses are considering wind, solar and storage. Some, such as Carlton & United Breweries, Mars Australia and Unilever Australia have committed to 100% renewable targets. This type of target will become common as the cost of wind and solar power continues to fall, with renewables expected to be 30-50% cheaper in just 10 years' time.

So far, manufacturers are simply using renewables in place of grid electricity. But abundant, cheap renewable electricity opens up an even more far-reaching possibility: the electrification of manufacturing processes that currently rely on burning fossil fuels.

*i This figure rises to 21% if we consider all energy and emissions related to Australian manufacturing.*

**By electrifying Australian industry, we can eliminate emissions from industrial heat processes, at the same time as enhancing Australia's competitiveness in the 21st century.**

## The big switch

Electricity is a remarkably versatile form of energy that can be used to power any industrial heat process, from cooking a can of beans to melting 100 tonnes of iron. There is also no practical temperature limit to electrical heat. A plasma torch furnace can reach 5,000°C or more, far higher than any coal or gas-fired furnace.

But electricity isn't just another source of energy – it allows us to make things in a smarter way. Currently, Australia's manufacturing is inefficient, consuming more energy per dollar of output than any other developed country.

By switching to electrical heating it is possible to double the efficiency of many industrial processes. This report shows we can halve the energy input needed to produce goods as diverse as beer, brick and cast metal. This greater efficiency is due to the ability of electrical heating technologies to:

- deliver heat at the precise temperature required (traditionally, industrial heat is often provided at temperatures well above what is needed)
- transfer heat directly to a material, with very little heat escaping to the environment
- provide heat at the point of use, minimising distribution losses.

The 'How to electrify' guides in Part C show how lower energy use reduces operational energy costs. The comparisons demonstrate that electrical heating processes can already be cheaper to run, especially when powered by on-site solar panels. This economic advantage will grow as the cost of renewable electricity continues its rapid decline. Manufacturers converting to electrical heat today can look forward to years of falling energy costs.

Another major advantage is productivity. Electrical heating technologies are generally quicker, more controllable and less labour intensive. For example, induction and infrared take just minutes to complete a heating task that would require several hours in a conventional gas furnace. The 'How to' guide on bricks shows how brick firing times can be almost halved by using microwaves.

Other benefits of electric heating include:

1. **Precision.** Heat supplied by electricity can be more precisely focused. This not only saves energy but improves the quality and consistency of some products, such as processed foods and metal components.
2. **Control.** Most electrical heating systems are easier to control and automate, and require fewer staff to operate, freeing them up for other roles.
3. **Modularity and size.** Many electrical heating technologies can be installed as small, modular units – allowing them to be implemented over time, spreading cost and risk. This can help foster an economy of reduced scale as smaller equipment requires less space. Facilities can be decentralised and sited close to raw material sources or product markets.

Affordable renewable electricity will help unleash the full potential of a range of electrical heating technologies, including:

## 1. Industrial heat pumps

Heat pumps use electricity to make hot water, air or steam. They can produce several times more thermal energy than they use in electrical energy, leading to remarkable efficiencies of 300 to 700%. Heat pumps also enable manufacturers to reuse sources of energy that are otherwise wasted, such as the heat expelled by refrigeration systems. Heat pumps save so much energy their installation cost can often be paid back within 2 years.

Industrial heat pumps are available which can produce water or steam up to 160°C – hot enough for many industrial processes. Perhaps the most exciting potential application for heat pumps is as an alternative to the inefficient centralised gas boiler systems found in most factories.

The 'How to electrify' guides on food, beer and milk powder show how heat pumps can reduce energy inputs by 50% or more.

## 2. Electromagnetic heating

A range of technologies use the electromagnetic spectrum to deliver heat. The major advantage of electromagnetic heating technologies is they generate heat within a target material, minimising heat losses. Energy use can often be cut in half by switching to electromagnetic heating.

Electromagnetic technologies perform heating tasks very rapidly, cutting down processing times. They are also safer than gas-fired heating, more controllable and produce a more consistent output. The most important examples are:

**Infrared.** Infrared radiation heats surfaces and thin material many times faster than a gas oven. It has a very broad potential across many industries, particularly for drying and curing ('How to electrify paper').

**Induction.** Electrical induction heating is a fast, efficient, non-contact method of heat-treating and melting metals. For example, in the 'How to' guide on aluminium casting, we show how induction can melt just the right amount of metal in minutes, reducing energy use by 50%.

**Dielectric heating.** Microwaves and radio-frequency waves provide an efficient method of heating bulky material, such as stacks of bricks or timber. Dielectric heating is fast, efficient and heats bulky material more evenly than conventional heating ('How to electrify bricks').

## 3. Electrical resistance

Electrical resistance heating involves generating heat by passing an electric current through a resistive heating element, like an electric bar heater.

Electric resistance heating has huge potential as it is a simple alternative to most industrial gas-fired heating systems. For example, electric resistance boilers produce hot water or steam up to 220°C and could replace gas-fired boilers. Some industries, such as carbon fibre production, already run predominantly on electric resistance heating due to its greater controllability, lower maintenance and absence of emissions from combustion. Electric resistance can also power high-volume, high-temperature processing of minerals, such as limestone and clay. The 'How to' guide on glass shows how to design an efficient, all-electric glass-making process.

The 'How to' guide on plastic shows how electric furnaces used in plastic recycling consume less than 5% of the energy required to make virgin plastic. All-electric plastic recycling will be an important part of the response to the global crisis of plastic waste.

## 4. Electric arc heating

The most common application of electric arc heating is in electric arc furnaces for melting metal. Electric arc furnaces are already used to recycle steel and will be a crucial component of a future zero emissions steel industry ('How to electrify steel'). Electric arcs are also used in plasma arc furnaces which offer new possibilities for electrifying high-temperature, high-volume processes, such as cement-making.

## 5. Hydrogen

Hydrogen can be made by passing an electric current through water (electrolysis) and is therefore an indirect route to electrifying industry. Making hydrogen this way can now be cost-competitive in places like Australia with excellent renewable resources.

Affordable, renewable hydrogen opens up a world of possibility, such as making steel without coal.

Other countries are already investing in hydrogen-based steel but nowhere has as much iron ore as Australia. 'How to electrify steel' presents one route to all-electric zero-carbon steel. This could become a major export, and contribute to the decarbonisation of a sector that currently causes 6-7% of global emissions.

Renewable hydrogen also provides an alternative to fossil fuels in the production of ammonia and a range of organic chemicals ('How to electrify ammonia'). It can also be combined with carbon to synthesise a range of hydrocarbons, including substitute natural gas, which could be used in industrial heating processes.

## An unmissable opportunity

Australian manufacturers that choose renewable electricity will be at the forefront of an unstoppable global transition.

A powerful coalition of governments, investors and business is driving industry towards a low-carbon future, and Australian manufacturing cannot afford to miss out.

Governments around the world, including the UK, Sweden, France and New Zealand are setting targets to be carbon-neutral by mid-century. Most Australian state and territories also have zero carbon targets, and in Victoria and the ACT they are legally-binding.

Meeting such targets will require deep emissions cuts in all sectors, including manufacturing. Countries, including China, Canada and the European Union, are encouraging manufacturers to decarbonise by imposing higher costs on their emissions. The EU's current emissions roadmap anticipates that industry will cut emissions by 80% by 2050. More countries are likely to follow, and those that don't face a future threat of carbon tariffs.

The impact of global carbon reduction policies will be disruptive and transformative. It will be felt by businesses throughout the world and those wedded to high-carbon strategies may not survive.

Conservative institutions, such as the Australian Prudential Regulation Authority and the Bank of England, are already warning of a systemic risk to the global economy. Institutional investors are also aware of the danger. They are demanding that businesses present evidence of carbon reduction strategies consistent with climate science. Investors have already diverted billions of dollars away from fossil fuel companies, and scrutiny is now extending to large consumers of fossil fuels like manufacturers.

Many major corporations are choosing to rise with the tide rather than be sunk by it. Hundreds of global businesses, including household names such as Coca-Cola, IKEA, L'Oreal, Nestlé, Sony and Walmart, have set ambitious emissions reductions targets. Some, such as Mars and Unilever, have even committed to eliminating emissions.

These businesses are not just targeting their own emissions, but those of their suppliers too. IKEA, for example, plans to reduce the average climate footprint of its products by 70%.

Nevertheless, we cannot rely on markets alone to drive change at the required speed and scale. Governments in Australia must follow other countries by developing coordinated strategy with the explicit aim of decarbonising industry. This strategy should include massive investment in low-carbon innovation and manufacturing, financial incentives for manufacturers to switch from fossil fuels to renewable energy and a one-stop advisory service to help with this switch (Section A5).

No manufacturer, large or small, will be able to resist the collective demands and expectations of governments, investors, corporations and consumers.

The good news is that Australia, with unparalleled resources in solar and wind, is in the ideal position to capitalise on this moment.

The manufacturing sector plays a unique role in the national economy, driving growth in productivity, innovation, exports and high-quality jobs. Electrifying industry is an unmissable opportunity that will spark new investment in energy-intensive production and trigger a revival in Australian manufacturing for decades to come.

# Units in this report

| Power | |
|---|---|
| **KW** | kilowatt or 1000 watts. A watt is a measurement or power – the rate of energy transfer. Kilowatts are a standard unit of measurement of electrical power. 1 kW = 3.6 MJ. The capacity of electrical equipment is rated in kilowatts. Eg an ordinary electrical kettle might be capable of 2 kW and a large heat pump 700 kW. |
| **MW** | megawatt or 1000 kilowatts. Megawatts are often used to describe the capacity of power stations and very large electrical heating equipment. |

| Energy | |
|---|---|
| **kWh** | kilowatt hour. A unit of energy equivalent to 1 kW of power sustained for 1 hour. Electricity is usually sold in kilowatt hours so in this report we use c/kWh as the standard unit of energy pricing. Kilowatt hours are the standard unit of energy in this report, and we sometimes use kWh to refer to thermal energy supplied by gas. |
| **MWh** | megawatt hour or 1000 kWh. |
| **MJ** | megajoule or 1000 joules An alternative unit of energy often used to measure mechanical or thermal energy. Raising the temperature of 1000 litres of water by 1°C requires 4.18 MJ. 1 MJ = 0.278 kWh. |
| **GJ** | gigajoules or 1000 MJ or 278 kWh. Gas is usually priced in A$ per gigajoule. In this report we sometimes convert A$/GJ into c/kWh. Eg A$10/GJ = 3.6 c/kWh. |
| **PJ** | 1 million gigajoules. Australian industry uses more than 400 PJ every year. |

In comparing electricity and gas prices it is useful to have a standard unit of measurements. In this report we use kWh to compare gas and electrical energy and c/kWh to compare prices.

# Part A

## The Case for Electrifying Industry

# A1 - Manufacturing success

## Australia's manufacturing moment

Manufacturing plays a special role in Australia's economy that cannot be filled by any other sector. But since the 1960s, when a quarter of employees worked in factories, Australian manufacturing has been in decline.[1] The last 10 years have been particularly tough, with manufacturing output declining, and nearly one in five manufacturing jobs disappearing for good.[2] Manufacturing employment is now smaller as a share of total employment in Australia than in any other advanced country.[3]

Successive governments have failed to turn the tide. Indeed we often hear that the decline of manufacturing is inevitable in a high-wage, remote country like Australia. Another common belief is that Australia's economy is now led by services, and jobs in this sector can simply replace those in manufacturing.

In reality, the decline of Australian manufacturing is neither inevitable nor benign. Comparable industrial countries, such as New Zealand and Ireland, have increased manufacturing output while creating new manufacturing jobs. A healthy manufacturing sector makes a unique strategic contribution to the national economy, in several ways:

**Manufacturing is the engine of productivity growth**[i]

Productivity is an important driver of economic growth and living standards. It tends to increase faster in manufacturing as the use of machines and automation enables more to be produced with less. Manufacturing also stimulates productivity growth in other sectors, by providing services with advanced technology such as computers and fibre optics.

**Manufacturing drives innovation**

We hear a lot about the importance of innovation to Australia but less about the fact that manufacturing is where most research and development is done. Proportionally, manufacturers spend more on innovation than any other sector of the Australian economy.[4] Without a vibrant manufacturing sector, Australia will struggle to be an innovation leader.

**Manufacturing strengthens trade performance**

Despite Australia's significant mining and agricultural exports, manufactured products account for almost 30% of our exports – more, in fact, than agriculture.[5] With uncertainty over the long-term demand for Australia's fossil fuel exports, the importance of goods exports can only grow.

**Manufacturing creates high-quality jobs**

Close to one million people are still employed in manufacturing. There are fewer part-time workers in manufacturing than other sectors, and average earnings are about 10% higher than the Australian average. The current slowdown in national wage growth is due, in part, to the loss of full-time, high-wage jobs in Australian manufacturing.[6]

**Manufacturing creates jobs in other sectors**

All sectors have multiplier effects, where employment leads to new jobs in other areas. These effects are especially high in manufacturing, because manufacturers buy far more from other sectors than other types of business because they rely on extensive supply chains. In high-technology operations like car factories the job-multiplier effect can be as high as 10-to-1.[7]

i *Productivity is the efficiency with which an economy transforms resources into goods.*

## The renewable energy opportunity for Australian manufacturing

Electrifying industry with renewable energy is an unmissable opportunity for Australian manufacturing.

Surveys show that Australians understand the importance of a strong manufacturing sector, regardless of their politics.[8] There is also overwhelming public support for governments to back the sector with active policy and financial assistance.

A growing body of evidence shows that new sources of energy and their efficient application have been essential to economic growth since the industrial revolution.[9] For example, the 19th century saw a shift away from wind and water power towards coal, triggered by the invention and refinement of the modern steam engine. The application of the steam engine in new technologies, such as locomotive railways, steam ships and steam-driven factory machinery, improved productivity across the whole economy.

In the 21st century the new source of energy is cheap wind and solar PV. All over the world businesses, including manufacturers, are racing to replace fossil fuels with renewables. With our unparalleled resources in solar and wind, Australia is in the ideal position to capitalise on this moment in history.

This report shows by electrifying industry it is possible to double manufacturing efficiency, harnessing the power of the sector to drive productivity growth, innovation, exports and create high-quality jobs. Now is the perfect time for governments to support the revival of Australian manufacturing.

> ***"the combination of falling generation costs with Australia's exceptionally large and high-quality solar and wind potential raises the possibility of a new global competitive advantage in electricity prices over the long term."[10]***
>
> ***Ai Group***

## The global shift to low-carbon industry

In 20 years' time manufacturing is going to look very different from today. Further digitisation, automation and 3D printing will increase the efficiency of production. We will also see the increased importance of new materials like graphene, carbon fibre and geopolymer cement.

Equally momentous will be the move away from fossil fuels, which made industrialisation possible and have since sustained it. A powerful coalition of governments, investors and businesses is propelling us towards renewable energy, motivated by economics and the imperative of limiting dangerous climate change.

This shift has already begun and cannot be resisted. For smarter manufacturers it represents an opportunity to produce goods more efficiently and demonstrate their long-term vision and credibility.

## Government and international action

Climate change threatens economic growth and the political harmony on which global trade depends. In recognition of this threat, nearly every national government in the world has committed to limiting global warming to well below 2°C, and to aim for no more than 1.5°C. Around the world governments are starting to acknowledge that these commitments mean we must reduce greenhouse emissions to zero.

In Australia, most state and territory governments have targets to be carbon neutral by 2050. Victoria and the ACT have gone further by enshrining zero emissions targets in legislation. National governments are also recognising this goal in policy and law. Sweden, France, Iceland, New Zealand, Costa Rica and Bhutan all aim to be net zero carbon by mid-century.[11] More countries will inevitably follow. The UK is discussing raising its 2050 emissions reduction target from 80% to 100%. Even more importantly the European Union (EU), may introduce a zero carbon target, extending its existing goal of an 80-95% reduction by 2050.[12]

So far efforts to reduce emissions have focused on the electricity, transport and buildings sectors. But attention on industry is growing, in recognition of the fact that zero carbon targets require a significant contribution from manufacturers. The EU's current emissions roadmap anticipates that industry will cut emissions by at least 80% by 2050.[13]

## Climate policy and the prospect of carbon tariffs

Ambitious countries will support and accelerate industrial decarbonisation with subsidies and grants. The International Energy Agency expects a massive expansion of green subsidies.[14] Governments are also increasingly supporting low-carbon products through green public procurement policies. Such financial assistance must be complemented by disincentives to emit, and many countries have already implemented carbon taxes and emissions trading schemes.

One of the EU's key mechanisms for cutting carbon is its emissions trading scheme, which since last year has started to impose higher costs on manufacturers. China's emissions trading scheme, already the world's largest, will progressively expand to involve more and more manufacturers.[15]

Such efforts are largely absent in Australia, and this raises an important question: how long will leading countries be willing to tolerate other countries who allow their manufacturers to emit carbon pollution without restraint? Increasingly carbon tariffs on imports are being discussed as a way of penalising free-riders.[16]

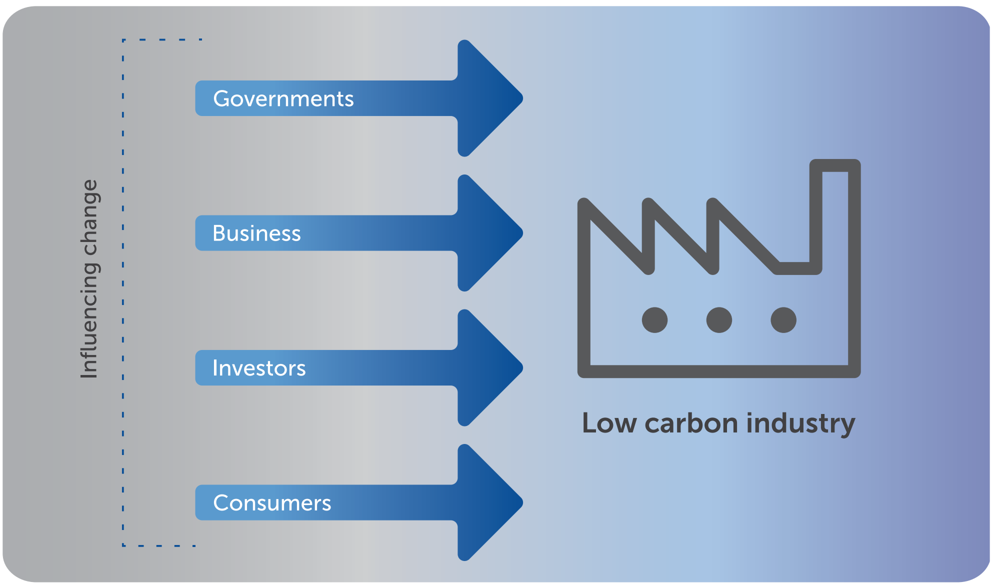
> ***"Now is not the time for a medium-sized economy to test global tolerance for free riders."*** [17]
>
> ***Innes Willox, CEO, Ai Group***

This would involve taxing imports with high-carbon content. French President Emmanuel Macron has said the EU will need to impose carbon tariffs on countries that fail to limit their industrial carbon emissions,[18] and a recent EU directive makes explicit provision for such tariffs.[19]

The prospect of carbon tariffs calls into question the wisdom of delaying emissions reductions in the manufacturing sector. Continuing on the high-carbon path could undermine Australia's long-term potential for exports and prosperity.

Despite Australia's exceptional potential to electrify industry, we risk getting left behind if change does not happen soon. Today's investments in high-carbon manufacturing may turn into tomorrow's financial burdens, a reality increasingly recognised by investors.

Figure A1.1 Governments, investors, consumers and businesses are driving manufacturers towards renewable energy



### Box A1.1 The Swedish route to zero emissions

Like Australia, Sweden has many attributes which support the low carbon electrification of industry. It is a small, wealthy, industrialised economy with a low population density. It has substantial natural and mineral resources, as well as plentiful renewable energy resources. Sweden has been decarbonising its energy supply for decades and now gets less than 5% of its electricity from fossil fuels.

Sweden is one of the few countries to have a legislated zero emissions target (by 2045). It is also one of the first to properly acknowledge that this target demands policies to encourage industrial decarbonisation. Sweden also realises that its cheap, abundant renewable energy gives it comparative advantage in a low carbon world.

The Swedish Government and manufacturers are exploring radical innovations to electrify industry, including two world-leading projects:

**HYBRIT –** a project to create zero carbon steel with hydrogen backed by A$80 million from the Swedish Energy Agency (see C9 'How to electrify steel'). Sweden holds 90% of the EU's iron ore reserves and sees an opportunity to become a pioneer in zero carbon steel.

**CemZero –** collaboration between cement-maker Cementa and power company Vattenfall to electrify energy-hungry cement kilns.

Such support is complemented by costs on carbon. Most energy-intensive Swedish manufacturers are covered by the EU's emissions trading scheme. Other manufacturers are subject to Sweden's carbon tax, meaning they must pay A$175 (SEK 1,150) for every tonne of emissions. This high tax provides a very strong incentive to reduce emissions.

## Investor action on climate

Companies need to borrow money and sell shares. Both their share price and the interest they pay on their loans depend on investors' confidence in their business strategy. If the perceived risk is too high, businesses can't borrow at any price.

Investors increasingly view high-carbon strategies as risky – vulnerable to new policies to curb emissions and to a backlash from ethical consumers. This concern has already led investors to divert billions of dollars away from companies that mine and exploit fossil fuels.[20]

Scrutiny is now extending to large *consumers* of fossil fuels. Investors want to assess a company's prospects in a low-carbon world. Many are joining forces, in groups like the Investor Group on Climate Change, to demand better information about all companies' carbon emissions and reduction strategies.[ii]

These demands have heavy-weight support from the Financial Stability Board (FSB), an international body monitoring financial stability. The FSB sees climate-related risks, including carbon exposure, as a major threat to the global financial system. Mark Carney, the head of the FSB and Governor of the Bank of England, has stressed the danger of the value of fossil-fuel dependent companies collapsing due to a rapid transition to a low-carbon economy.[21]

The FSB formed the Task Force on Climate-related Financial Disclosures (TCFD) to establish a reporting system for corporate climate risks.[22] The TCFD advises energy-intensive manufacturers to publish analyses of the impact to their business of "stricter constraints on emissions and/or pricing carbon emissions", and to report on their consumption of fossil fuels and the energy intensity of their products.[23]

*ii Most major companies have heeded this call and publicly report their emissions to CDP, an international corporate emissions platform.*

The TCFD's recommendations have been publicly endorsed by investors responsible for managing US$100 trillion of assets – equivalent to the annual global GDP. This includes the world's leading pension funds and insurers, banks, asset managers and the largest sovereign wealth fund.[24] Australia's financial regulator the Australian Prudential Regulation Authority has also responded by stepping up its scrutiny of financial companies' disclosure and management of climate risks.[25]

Investors are now exerting pressure on governments to ramp up climate action. The Investor Agenda, a powerful group of 288 institutional investors managing US$26 trillion in assets, has asked all governments for better climate policy, in order to achieve the goals of the Paris Agreement and accelerate private sector investment in the low-carbon transition.[26]

> ***"Organizations that invest in activities that may not be viable in the longer term may be less resilient to the transition to a lower-carbon economy; and their investors will likely experience lower returns."***
>
> ***Task Force on Climate-related Financial Disclosures***

## A new legal duty to manage climate risk

Failure to disclose and manage carbon exposure entails not only financial, but also legal risks. The corporate governance guidelines of the ASX state that listed companies should disclose their environmental risks and how they will manage them.[27] The 2019 edition of these guidelines will go further, advising companies to implement the TCFD's recommendations and consider carefully the risks of the shift to a low-carbon economy.[28]

In 2016 senior Australian lawyers issued a legal opinion that company directors who ignore the risks from climate change could be legally liable.[29] One of the lawyers, barrister Noel Hutley SC, said: "it is likely to be only a matter of time before we see litigation against a director who has failed to perceive, disclose or take steps in relation to a foreseeable climate-related risk that can be demonstrated to have caused harm to a company".[30]

Australian manufacturers cannot ignore this new form of liability or the shifting investor landscape. Any viable business strategy must now include emissions reduction, and many companies are starting to act.

> ***"The transition to a low-carbon economy is underway and that means the so-called transition risks are unavoidable." APRA will encourage Australian companies to "float with the transitional current rather than fighting against the rising tide."*** [31]
>
> ***Geoff Summerhayes, Executive Board Member, Australian Prudential Regulation Authority.***

## Demand by supply chain and consumers

Shrewd companies are turning climate risk into a business opportunity. They are bolstering their credibility with investors, customers, employees and policymakers by showing they understand the low-carbon transition.

More than 100 major global corporations have now joined the Science Based Targets initiative (SBTi),[iii] which helps companies determine a pathway for reducing emissions in line with climate science. Participants include household names such as Coca-Cola, IKEA, Mars, L'Oreal, Nestlé, Sony and Walmart. Several hundred other companies have committed to signing up.[32]

The initiative also includes energy-intensive manufacturers of chemicals, metals, paper, packaging machinery and construction materials. For example, Indian steel-maker Mahindra Sanyo Special Steel has committed to reducing emissions from steel production by 35% by 2030. By the same date paper manufacturer Stora Enso will reduce emissions from a tonne of their product by 31%.[33]

A small selection of corporate emissions reductions targets is listed in Table A1.1. These targets are ambitious, and some manufacturers, including Mars and Unilever, have even committed to eliminating emissions. Success will necessitate major changes to manufacturing processes, and an almost total rejection of fossil fuels.

*iii A collaboration between CDP, the United Nations Global Compact, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF).*

## Supply chain pressures

Arguably the greatest incentive for manufacturers to reduce emissions will come from pressure exerted by the retailers and famous brands that buy their products. All signatories to the SBTi plan commit to reducing not only their own emissions, but those of their supply chain (Table A1.1). Many companies, such as Electrolux and Sony, have started to track suppliers' use of energy and management of emissions, often using external auditors.[34 35] Unilever aims to halve emissions of its products across their whole life-cycle by 2030.

Global brewer Heineken found that 53% of the emissions of a bottle of Heineken beer are related to the glass bottle itself. Heineken is now planning to set an emissions reduction target for its packaging, and will work with suppliers to achieve it. The company has even suggested that if the glass industry cannot deliver, they will explore making their famous bottle with other materials.

> ***"We are also going to take a close look at our packaging because it represents a significant portion of our carbon footprint. The aim ... is to try to make the glass sector move. We want to inspire them to move in the direction of climate-controlled glass production."*** [36]
>
> ***Jean-François van Boxmeer, CEO, Heineken***

Coca-Cola also realised the greater part of their emissions comes from their bottles, not the drink. This led to the development of PlantBottle™ plastic bottles made partly from sugar cane waste, rather than oil. To date, more than 35 billion PlantBottles have been distributed, reducing emissions by 315,000 tonnes of carbon dioxide.[37]

IKEA is another company that is serious about emissions reductions. Like Heineken, most of IKEA's emissions relate to its supply chain, and the company is working with suppliers to reduce the average climate footprint of its products by 70%.[38] This will require suppliers to switch to renewables, not just for electricity, but also for heat. IKEA also plans to eliminate virgin fossil-fuel from its textiles and plastic products.[39]

As the world's largest corporations strive to achieve ambitious emissions targets, manufacturers everywhere will have to adapt.

> ***"We recognise that our own carbon footprint is the smallest part of our value chain carbon footprint, dwarfed by the impact of our supply chain and customer use of our products. By 2022, all of our strategic food suppliers will be required to have implemented a 10-year strategic climate mitigation and adaptation plan."*** [40]
>
> ***Marks & Spencer - the world's first carbon neutral retailer.***

## Opportunity knocks

Government action, investor scrutiny and business strategy are combining to drive a transition to low carbon manufacturing. The good news is that Australia is in a prime position to take advantage of this changing landscape.

In a low-carbon world, energy-intensive industry will migrate to countries like Australia to take advantage of our cheap, abundant renewable energy. Good renewable resources also provide a reason to stay for the long term, countering the recent tendency for manufacturers, such as the car industry, to relocate to places with cheaper labour or bigger tax incentives.

Australian companies that harness renewables to increase their energy efficiency and boost productivity will be at the forefront of this shift, offering investors long-term stability as demand increases globally for low emissions products.

> ***"Renewable energy is the way that Australia can once again become a cheap energy superpower and industries like aluminium smelting will relocate onshore."*** [41]
>
> ***Kobad Bhavnagri, Head of Bloomberg New Energy Finance in Australia***

**Table A1.1 emissions reductions targets of selected signatories to the Science Based Targets initiative**

| Company | Sector | Emissions reduction target* | Supply-chain targets? |
|---|---|---|---|
| Carlsberg | Brewing | 92% by 2030 | Yes |
| Coca-Cola (HBC AG) | Beverages | 50% by 2020 | Yes |
| Danone | Food | 30% by 2030 | Yes |
| Dell | Technology hardware | 40% by 2020 | Yes |
| Diageo | Alcoholic beverages | 50% by 2020 | Yes |
| Electrolux | Home appliances | 80% by 2025 | Yes |
| Heineken | Brewing | 80% by 2030 | Yes |
| IKEA | Furniture | 80% by 2030 | Yes |
| Konica Minolta | Technology hardware | 60% by 2030 | Yes |
| Mars | Food | 100% by 2040 | Yes |
| SIG | Packaging | 60% by 2040 | Yes |
| Sony | Technology & entertainment | 90% by 2050 | Yes |
| Stora Enso | Paper and wood products | 31% by 2030 | Yes |
| TETRA PAK | Food packaging | 58% by 2040 | Yes |
| Unilever | Consumer goods | 100% by 2030 | Yes |

**Companies' direct emissions and emissions related to electricity (scope 1 and 2 emissions). Supply-chain targets are additional to this (scope 3 emissions).*

# A2 - Industrial heat in Australia

To remain competitive and thrive in the low-carbon era, manufacturers everywhere will need to adapt. Current high-carbon production processes are incompatible with national and international goals to limit the impact of climate change.

Most industrial materials such as steel, paper, plastic, cement, glass and ceramics do not exist in nature. We must create them by transforming materials that we dig up or grow. Material transformation on an industrial scale requires two types of energy.

First we need motive power to drive machinery. Over several centuries the efficiency of motive power has improved as we have progressed from wind and water (18th century), to steam (19th century) and then to electric motors (20th century).

Secondly, we need thermal energy – often a lot of it. The usual method of generating this heat has not changed fundamentally since the bronze age: we light a fire. Every year in Australia burning fossil fuels for industrial heat processes produces 42 million tonnes of carbon dioxide – 8% of the national total.[i] That's as much as Australia's entire car fleet and more than the state of South Australia. Globally the contribution of process heat is higher – about 12% of all emissions[42] – and in China the proportion may be as much as 30%[43]

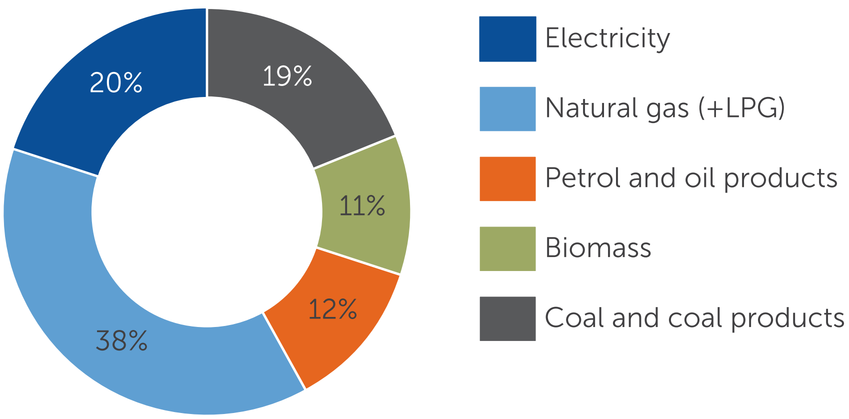
These emissions rarely feature in public discussion about climate change, and until now no one has set out how to tackle them.

This report explores the potential for industry to generate heat differently, through the smart use of renewable electricity.[ii] It shows that many industrial heat processes can be electrified, saving energy and money, as well as dramatically reducing emissions.

***"It's black and white – if industrial emissions are not resolved, we won't meet our Paris commitments."*** [44]

***Hugh Grossman, executive director of RepuTex (energy consultancy).***

Figure A2.1 Energy end use in Australian manufacturing, 2016.[53]




*i If we consider all energy use as well as process emissions, the Australian manufacturing sector produces 110 million tonnes of emissions – 21% of the national total (See National Inventory by Economic Sector 2015, Commonwealth of Australia 2017.).*

*ii This report covers the manufacturing sector as defined by the Division C of the Australian and New Zealand Standard Industrial Classification (ANZSIC).*

## Fossil fuels as energy source and feedstock

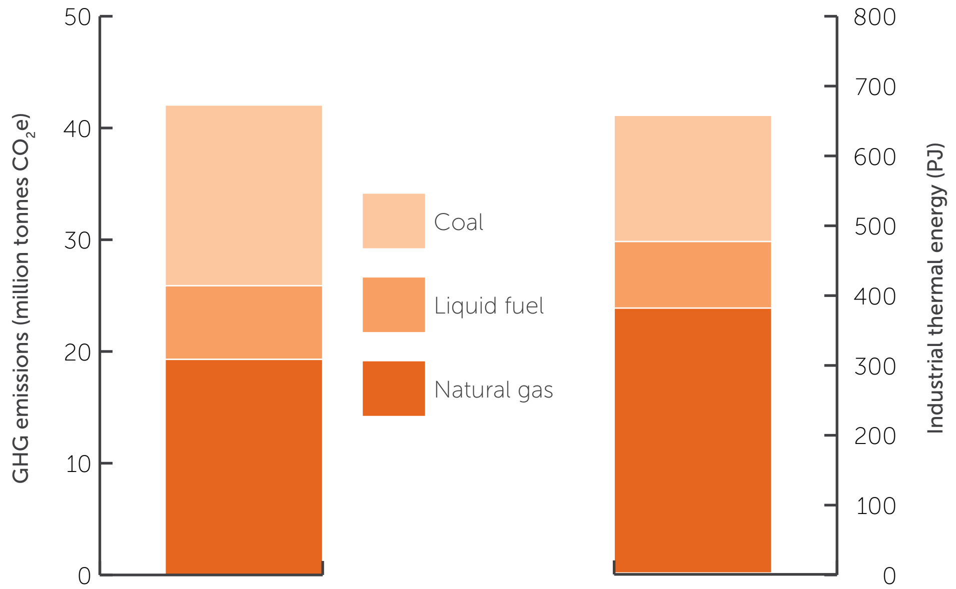
The manufacturing sector uses 29%[45] of all energy consumed in Australia (1209 PJ).[iii] About 70% of this energy is derived directly from burning fossil fuels and the rest from electricity and bioenergy (Figure A2.1). Electricity supplies about 20% of manufacturing energy use, much of which is for lighting, utilities and driving machinery.

Industry currently uses fossil fuels for two main purposes. The first is to generate heat. Natural gas provides most of this heat energy. The second is using fossil fuels as a feedstock (a material input into a product) in several processes, of which the most important are:

- natural gas in ammonia production (12% of domestic industrial gas use)
- coal used as feedstock (and simultaneously as fuel) in iron and steel production (50% of domestic industrial coal use)
- crude oil used to make polymers for plastics and rubber production (4% of domestic oil refining).

By switching to renewable alternatives for both fuel and feedstock, the Australian manufacturing sector could reduce annual emissions by at least **42 million tonnes** - representing 660 petajoules of energy (Figure A2.2).

**Figure A2.2 Proportion of solid, liquid and gaseous fossil fuels in industrial thermal energy use and emissions, Australia 2016**




*iii This excludes petroleum refining which is not covered in this report.*

## Some industrial heat processes are already electrified

While fossil fuels supply the majority of industrial heat demand, some heat processes are already electrified. The most significant of these are:

- **Electrolysis –** chemical decomposition produced by passing an electric current through a material. Several metals such as aluminium, zinc and ferrochrome are produced through electrolysis. The chlor-alkali process, which produces both chlorine and caustic soda is also electrolytic. Electrolysis is an energy-hungry process. For example, melting aluminium requires on average 14 MWh of electricity per tonne of production (Box A2.1).
- **Arc furnaces –** a furnace which gets its heat from an electric arc (an electric current, in which electrons jump across a gap, producing very high heat). The most common use of an electric arc furnace is to recycle steel (see C9 'How to electrify steel'). Arc furnaces are also used in the production of silicon, calcium carbide, ferroalloys and other non-ferrous alloys.
- **Electrical resistance heating –** this involves generating heat by passing an electric current through a resistive heating element (Section B3). Electric ovens and boilers work this way. Some industries use electrical resistance furnaces for processes which require a high degree of temperature control such as plastic extrusion and carbon fibre production (see C7 'How to electrify plastic' and Box B3.1 on carbon fibre).

The focus of this report is the adaptation of industrial processes which are not yet electrified. For processes that already run on electricity, such as aluminium smelting, the priority is to supply them with renewable electricity. The next section shows that manufacturers of all sizes and types can now improve the efficiency of heat processes by using cheap and reliable, renewable electricity.

## A note on bioenergy

Figure A2.1 shows that about 11% of energy for manufacturing comes from biomass. Nearly all of this is wood, wood waste and bagasse (sugar cane waste) and much of it is consumed locally by the timber and sugar cane industries which produce it. Finding alternatives to this use of biomass is not an objective of this report. The potential for greater consumption of bioenergy by industry is discussed in Box A3.3.

### Box A2.1 Powering Australia's energy-hungry aluminium smelters

Australia is home to four aluminium smelters, which use huge amounts of electricity. The smelter at Portland, Victoria consumes 10% of the state's electricity. The 850 MW smelter at Tomago consumes 12% of the electricity in New South Wales. When these smelters were built in the 1980s they enjoyed low electricity prices, but they have long relied on government funds to remain operating.[54]

Renewable energy in Australia has now reached a level of cost and maturity that it can power energy-hungry processes like aluminium smelting. Continued government aid should facilitate this transition, securing jobs in the aluminium sector for the long term.

## Industrial process heat emissions by sector

Figure A2.3 shows direct fossil fuel emissions in Australia by industry type. Nearly half of these emissions are from burning natural gas for heat (Figure A2.2). The largest emitting sector is non-ferrous metals, due mostly to the enormous natural gas consumption at just six alumina refineries in Western Australia and Queensland.

The second largest emitter is the chemicals sector, which includes oil refining and production of polymers for plastics and rubbers, as well as many hundreds of different industrial chemicals. Most emissions from this sector come from just two polyethylene plants and six ammonia plants. Chemical sector emissions also include more than 2 million tonnes from the ammonia production attributable to feedstock reactions rather than heat (C10 'How to electrify ammonia').

Most emissions from the iron and steel sector come from coal rather than natural gas. Conventional steel production involves converting coal into coke, which then acts as both feedstock and fuel within a blast furnace (C9 'How to electrify steel'). There are only two blast furnaces in Australia, and a small number of electric arc furnaces for recycling steel. The iron and steel sector emissions in Figure A2.3 include all coal and coke-related emissions.

Figure A2.3 Direct energy-related emissions from Australian industry by sector 2016

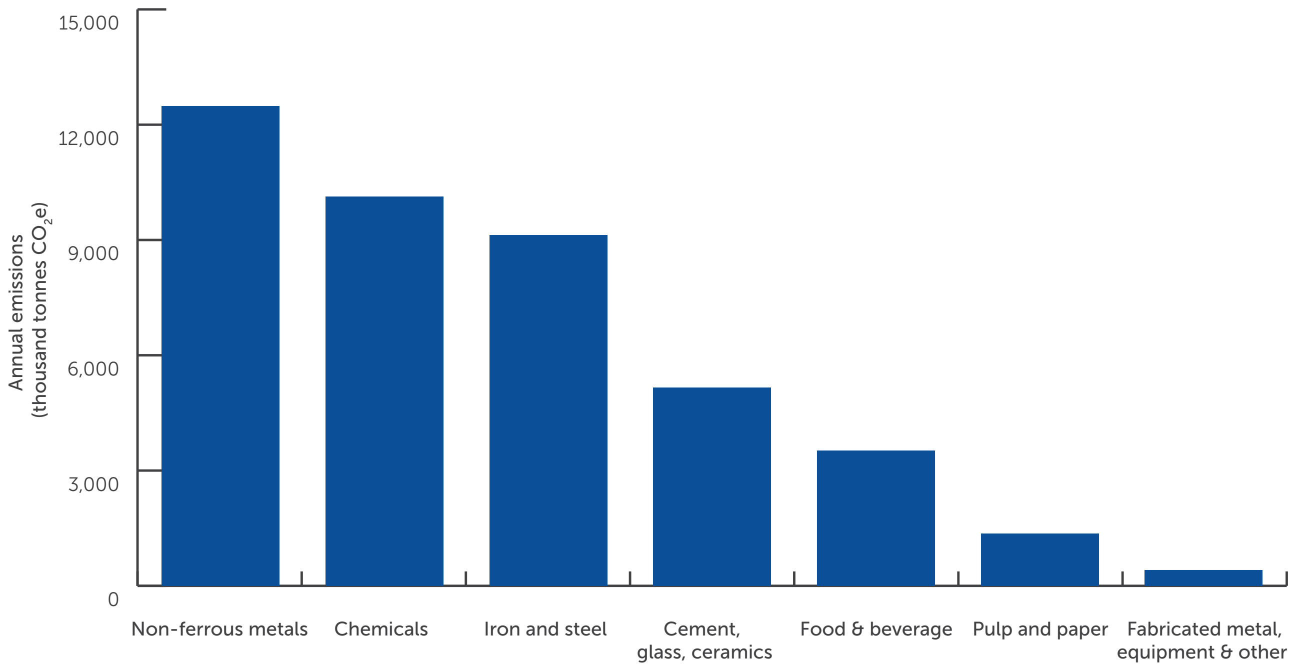
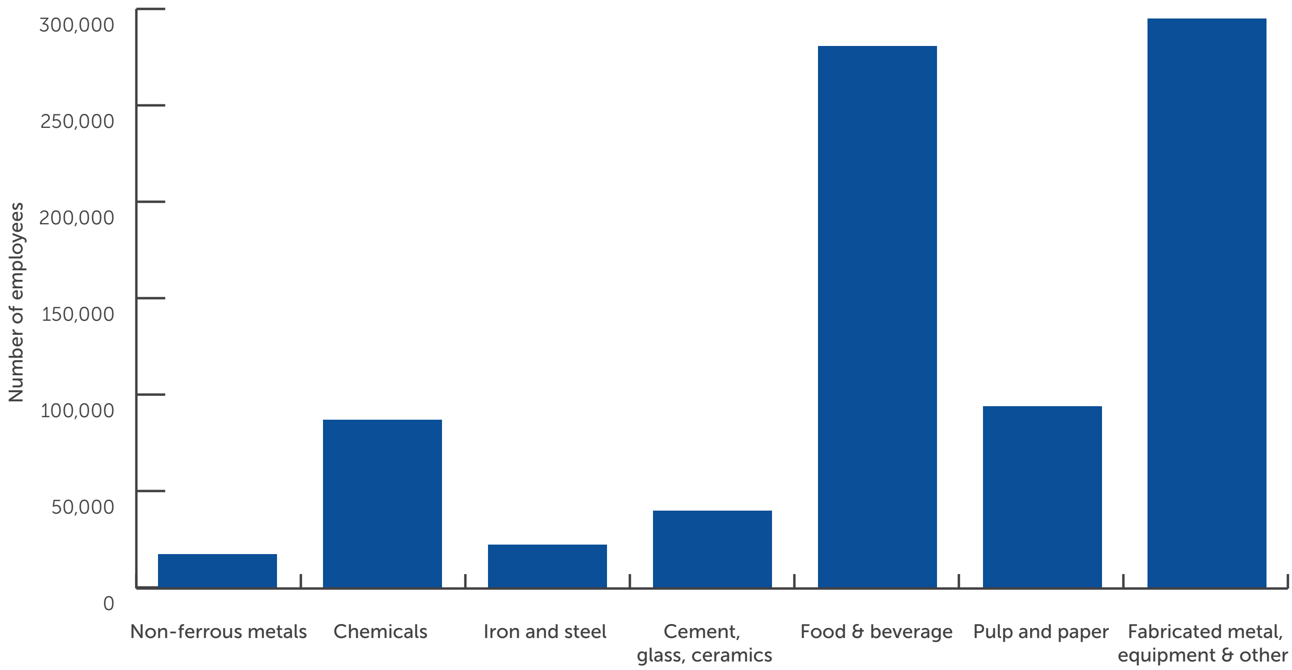


Figure A2.4 Employment in Australian industry by sector 2017




## Creating jobs with renewable energy

This report shows how, by using renewable electricity for industrial heat processes, we can reduce emissions. But it also shows how electrifying can lead to more jobs in manufacturing, by reducing energy bills and giving companies an advantage in the global market.

This applies to all sectors, whatever their level of emissions. Figure A2.3 gives a misleading picture of the importance of each sector to the economy. As mentioned above, emissions from the metals and chemicals sectors are attributable to a handful of installations. In contrast thousands of facilities are engaged in producing food, drink, fabricated metal, machinery and equipment. These sectors employ more than half of the 830,000 people working directly in Australian manufacturing (Figure A2.4). There is an equally compelling case that these lower-energy sectors switch to renewable electricity, especially small-to-medium enterprises with tighter budgets. By moving to zero carbon production they can boost their bottom line, international competitiveness and build on their strong export potential.

In identifying electrical heating technologies and industry case studies we have taken account of sectors' contributions to both emissions and employment.

### Box A2.2 Fugitive emissions from fossil fuels

The emissions discussed here exclude the significant fugitive emissions of methane which occur during the extraction, processing and transporting of fossil fuels – nearly 50 million tonnes of carbon dioxide equivalent per year.

The proportion of national emissions attributable to industrial heat processes would rise to at least 10% if we allocated a fair share of fugitive emissions. The true scale of fugitive emissions is likely to be higher than official estimates as they are not properly monitored, especially those from coal seam gas extraction.[55]

## Types of industrial process heating

Industrial processes use heat to transform raw materials into something more useful. Table A2.1 lists some of the most common categories of heat-driven process. These include:

- **Drying.** Removing water from a material is energy-intensive. It has been estimated that 12 to 25% of industrial process heat is used simply for drying products such as paper, brick, wood, textiles and food products.[46]
- **Food preparation.** The food and beverage sector uses heat for cooking, sterilising, pasteurising and drying. The temperature requirements of the food sector tend to be low (below 200°C) and are often delivered by steam.
- **Chemical reactions.** Many manufacturing processes depend on chemical reactions which occur at high temperatures. For example, hydrogen and nitrogen form ammonia at around 450°C, and iron ore reduces to iron at temperatures above 800°C. Calcination is a type of high-temperature reaction used to process non-metallic minerals such as clay and alumina. The most important industrial calcination process is the conversion of limestone which takes place at 900 to 1,500°C in a cement kiln.
- **Melting.** Heat is required for all melting processes. For example, glass is manufactured by melting sand and other materials at 1,500°C, and metals and plastics are melted before being recycled or moulded into products.

## Fuel-based heating and the inefficiency of central steam-boilers

The most common way to generate heat in industry is to burn a fuel. This creates hot combustion gases which either heat the material directly (like a gas oven), or indirectly through radiant tubes or panels (like a gas boiler). Manufacturers employ a huge array of furnaces, kilns, and melters which use fuel-based heating.

Many processes use steam to transport and transfer thermal energy. Steam is a safe and efficient energy carrier which transfers thermal energy in many lower temperature processes (below 200°C). Applications of steam heating include cooking, drying and many chemical processes such as the Bayer method of processing bauxite. It has been estimated that half of the energy used in the chemicals sector is to generate steam.[47]

Steam is usually produced in a central gas-fired boiler. The hot steam is then distributed throughout the facility in long pipes. This method is convenient but leads inevitably to heat loss through distribution pipes. Even small holes or gaps in insulation lead to significant waste. A pipe carrying steam at 170°C with a single 1-centimetre-wide puncture would lose nearly half a gigajoule of steam per hour – costing well over A$100 every day.[48]

Another inherent inefficiency of central boiler systems is that they generate steam at the highest temperature required in the facility, meaning energy is wasted for lower temperature applications. Often in such systems only 30 to 50% of the steam is used effectively.[49] This presents a huge opportunity for improvements in end-use efficiency.[50]

## Table A2.1 Categories of process heating[iv]

| Process | Definition | Example industrial applications | Example equipment | Temperature |
|---|---|---|---|---|
| Agglomeration and sintering | Heating a mass of fine particles so they fuse into larger lumps | Creating lumps of iron ore suitable for a blast furnace<br>Fusing ceramic powder to make pots etc | Furnaces, kilns, microwaves | 1,300°C (iron ore) |
| Calcining | Calcining is the removal of chemically-bound water or gas | Main application is the production of cement clinker<br>Lime production, clay activation and recovery of lime in paper and pulp industry | Kilns (gas or coal-fired)<br>Flash calciners – gas-fired | 800°C-1500°C |
| Chemical separation | Separation of a chemical mixture into two or more distinct products | Oil refining, air separation, refining metals, distillation | Pyrolysis furnace | 100°C-900°C |
| Coking | Conversion of coal into almost pure carbon by prolonged heating in the absence of oxygen | Manufacture of coke, principally for iron-making | Coking oven | 1,100°C |
| Curing | Heating a polymer to toughen it. | Setting of polymer-based glues, paints and coatings in many industries. | Furnaces, ovens, infrared, ultraviolet | 0-200°C |
| Drying | Removal of water that is not chemically-bound | Drying food, paper, textiles, waste plastic, sand, fly ash etc | Steam dryers, fuel-based dryers, rotary dryers, fluidised beds, infrared | 100°C -300°C |
| Forming and reheating | Heating to soften and improve workability of materials | Extrusion and moulding of plastics, rubber and glass<br>Metals are heated to enable rolling, extrusion and forging | Ovens and furnaces | 200°C-1000°C |
| Heat treating | Controlled heating and cooling of a material to achieve properties, such as hardness, strength and flexibility. | Hardening, annealing and tempering of fabricated metals, glass and ceramics | Gas-fired furnaces and kilns, electric induction coils | 200°C-800°C |
| Melting | Heating a solid material until it melts | Melting metal prior to casting or recycling<br>Glass-making | Furnaces - reverberatory, crucible, tower<br>Induction furnaces | 200°C -1,800°C |
| Smelting | Chemical reduction of a metal from its ore through heating | Reduction of iron ore to produce pig iron<br>Extraction of aluminium from alumina | Coal-fired blast furnaces<br>Electrolytic smelters for aluminium, zinc etc | 1,500°C-2,000°C |
| Various food processes | Baking, roasting, frying, and sterilisation | Food and drinks industry | Ovens, gas boilers, infrared | 60°C-250°C |

iv *Table partly from: Improving Process Heating System Performance: A Sourcebook for Industry. US Department for Energy.*

## From energy efficiency to emissions efficiency

Current methods of producing many everyday goods and materials depend on burning fossil fuels. This is the cause of at least 8% of Australia's emissions, and 12% of global emissions.

There is currently a lack of policy to curtail these emissions, despite the need to do so to meet Australia's commitments under the Paris climate agreement and reduce the impacts of dangerous climate change. Internationally this is changing with both China and the European Union imposing a carbon price on manufacturers (Section A1). In Australia the limited action in this area has focused on energy efficiency. Clearly more efficient use of energy is desirable, reducing both costs and emissions. Australian manufacturing is inefficient, consuming more energy per dollar of output than any other developed country,[51]

There is ample scope for Australia to improve its energy productivity which, unlike nearly every other developed country, is actually declining.[52]

However it is no longer enough simply to make fossil fuel systems more efficient. Such an approach will only prolong our reliance on fossil fuels. Instead we should aim to eliminate emissions entirely, at the same time as using energy more efficiently. Electrification can achieve both objectives, as long as the source of electricity is renewables such as solar PV and wind (Section A4).

The focus of this report is greenhouse gas emissions, rather than energy efficiency. Fortunately, electrification allows us to eliminate emissions *and* use energy more efficiently.

Figure A2.5 Steelworks blast furnace

## Box A2.3 This report's approach to energy efficiency

Many reports about industrial emissions reduction focus almost exclusively on more efficient use of energy. Energy efficiency is important, but it is no longer enough simply to make fossil fuel systems more efficient. This approach will only prolong our reliance on fossil fuels.

Instead we should aim to eliminate emissions entirely, at the same time as using energy more efficiently. Electrification can achieve both objectives when powered by clean, renewable sources.

The focus of this report is greenhouse gas emissions, rather than energy efficiency. But electrification allows us to eliminate emissions *and* use energy more efficiently.

**Why does electrification allow for more efficient use of energy?**

Most fossil fuel-fired heating processes are inefficient, with much of the heat being wasted. For example, section A2 describes how using a central boiler to generate steam is inherently inefficient, with heat losses often exceeding 50%. Electrical heating technologies use energy more efficiently because they can:

- deliver heat at the precise temperature required (traditionally, industrial heat is often provided at temperatures well above what is needed)
- transfer heat directly to a material, with very little heat escaping to the environment
- provide heat at the point of use, minimising distribution losses.

In some cases electrification can even avoid the need for heat altogether – for example using reverse osmosis to remove water or ultraviolet light to cure paints.

**Energy as a service**

In this report we approach energy as a service which enables production of a material. We describe practical energy-efficient techniques to delivering an end product. We are not aiming to match the temperatures or thermal energy inputs of existing processes. Indeed part of our objective is to exploit the advantages of electrification to use less thermal energy.

This means that throughout this report we compare the cost of a service delivered rather than the cost per unit of electrical or fossil fuel energy. For example, if the service we need is firing 1 tonne of bricks, we are interested in the comparative costs, in terms of money and energy, of achieving that outcome.

## Box A2.4 This report's approach to materials efficiency

In our global economy we waste a lot of the materials we manufacture. Sometimes it seems as if we're engaged in a massive project to dig stuff up from one hole only to shove it in another hole, with a lot of energy expended in the process.

We could significantly reduce emissions and energy use across the manufacturing sectors simply by making less stuff. This doesn't require self-denial but a full recognition of the value of materials. This would lead to greater levels of reusing, recycling, repairing, extending product-life and designing products so they are easier to recycle or maintain. Our end goal should be a circular economy where waste is nearly eliminated and materials are continually reused.

Even in a successful circular economy there will still be a need for some virgin materials, and therefore a need for the type of technologies presented in this report.

Materials efficiency is not a central theme of this report. Nevertheless, electrified heating often produces a more consistent product, and therefore less material wastage. We also call for far greater recycling of plastic as part of a strategy for limiting the use of oil refining in plastics production. BZE plans to publish a future report on materials efficiency and the circular economy.

# A3 - Why electrify industrial heat?

Manufacturers in the zero-carbon future will turn to various sources of renewable energy to replace fossil fuels. This report shows the enormous potential of one source: renewable electricity.

Electricity has many advantages as a source of energy for industry (Box A3.1). It is faster, safer, more efficient and capable of powering any industrial heat process.  There is no limit on the temperatures electricity can generate. Electricity is also the most versatile form of energy, which can be converted into mechanical, chemical or thermal energy.

Part B of this report reviews the most important electrical heating technologies, and Part C reviews potential applications in 10 major industries. Parts B and C present powerful evidence of the many benefits of electrifying industry, summarised in Box A3.1 opposite. The technology section shows that, by electrifying heat processes, manufacturers can reduce their energy use, often by 50% or more. They can also cut costs, increase output, improve quality and provide safer working conditions.

In some cases the increase in production speed will be the most attractive aspect of electrification. The electromagnetic technologies are particularly impressive in this regard. Induction, infrared and microwave heating often perform heating tasks several times faster than gas-fired systems, sometimes reducing a process which takes several hours to just a few minutes.

The 'How to' guides show how, through smart use of electrical heating, we can halve the energy input into the manufacture of many products, including beer, food, milk powder, brick, plastic and aluminium castings.

## Saving energy means saving money

Most of the 'How to' guides in Part C include cost estimates for the energy required to operate alternative electrical heating systems, compared to existing gas systems. These comparisons show how the superior efficiency of electrical heating can translate into lower running costs. Over the coming decade this economic advantage will grow as the cost of renewable electricity continues to fall.

In 2018, for on-site solar PV generation, where network costs are avoided, the operational energy cost is already lower for electrified processes including paper, aluminium casting, milk powder, food and beer.

Where a manufacturer sources renewable electricity from a third party (a power purchase agreement) electrified processes will generally be cheaper to run for gas prices in the medium to high range.

In Sections A4 and Appendix 1 we show that by 2028, renewable electricity prices could fall by up to 50% compared to today. On-site PV could be available at 4 c/kWh at which point it may be cheaper than gas per unit of energy.[i] Renewable electricity secured through a power purchase agreement will be available at 7.5-9 c/kWh, including network costs.

At these prices electrified processes powered with renewable electricity will often be cheapest. Where electricity is sourced from on-site PV generation, the cost-advantage of electrified processes will be stark. For example, compared to a low cost of gas, melting aluminium could be 40% cheaper and brewing beer 50% cheaper. Where renewable electricity is sourced from a power purchase agreement, electrified processes will often be cheaper than gas. For example, paper drying will be cheaper for gas prices at A$12/GJ and above.

## A powerful case for switching now

Electrifying industry must go hand-in-hand with a switch to renewable electricity. At the moment electricity from the Australian grid is expensive and emissions-intensive. This is changing as coal-fired power stations are replaced with renewable energy and we move towards a zero-carbon grid. But manufacturers don't need to wait for a national transition. As we show in Section A4, they can choose to switch to renewable electricity now, saving money in the process.

The falling cost of renewable electricity makes the case even more compelling. Within 10 years the cost of renewable electricity generated on-site is likely to halve.

**This represents a profound opportunity to modernise Australian manufacturing, reducing costs, emissions and energy use.**

i  4 c/kwh equates to $11.1 per gigajoule.

### Box A3.1 Ten benefits of electrifying industrial process heat

1. ***Electricity can power any heat transfer process.*** In principle there is no industrial heating process that cannot be electrified. Electricity can be used to achieve any required temperature, and is already used for some extreme heat processes, such as waste incineration at 3,000˚C. Natural gas-fired processes have a temperature limit of about 1,900˚C.
2. ***Electrical heating is more efficient.*** Electrical heating methods can often halve the energy required for a particular process.[57] This is because they target heat precisely where it is needed so less heat is wasted. Electric heat pumps enable reuse of waste heat, achieving efficiencies above 400%. Industrial gas-fuelled systems are never more than 90% efficient and in many cases are well below 50% efficient.
3. ***Electrical heating is faster.*** Some electrical heating technologies, such as induction and infrared, take only seconds or minutes to complete a heating task that would take hours using a gas-fired system. The greater output that results is often the biggest financial advantage from electrifying.
4. ***Electricity is available everywhere.*** Our towns and cities are already connected to the electricity grid. Electricity is more widely available than any other industrial energy source. In off-grid locations, wind, solar power and batteries can provide a low-cost source of electricity.
5. ***The falling cost of renewable electricity.*** Wholesale renewable electricity is now competitive with gas. At today's best prices manufacturers can pay less for a unit of renewable electricity than some were paying for gas in 2017.[i] The cost of renewables is projected to fall a further 50% in the next 10 years (Section A4). Manufacturers converting to electrical heating today can look forward to years of falling energy costs.
6. ***Manufacturers can go 100% renewable today.*** Any business can now decide to go 100% renewable, either by building their own wind or solar farm or commissioning renewable electricity through a third party (Section A4). By doing this they can secure a long-term energy price, ending the uncertainty caused by fluctuating gas and electricity prices.
7. ***Electrical heating is precision heating.*** Heat supplied by electricity is easier to control and can be more precisely focused. This not only saves energy but improves the quality and consistency of some products such as processed foods and metal components.
8. ***Electrical heating reduces labour costs.*** Combustion heating systems require constant monitoring. Most electrical heating systems don't need this, and because they are easier to control and automate, they also require fewer staff to operate the system. Electrical heating complements the manufacturing sector's transition towards greater digitisation and automation.
9. ***Modularity and size.*** Many electrical heating technologies can be installed as modular solutions – allowing them to be implemented over time, spreading cost and risk. Electrical process equipment is also typically smaller than combustion equipment. This can help foster an economy of reduced scale, as smaller equipment requires less space, and facilities can be decentralized and sited closer to raw material sources or product markets.
10. ***Energy security.*** Combustion equipment depends on the availability of specific fuels. Fossil fuels are a finite resource with volatile prices. Switching to electricity provides flexibility, enabling a manufacturer to take advantage of new methods and sources of generation without changing anything on the factory floor.

*i Best value renewables PPA - $55/MWh is equivalent to $15.27 per gigajoule for gas. Some companies were paying more than $20 per gigajoule for gas during 2017.*

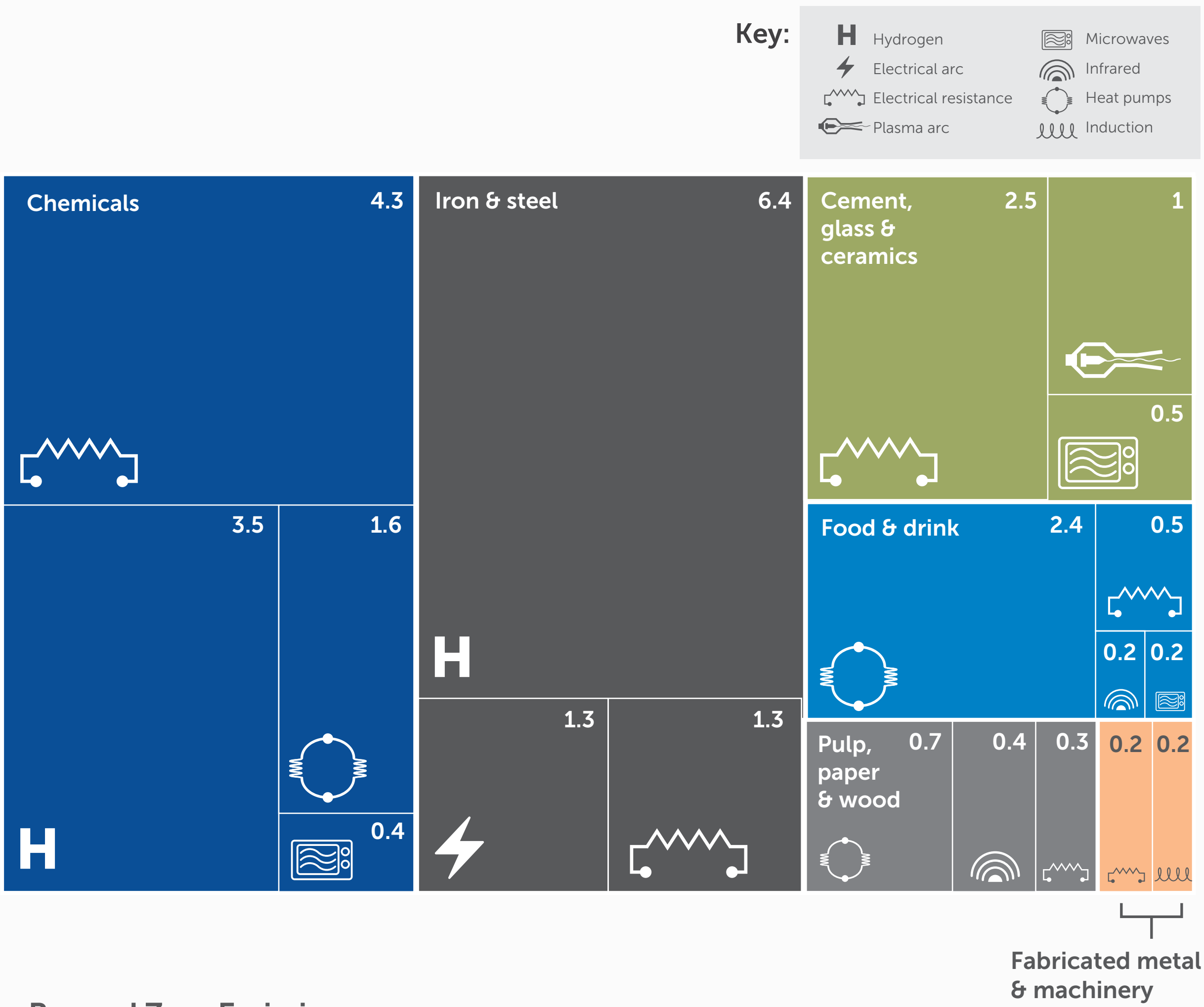
## Releasing the potential of renewables with electrical heating technologies

*Electrifying Industry* describes how the manufacturing sector can be powered with renewables using electric heating technologies. To show one way this might be achieved, we have developed one pathway for the electrification of industry, based on the analysis in Parts B and C. This pathway is illustrated by Figure A3.1 which is explained by the notes on the next page.

In our pathway, renewable electricity replaces 450 PJ of fossil fuels – the current annual energy consumption of the whole manufacturing sector, excluding non-ferrous metal production.[56] This pathway would eliminate 30 million tonnes of greenhouse gas emissions – 6% of Australia's total.

Our low carbon pathway uses seven types of electrical heating technology, as well as hydrogen – an indirect route to electrifying industry. Part B contains more detailed analysis about the potential for each of these technologies to contribute to the displacement of fossil fuels in the different manufacturing sectors.

**Figure A3.1 One scenario for the electrification of Australian manufacturing. Contributions of various technologies with estimates of greenhouse gas emissions displaced (million tonnes of $CO_2e$).**



## Notes on Figure A3.1

The numbers in Figure A3.1 represent millions of tonnes of greenhouse gas emissions that could be displaced by each electrical technology. For example, electrical resistance heating could remove 4.3 million tonnes of annual emissions from fossil fuel powered heating in the chemicals sector.

### Heat pumps

**Temperature range: up to 160°C**

Industrial heat pumps generate hot water, air or steam by using electricity to extract thermal energy from one place and transferring it to another. They are spectacularly efficient (300 to 700%), producing several times more thermal energy than they use in electrical energy.

Heat pumps are central to electrification as they have the broadest application – most factories only need low-grade heat below 160°C. In Section B1 we estimate heat pumps can displace 95 PJ of natural gas by replacing traditional centralised gas boiler systems.

Our pathway uses heat pumps in these sectors: chemicals (dark blue), food and drink (light blue) and pulp, paper and wood (light grey).
Read more: Section B1, How to electrify guides: C1: Prepared food; C2: Beer; C3 Milk powder.

### Electromagnetic heating

**Temperature range: up to 2,000°C**

Electromagnetic heating technologies uses the electromagnetic spectrum to deliver heat. They are faster and more efficient than gas-fired processes. Our pathway includes three types of electromagnetic technology:

- *Infrared* to produce food and drink (light blue) and pulp, paper and wood (light grey)
- *Induction* to produce fabricated metal and machinery (orange)
- *Microwaves* to produce ceramics (green) and various chemicals (dark blue).

In Section B2 we estimate electromagnetic heating technologies could displace 32 PJ of fossil fuel energy.
Read more: Section B2, How to electrify guides: Paper (infrared); C5: Aluminium casting (induction); C6: Brick (microwaves).

### Electrical resistance

**Temperature range: up to 1,800°C**

Electrical resistance generates heat by passing an electric current through a resistive heating element, like an electric bar heater. Electrical resistance provides a straightforward alternative to many gas-fired heating systems, and our pathway employs it in all manufacturing sectors.

The ‘How to’ guide on electrifying glass shows how electric glass melters could form the basis of an all-electric, more efficient glass industry using 30% less energy.
Read more: Section B3; How to electrify guides: C7 plastic; C8: Glass.

### Electric arc heating

**Temperature range: up to 5,000°C**

Electric arc heating is a specialised technology, most commonly used in furnaces to process metals such as steel. Electric arcs are also used in plasma arc furnaces and offer new possibilities for electrifying high-temperature, high-volume processes like cement making.

Our pathway uses electrical arc furnaces to produce iron and steel (dark grey), and plasma arc furnaces to produce cement and ceramics (green).

In Part B we estimate electrical resistance and electric arc heating could displace 140 PJ of fossil fuel energy.
Read more: Section B3; C9: How to electrify steel.

### Renewable hydrogen

Hydrogen is an industrial chemical made by passing an electric current through water (electrolysis) and is an indirect route to electrifying industry. It is an industrial feedstock that can replace fossil fuel feedstocks. The prospect of hydrogen-based steel is particularly promising as steel making currently causes 6-7% of global emissions.

Our pathway uses hydrogen to make chemicals (dark blue) and iron and steel (dark grey).
Read more: Section B4, How to electrify guides: C9: Steel; C10: Ammonia.

## A many-sided transition

The transition described in our pathway is likely to be led by industrial heat pumps. Most individual factories, particularly small and medium-sized enterprises, require heat in the range that can be supplied by heat pumps (below 160°C). Due to their efficiency and ability to recover waste energy, heat pumps are cost-effective today. Thousands of factories, particularly in the food and drink sector, could save money and energy by installing an industrial heat pump.

The versatility of electrical resistance makes it the technology with the broadest application across the largest number of industries. Electrical resistance could power the huge variety of furnaces, ovens and kilns across the manufacturing sector. It has particularly large potential to replace the wide array of gas-fired heating processes in the chemicals industry. Electric arc furnaces will play a vital role in the zero-carbon steel industry.

Electromagnetic heating will be crucial to the electrification of specific processes. For example, electrical induction easily outperforms any other technique for melting metal, and microwave heating has enormous potential to reduce energy and production times in the ceramics industry, including brick-making.

Our pathway also highlights the growing importance of renewable hydrogen, reflecting its potential to replace fossil fuel feedstocks, in the production of steel, ammonia and organic chemicals such as ethylene. Hydrogen is indispensable to the decarbonisation of these emissions-intensive industries – see the 'How to electrify' guides on steel and ammonia. The International Energy Agency has shown Australia is one of the best places in the world to make renewable hydrogen due to our excellent renewable energy resources.

## Other pathways are possible

Figure A3.1 represents just one pathway for Australian manufacturers to fuel switch to renewables – there are many other possible scenarios. The ultimate technology mix will be driven by multiple factors such as business need, cost-effectiveness and the rate of learning by Australian industry.

The contribution of different electrical heating technologies is hard to predict as there is considerable overlap in their application. For example, microwaves, resistance heating and plasma furnaces all have potential roles in minerals processing. And infrared and heat pumps could both be used for drying paper (See 'How to electrify recycled paper'). Electrical heating will also compete with other sources of renewable heat, such as solar thermal and bioenergy (Box A3.2 and Box A3.3).

Our pathway represents the displacement of fossil fuels used in Australian manufacturing as it exists today. It does not capture the many opportunities for industrial expansion. In a low carbon world, it makes financial sense to make energy-intensive products in places like Australia with excellent resources of renewable energy. We have an opportunity to massively increase the production and export of products such as ammonia, steel and carbon fibre, to choose three that are covered in this report. There are also opportunities for less-energy intensive but much higher-employing sectors such as food, textiles and equipment. As global consumers become increasingly attracted to greener goods, these sectors can differentiate their products through zero carbon production.

The pathway does not include the potential for some fossil fuel input to be simply avoided, rather than replaced through electrification. For example, our *Rethinking Cement* report (2017) showed that Australia could reduce the need for cement kilns by 80%. Also, in the plastics sector, we can avoid the use of fossil fuels by developing a modern plastics industry based on reducing, recycling and bio-based plastics ('How to electrify plastic').

## Other technologies will assist the transition

### Other electrical technologies

Many other technologies, not covered in detail in this report, have the potential to play a supporting role in the transition to zero-carbon industry.

For example, we touch briefly on concentrated solar PV which converts sunlight into both electricity and heat with 80% efficiency (Box B5.1). This technology is still emerging but has great potential for industries with a low-level heat requirement and sufficient available land. We also outline heat storage systems which allow efficient storage of excess renewable electricity as heat for later reuse (Box B5.2).

Some electrical technologies remove the need for heat altogether. For example, ultraviolet radiation can be used to cure coatings applied to wood, metals, paper, plastic and other material. Ultraviolet processing is a non-thermal process which can replace thermal curing systems, typically using 75% less energy.

We have also omitted membrane technologies, such as reverse osmosis. These technologies are used to separate, purify or remove water from a liquid. They are a low-energy, non-thermal alternative to thermal purification techniques such as evaporation.

### Other types of renewable energy

Electrification is not the only means of providing zero-carbon process heat. Other renewable energy options for industry include bioenergy and industrial solar thermal – summarised in Box A3.2 and Box A3.3.

The potential of these alternatives is limited because they are location-dependent. Solar thermal relies on cheap, sun-exposed land next to the factory, and bioenergy is usually only cost-effective near the source of organic waste. It is not practical for most manufacturers, especially smaller ones, to relocate to be closer to a source of renewable energy.

The policies we propose in Section A5 are designed to promote all types of renewable energy and electrical heating technologies. However, this report shows that for most industries and manufacturing processes, only electrification has the flexibility and capacity to supply heating energy.

## Box A3.2 Bioenergy in manufacturing

Bioenergy is a solid, liquid or gaseous fuel derived from organic materials such as wood, agricultural crops and municipal waste. It offers an alternative renewable fuel for industry, replacing fossil fuels for heat processes, particularly those requiring steam or hot water. Technologies to facilitate a switch to bioenergy are commercially available, including biomass boilers, gasifiers and digestors.

Bioenergy already provides about 11% (115 PJ) of the energy used in the Australian manufacturing sector. Three industrial processes account for the vast majority of current bioenergy consumption:

- Sugar mills use waste bagasse to provide heat and power (86 PJ)
- Timber yards use waste wood to provide heat and power (15 PJ)
- Paper mills use waste wood products to generate steam (7 PJ).

These sources of bioenergy can be economic because they are wastes produced and consumed on-site. They typically cost less than $1 per gigajoule – cheaper than any other form of energy.[58] Most other sources of bioenergy are much more expensive.

**There is plenty of bioenergy, but we cannot burn it all**

The Clean Energy Council has identified huge long-term potential for additional bioenergy from agricultural wastes, landfill gas and forestry residues. In theory these sources could provide as much as 450 PJ per year, or more than the manufacturing sector's use of natural gas.[59] In practice there are major economic and environmental obstacles to the full exploitation of this resource.

Most available bioenergy is from very disparate agricultural wastes, such as wheat residues. Collecting, handling and transporting such wastes would add significantly to their cost. Wood pellets, for example, cost at least A$12 per gigajoule and cannot compete with natural gas at this price.[60] Bioenergy needs to be at least one third cheaper than natural gas to make up for its lower heating value (less than half of natural gas) and additional costs of handling and storage.

There are also environmental constraints on using all agricultural and forestry residues. These wastes contain carbon and other nutrients extracted from the land, and burning them permanently deprives the land of these nutrients, depleting the soil in the long term. For this reason we must continue to return most residues to the land that produced them.

**Appropriate and sustainable use of bioenergy**

Taking account of the limitations of cost and environmental impact, we estimate that a quarter of Australia's unexploited bioenergy could become available to industry. This equates to an additional **112 PJ or 11%** of current demand, more or less doubling bioenergy use from today.

The highest value use of biomass is not combustion for heating, but for feedstocks. Bioenergy, particularly wood waste, is a vital replacement for fossil fuel feedstocks for certain products, such as synthetic hydrocarbons, bio-based plastics and steel made in arc furnaces. We should prioritise allocation of bioenergy to these feedstock applications.

We may be able to supplement waste bioenergy with energy crops – trees and other plants cultivated to provide energy. These can be sustainable in some circumstances, such as where trees are planted on previously cleared land, helping to improve degraded soils by adding carbon and removing salt.

We must, however, limit the use of energy crops. In most cases they are a low-value use of land compared to producing food, fibre, materials or simply allowing native vegetation to flourish. Energy crops are also an inefficient way of extracting energy from an area of land. Sugar cane, the highest yielding of major crops, can produce a maximum of about 800 GJ/Ha per year in Australia. Other crops such as wheat and barley achieve barely 10% of this.

Solar panels convert sunshine into energy far more efficiently than any plant, producing 3-5 times more energy per hectare than sugar cane. Electricity is also a far more useful and transportable form of energy than biomass.

Native forests are not an appropriate source of bioenergy. Burning natural vegetation is unsustainable, inefficient and indefensible. We must increase efforts to preserve the natural habitats that remain – they provide us with vital services necessary to life, and are irreplaceable.

### Box A3.3 Industrial solar thermal

The simplest way to generate industrial process heat is to convert sunlight into thermal energy. Solar thermal technologies do this, often with efficiencies well above 50%.

Solar thermal is a commercially-proven technology and the International Energy Agency has collected hundreds of examples of its use in industrial processes.[61] The largest projects under construction are in the 1 gigawatt range, capable of producing thousands of tonnes of steam per day.[62]

The most developed types of solar thermal system are described below in order of increasing cost, complexity and temperature capability.

*Flat plate collectors* absorb sunlight and heat a transfer medium, usually water. They can provide hot water at 30-85°C for industrial purposes such as cleaning.

*Evacuated tubes* absorb sunlight, heating a fluid which transfers the heat to a heat pipe in the centre of the tube. These tubes lose less heat than flat plates and can deliver temperatures up to 150°C. By adding curved mirrors behind the tubes, the maximum temperature increases to 200°C.

For higher temperatures sunlight must be concentrated. *Parabolic trough systems* use curved mirrors that track the sun, concentrating sunlight onto pipes that run parallel to the trough. Linear Fresnel reflectors are similar but use flat mirrors to concentrate sunlight onto a central linear receiver. Both these systems use oil as a transfer fluid and can supply steam at 100-450°C.

Higher temperatures can be achieved with a *solar tower* surrounded by sun-tracking mirrors (heliostats). The mirrors reflect sunlight onto the top of the tower, heating a storage medium such as molten salt to 600°C or higher. The ability to store heat enables the heat supply to continue for several hours when the sun is not shining.

*Solar towers* and *parabolic dish systems* can even provide temperatures, up to 2,000°C. Parabolic dishes are the most efficient type of concentrated solar system but are not yet commercially proven.

**Potential to replace fossil fuels**

Solar thermal technologies have the technical capability to provide the heat for most industrial processes. By using solar thermal manufacturers would not only lower emissions but reduce operational expenditure and exposure to fluctuating energy prices.

However, because the cost of installing solar thermal systems increases in line with their temperature capability,[63] they are not economic for temperatures above 250°C.[64] Below that temperature, and especially below 150°C, they can be a cost-effective alternative to gas. A 2015 report for ARENA found solar thermal often beats gas on cost, even where a gas system is already installed.[65]

Several other factors affect the suitability of solar thermal. Firstly, these systems require suitable space that is not always available in industrial sites or densely populated areas. Secondly, their performance is linked to a site's level of solar radiation, meaning they do not perform as well in cloudy parts of Australia, including Melbourne and Sydney. Thirdly, there is the consideration of how a manufacturer's use of heat correlates with the output of a system affected by daily and seasonal variations in sunshine. Often additional heat storage will be needed to manage these variations, pushing up overall costs.[66]

These limitations restrict the potential use of solar thermal in Australian industry. Energy consultancy EnergyAE has estimated the technology could supply 11% of heat demand by manufacturers, with the highest potential in the food, beverage, textiles and paper sectors.[67]

This estimate excluded alumina processing, Australia's largest industrial user of gas (160 PJ per year).

An ongoing ARENA-funded study is looking at the potential of concentrated solar thermal in alumina processing.[68] Early findings are that concentrated solar could replace 29-45% of gas without major changes to existing equipment.[69] If this potential were fully realised by the alumina industry, we could displace an additional 11% of all fossil fuel energy used byindustrial heat processes in Australia.

We estimate, therefore, that the range of solar thermal technologies, has the potential to **displace about 22% of fossil fuels** currently used in industrial heat processes.

# A4 - Road to renewables

The success of zero-carbon electrified industry depends on affordable, renewable electricity. Renewable energy is now a cost-competitive option for manufacturers, and its cost will continue to fall (Figure A4.1).

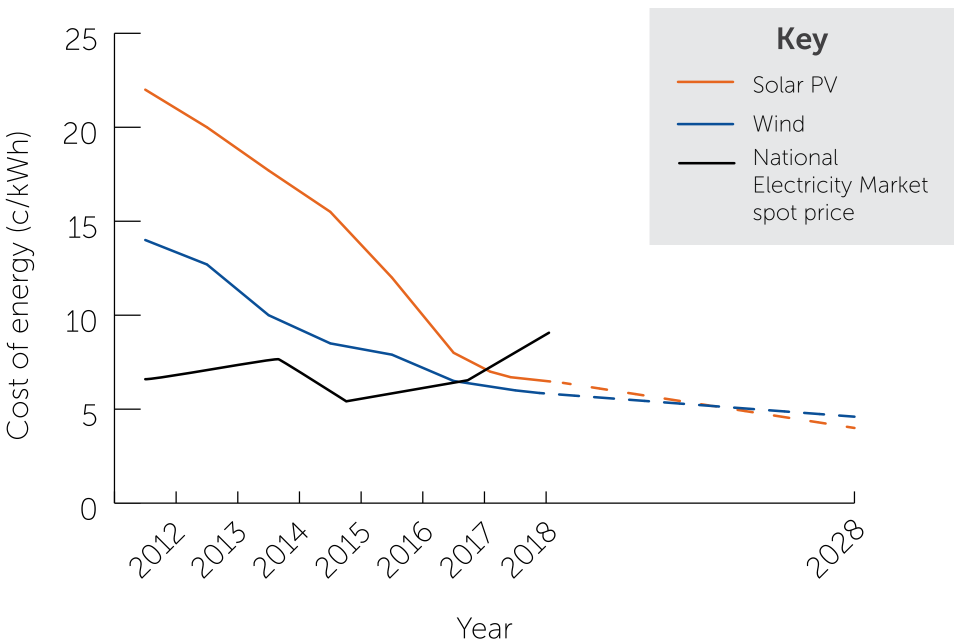
While the cost of renewable energy has been falling, the cost of grid electricity has risen for all consumers. Since 2007 retail electricity prices have increased by 80-90% in real terms.[70] For many industrial users renegotiating contracts in 2017 and 2018, the price of electricity doubled or even tripled.[71]

Multiple failures in national energy policy underlie these rising costs. The largest single cause of price rises has been regulations incentivising massive investment in new and upgraded network infrastructure – poles and wires. Much of this investment has proven unnecessary, but consumers have had to pay for it nonetheless through higher network charges.

More recently, higher network costs have been exacerbated by higher wholesale electricity prices. The wholesale price doubled from less than 5 c/kWh in 2015 to around 10 c/kWh in 2017. This spike was caused by higher prices for coal and gas, and the failure to replace mothballed coal-fired power stations with renewable energy.[72]

Public disputes about the price of energy have obscured a major development which is ultimately more important: the plummeting costs of renewable electricity. Manufacturers no longer need to wait for energy policy and the return of lower prices. They can reduce electricity costs and take control by securing a supply of cheap renewable energy.

**Figure A4.1 The cost of renewable energy in Australia has plummeted and will continue to fall.**



## Manufacturers are saving money with renewable energy

Table A4.1 identifies leading companies taking advantage of the new era of renewable energy. These organisations are either building their own renewable installations or agreeing contracts for renewable energy supply. The list includes small and medium-sized companies, as well as major manufacturers such as Adelaide Brighton, BlueScope Steel and Sun Metals.

Lower prices provide the greatest incentive for switching to renewables. But renewable energy isn't just cheaper, it's also less risky. Whether companies decide to generate their own energy or commission it from a third party, they lock in energy prices for the long term. They no longer have to endure of the vagaries of the market and suddenly escalating energy prices.

### Renewable energy power purchase agreements

Many of the organisations in Table A4.1 have benefited from a relatively new option: renewable energy power purchase agreements (PPAs). These PPAs enable a customer to enter into a long-term (5-20 year) agreement for renewable energy without any upfront costs or construction project risk. PPAs also allow organisations to enter into energy contracts as part of a consortium, in order to further reduce costs.

Although the precise costs of these deals are usually confidential, anecdotal evidence suggests typical cost savings of 20-50% compared to standard electricity contracts.[73] Origin Energy and the Telstra consortium are reported to have agreed a wholesale price at around 5.5 c/kWh – around half of recent average industry prices for grid electricity.[74] Manufacturer ANCA is paying 8 c/kWh for its renewable electricity, 30% less than it would have paid for a standard retail contract (Box A4.2).

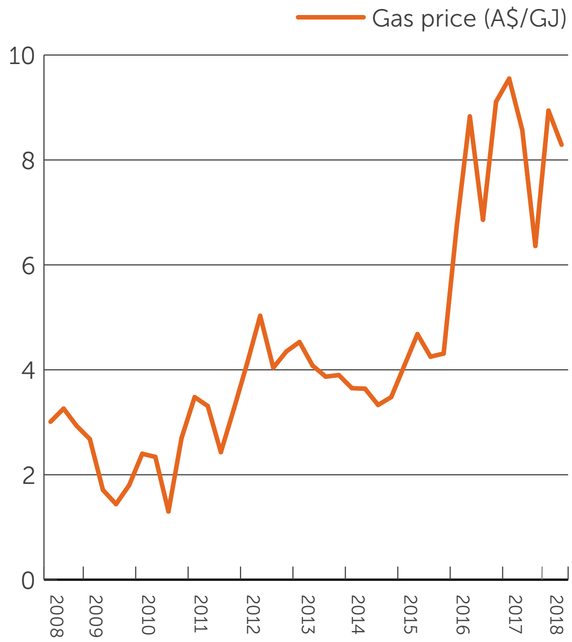
The market for renewable energy PPAs is set to boom, as more large energy users become aware of their benefits. This will drive their cost down further and aid the expansion of renewable energy in Australia.[75]

### Box A4.1 Higher gas prices are here to stay

Australia was long the country of cheap gas, with prices in the range of A$3-4 per gigajoule (GJ). This era ended with the massive expansion in large liquefied natural gas (LNG) export facilities, which linked Australia to international gas markets. The wholesale gas price has risen since 2007 to a high of more than A$10/GJ in 2016.[100]

Most forecasters expect further increases in the wholesale gas price in the medium term. For example, the Australian Energy Market Operator projects that wholesale gas prices will increase by 48% over the next 20 years.[101] The University of Melbourne's Climate and Energy College has shown that wholesale gas prices are unlikely to drop below A$8/GJ in the near future.[102] This price floor is partly due to the high cost (at least A$7/GJ) of extracting gas from unconventional sources such as coal seams.[i] For our analysis we assume a wholesale gas price range of A$8-$15/GJ between now and 2028.

**Figure A4.2 Rising gas prices in Australia**




*i Western Australia may prove an exception. All current gas exploitation is conventional and the recent wholesale price has been 30-50% less than in the east coast.*

**Table A4.1 A selection of organisations using utility-scale renewables energy[83]**

| Organisation | Capacity (MW) | Type | Renewables location | Operational |
|---|---|---|---|---|
| Origin Energy[84] | 530 | Wind PPA | Stockyard Hill Wind Farm, VIC | 2019 |
| Adelaide Brighton | 279<br>(% of output) | Wind PPA | Lake Bonney, SA | 2018 |
| Consortium including Telstra, ANZ, Coca-Cola Amatil and the University of Melbourne[85] | 226 | Wind PPA | Murra Warra Wind Farm, VIC | 2019 |
| Melbourne Renewable Energy Project - Consortium including City of Melbourne, University of Melbourne and RMIT.[86] | 80<br>(PPA for 25) | Wind PPA | Ararat, VIC | 2018 |
| ANCA (Victorian machine manufacturer) | 50<br>(% of output) | Wind PPA | Ararat, VIC | 2018 |
| Nectar farms | 196<br>(15% of output) | Wind + solar PPA | Bulgana, VIC | 2018 |
| Mars Australia | 200 | Solar PPA | Ouyen, VIC | 2019 |
| Carlton & United Breweries | 112<br>(PPA for 37) | Solar PPA | Mildura, VIC | |
| Telstra | 70 | Solar PPA | Emerald, QLD | |
| University of New South Wales | 250<br>(PPA for 60) | Solar PPA | Balranald, NSW | 2019 |
| BlueScope Steel | 35 | Solar PPA | Finley, NSW | 2019 |
| Liberty One Steel | 400 | Solar self-build | Whyalla, SA | 2019 |
| Sun Metals | 124 | Solar self build | Clare, QLD | 2018 |
| SA Water | 6 | Solar self-build | Solar | 2018-2020 |
| Primo Smallgoods | 3.2 | Solar on-site | Brisbane, QLD | 2019 |
| Nature's Organics | 1.3 | Solar on-site | Ferntree Gulley, VIC | 2018 |
| SCS Plastics | 0.3 | Solar on-site | Shepparton, VIC | 2018 |
| Dobinson's Spring & Suspension | 0.5 | Solar on-site | Rockhampton, QLD | 2018 |

## Box A4.2 Wind drives a great deal for ANCA

ANCA is a global leader in the manufacture of tool grinding machines. In January 2018 ANCA's Melbourne facility signed up to a renewable PPA with Flow Power. Under the deal ANCA buys a fixed percentage of wind power from the 240 MW Ararat wind farm.

ANCA is paying an average of 8 c/kWh for this wind energy. That's well below the price paid by most manufacturers today, and 30% less than the next best quote ANCA could get for grid electricity.

Renewable energy now supplies about 80% of ANCA's electricity use in Melbourne. The company is now considering increasing that to nearly 100% by installing solar panels.

ANCA CEO at the time, Grant Anderson said: "This is a win-win helping both our business and the environment."

## Self-generating renewable electricity

Many companies are also building their own renewable energy capacity. For sites with sun-exposed land or roof space, the simplest option is to install solar PV panels. This is also likely to be the cheapest option as it provides electricity free from network fees. Commercial solar PV systems above 500 kW can now supply power for below 7 c/kWh.[76] This is already below the typical cost of grid electricity but is projected to fall a further 50% in the next 10 years (Table A4.2). Around 50,000 Australian businesses have installed rooftop solar and this number is growing every day.[77]

Industrial users needing more energy than they can generate on-site can build their own off-site wind or solar PV plant. The first major example of this in Australia is Sun Metals, which is building a 124 MW solar farm to provide some of the power for its zinc refinery in Queensland. Sun Metals says the solar power will help to justify a potential $300 million expansion, creating 827 jobs during construction and 100 permanent jobs.[78]

Liberty OneSteel in South Australia is going even further, with plans for 1 GW of solar energy and more than 200 MW of energy storage in the form of batteries and pumped hydro. This infrastructure will be used to power the company's steel operations in South Australia, Victoria and New South Wales. The company aims to slash energy costs at the Whyalla Steelworks by at least 30% (Box A4.3).

> ***"We see Australia with its incomparable energy resource – as the natural home for expansion of energy-intensive industry, with renewables to play an integral role."*** [79]
>
> ***Sanjeev Gupta, Liberty OneSteel***

These investments by Sun Metals and Liberty OneSteel demonstrate that renewable energy is now a mature technology that can power highly energy-intensive manufacturing. This was foreshadowed in Beyond Zero Emissions' *Renewable Energy Superpower report*, which highlighted that industries would favour places with cheap, abundant renewable energy.

These Australian pioneers are reflective of a worldwide trend. Over 100 global corporations have committed to source 100% of their electricity from renewables by 2020.[80] In April 2018 both Google and Apple announced their successful achievement of this goal. Australian companies, such as Carlton & United Breweries, Mars Australia and Unilever Australia are following suit with their own 100% renewable targets. According to a 2018 survey, nearly half of Australian businesses are considering wind, solar and storage.[81] Globally one third of businesses are considering using renewables as their main source of energy.[82]

## Box A4.3 GFG Alliance – capitalising on Australia's energy advantage

In 2017 UK-based GFG Alliance bought Australian steel-maker OneSteel. The company's chair, Sanjeev Gupta, has since emerged as a leading advocate of renewables in Australian manufacturing. Gupta realises that Australia's renewable resources give industrial energy users an advantage over overseas competitors.

To capitalise on this advantage, GFG Alliance plans to build 1 GW of solar and energy storage, much of it near the Whyalla Steelworks in South Australia. They will use this renewable energy to power their steelworks, with expected cost savings of 40%.

The company is also planning build an additional 10 GW of large-scale solar across Australia, with the expectation of selling the energy to industrial users.

> ***"...as the cost of renewable energy declines, Australia's abundant energy resources can be used to scale up energy-intensive skilled manufacturing industries with low-cost and long-term sustainable energy supply."*** [103]
>
> ***Liam Reid, head of power business development, GFG Alliance***

## Box A4.5 Renewables plus storage = reliable 24-hour supply

Wind turbines and solar panels generate electricity while the wind is blowing or the sun is shining.

In a future 100% renewable grid, reliable 24-hour energy supply will rely on storing this energy. Several technologies will compete for this energy storage service, including pumped hydropower, concentrated solar power and stored hydrogen.

Manufacturers will have the option of accessing energy storage provided by the energy markets, or installing their own storage. If they choose the latter, the most practical and affordable storage technology is likely to be batteries.

Commercial-scale batteries are becoming attractive thanks to an 80% reduction in price since 2010. [104] Existing large systems including the 100 MW Tesla battery in South Australia, and a 20 MW battery attached to the Bulgana Wind Farm supplying Nectar Farms (Table A4.1). Batteries of 25 MW and 30 MW are now being built in rural Victoria.

Bloomberg New Energy Finance expects battery costs to fall another two thirds by 2030 (to A$93/kWh). This will lead to the installation of 27 GW of batteries in Australia by 2050 – a greater capacity than all coal-fired power stations in Australia in 2018.[105]

## Box A4.4 World's largest renewable project could power industry in Western Australia

The Asian Renewable Energy Hub is a A$20 billion plan to electrify the East Pilbara region of Western Australia. An international consortium proposes building the world's largest renewable energy project with 6 GW of wind and 3 GW of solar generation. This would generate about the same amount of electricity as Australia's entire 2020 renewable energy target – 33,000 GWh.

The consortium plans to sell most of this electricity to south-east Asia via an undersea cable. But it also expects to attract domestic demand from industries such as minerals processors and hydrogen producers. If this project goes ahead as planned, it will be an emphatic demonstration of Australia's unrivalled capacity to power energy-intensive industry with renewable energy.

## Renewable prices continue to fall

In Parts B and C of this report we compare the operational energy costs of processes powered by gas and renewable electricity. These comparisons are based on the range of future renewable electricity and gas prices set out in Tables A4.2 and A4.3. We are not attempting to forecast future energy costs but to present one plausible scenario.

In Australia the wholesale price for solar PV and wind energy has fallen steeply over the last five years (Figure A4.1). A similar trajectory has been observed in most countries. This decline will continue as manufacturers find more ways to cut costs, improve efficiencies and benefit from economies of scale in the growing solar and wind industries.[87]

By 2028 the cost of wind power could fall by a further 23% and the cost of solar PV by a further 53% (Table A4.2). This would make wind power available at 4.7 c/kWh and solar at 3.6 c/kWh. The average for wind and solar PV would be 4 c/kWh, assuming a higher proportion of solar PV. At these prices, manufacturers' current advance on renewable energy would become a stampede.

Lower costs for renewables require no breakthroughs in technology but simply the continuation of long-term trends. Our projections are based on historical cost reductions, growth rates and learning curves.[i] For more details about these calculations see Appendix 1: Future renewable energy prices.

Our price projections are consistent with those of other analysts such as the International Renewable Energy Agency[88] and Germany's Mercator Research Institute.[89] Indeed, some overseas projects have already achieved lower prices than our projection for 2028. In the last year renewable energy contracts have been signed in Mexico, Saudi Arabia and Dubai for around (AU) 2c/kWh.[ii]

Some analysts believe costs will fall even more quickly. Leading Australian solar researcher, Professor Martin Green, expects a solar PV price of about 1.5c/kWh by 2020, and the National Renewable Energy Laboratory in the US believes the cost of wind power could halve by 2030.[90]

### Network charges

Where renewable energy can be generated on-site, a manufacturer will only pay the cost of generation. For some of our 'How to' guides in Part C (such as steel and ammonia) we have assumed a manufacturer would build its own renewable plant and pay zero network costs.

Where renewable electricity is generated off-site there will be an additional network cost. Network fees vary widely among industrial electricity users. In general the higher the usage, the lower the network fee per kilowatt hour. Based on published network tariffs, we have assumed a network charge of 5 c/kWh in 2018, remaining unchanged in 2028 (Apx 1: Future renewable energy prices).

### Gas prices

We have assumed that gas prices will not return to their previous low prices. Instead the wholesale gas price will range between A$8 and A$15/GJ between now and 2028. This projection is based on forecasts from the Australian Energy Market Operator and the University of Melbourne (Box 4.1).

Gas customers pay a premium on top of the wholesale price, which reflects their location, level of demand, transport and retail costs. A large industrial user can expect to pay A$1 to A$2 above the wholesale price for delivered gas, though few manufacturers use enough gas (1 petajoule per year) to qualify as 'large'.

In 2017 smaller industrial customers paid around A$14/GJ – around A$4/GJ on top of the wholesale price. [91] This average conceals a wide range of contracted prices from as low as A$5/GJ to as high as A$20/GJ.[92] Some small users, unconnected to gas pipelines, pay even more to truck in LPG (liquefied petroleum gas).

For our analysis we assume that between 2018 and 2028 manufacturers will pay delivered gas prices in the range of A$9 to A$17 per gigajoule (Table A4.3).

*i The learning curve is the rate at which the price of a manufactured products falls relative to industry maturity, typically represented as the percentage reduction in cost for every doubling of cumulative production.*

*ii Overseas prices cannot be directly translated into Australian prices as countries have different incentives and cost structures which can be hard to quantify.*

## Box A4.6 Electricity pricing

Electricity bills are made up of several components:

- wholesale costs for the generation of electricity
- network costs or the transmission and distribution networks (poles and wires)
- retail costs of the billing company.

Australian manufacturers pay a wide range of prices for energy from as low as 4c/kWh to as high as 30 c/kWh. Large industrial users, who account for almost half of industrial electricity consumption, pay significantly lower electricity prices – often close to the wholesale price. Smaller industrial users pay more for electricity, and network charges make up a much larger proportion of their bill.

The Australian Competition and Consumer Commission estimates such customers pay on average 6 c/kWh for network charges – out of 12.9 c/kWh overall. Retail costs comprise only a very small component of industrial electricity bills (3% or less).

A manufacturer's demand profile also has a large influence on its electricity bill. Kilowatt hour charges are often relative to the peak in electricity use – even if this peak only last for 30 minutes in a month or year. This means a company with a flat electricity demand will usually pay less per kilowatt hour than a company with large spikes in usage. (This presents a large incentive to minimise the peaks.)

Other factors which influence industrial electricity prices are distance from transmission grid, ability to negotiate and the timing of the contract.

**Table A4.2 Range of renewable electricity costs to 2028 used in this report**

| | | Renewable electricity costs (c/kWh) | | | |
|---|---|---|---|---|---|
| | | **2018** | | **2028** | |
| | | On-site generation | PPA | On-site generation | PPA |
| **Wholesale costs** | | 7 | 7 | 4 | 4 |
| **Network costs** | **Large user** | - | 3.5 | - | 3.5 |
| | **Small & medium user** | - | 5 | | 5 |
| **Total cost** | **Large user** | **7** | **10.5** | **4** | **7.5** |
| | **Small & Medium user** | | **12** | | **9** |

**Table A4.3 Range of gas costs to 2028 used in this report**

| Gas cost range 2018-2028 (A$/GJ) | | |
|---|---|---|
| **Low** | **Medium** | **High** |
| 9 | 13 | 17 |

## How can we generate this additional electricity for industry?

Electrifying industry will require additional installations of renewable electricity. Fortunately, Australia is uniquely blessed with abundant renewable energy resources.

Our *Renewable Energy Superpower* (2015) report found that Australia could generate more than 50,000 TWh every year from wind and solar PV, even if we restrict potential installations to available land within 10 kilometres of an existing transmission line.[93] This means Australia is in the unusual and enviable position of having the natural resources to generate far more renewable electricity than we could ever need.

Table A4.4 shows the additional generation and capacity required for three scenarios of electrification of industry.

- **Scenario 1** is the electrification of all Australian manufacturing which currently uses fossil fuels for heat energy. This scenario excludes the production of steel and ammonia, as well as petroleum processing. We have assumed that by electrifying we are able to halve energy input for industrial heat processes from 148 TWh to 74 TWh. This is 33% of Australia's current annual generation of 225 TWh per year.[94] Scenario 1 would require approximately 28 GW additional resources in wind and solar PV plants.
- **Scenario 2** comprises scenario 1, plus the electrification of the steel and ammonia sectors, which is achieved largely by using renewable hydrogen. We assume that hydrogen-based steel and ammonia production uses the same quantity of energy as conventional production today. (See 'How to electrify steel' and 'How to electrify ammonia'.) Scenario 2 would use 116 TWh of electricity per year, requiring approximately 44 GW additional resources in wind and solar PV plants.
- **Scenario 3** comprises scenario 2, plus trebling today's output of the domestic steel and ammonia sectors, requiring a commensurate increase in renewable hydrogen production. Scenario 3 would use 201 TWh of electricity per year, requiring approximately 77 GW additional resources in wind and solar PV plants.

The additional generation and investment required for these scenarios is certainly significant, but hardly daunting. Bloomberg New Energy Finance already expects 123 GW of wind and solar power by 2050, based on economics alone.[95] Even Scenario 3 only scratches the surface of Australia's extraordinary renewable energy potential.

Bloomberg's forecast requires a build rate of less than 4 GW per year. But wind and solar farms can be constructed in less than a year and we could build new capacity much more quickly. In 2018 energy companies are on-track to install 5 GW of renewable energy capacity in Australia.[96] This investment is occurring despite the uncertain political environment for renewable energy. Far greater installation rates could be achieved if all state and federal governments demonstrated unreserved and bipartisan support for the industry.

## Electrified industry can bolster the grid

An electrified manufacturing sector will support the balancing of supply and demand required by all electricity grids. In a system with a large proportion of variable renewable energy, like solar and wind, it is particularly useful for some customers to temporarily reduce their electricity use during periods of peak demand or limited supply. Large energy users can receive significant financial rewards for providing this service.

A recent report showed that businesses could reduce their electricity bill by up to a third through a range of demand management measures.[97] This could lower prices for everyone by reducing peak demand.'

**Table A4.4 Scenarios for extra generation and capacity required for electrification of industry.**

| Scenario | | Generation required (TWh) | Additional renewable capacity (GW)* | Additional generation required (% of current) |
|---|---|---|---|---|
| 1 | 100% electrification of industry (energy only, not feedstock) | 74 | 28 | 33% |
| 2 | 100% electrification of industry + hydrogen for steel and ammonia | 116 | 44 | 52% |
| 3 | 100% electrification of industry + hydrogen for expanded steel and ammonia sectors | 201 | 77 | 89% |

**This assumes an average 30% capacity factor for PV and wind.*

By switching to electricity for industrial heat processing, manufacturers will help to establish an important source of flexibility in energy demand. Many manufacturers can reduce electricity consumption at short notice without affecting production. For example induction furnaces routinely heat metal to 40-80˚C above their melting point. This means that, like a battery, they hold a significant amount of reserve energy and can be turned off for up to an hour. One European study showed operators of induction furnaces could save 11% in energy costs by switching the furnace off at times of high electricity costs.[98]

This report also foresees enormous potential for electric boilers to provide steam, particularly in the chemicals sector. Electric boilers have a very fast response time and can be operated flexibly to take advantage of low-cost intermittent power supply from renewables.[99]

## The switch to renewables has only begun

For the first time on a large-scale, manufacturers can now secure their own supply of renewable energy. Increasingly, organisations are realising that switching to renewable electricity can reduce their energy bill as well as their emissions. Manufacturers of all sizes are taking advantage of this exciting development, and pioneers such as Sun Metals and Liberty One Steel are investing hundreds of millions of dollars in the transition to renewables.

The transition will accelerate as costs continue to fall. ***By 2028 solar and wind energy could be 40% cheaper than today, and by far the cheapest cost of electricity generation.***

This represents a significant moment for Australian manufacturers.

They have an opportunity not only to switch to renewables but to electrify industrial heat processes currently fired by fossil fuels. There are many advantages to electrifying industry, such as reducing costs, increasing output, improving quality and supporting digitisation. In the next section we explore the electrical heating technologies that will enable manufacturers of all types to move beyond fossil fuels to an all-electric future.

# A5 - Making it happen

## Making it happen

There is a strong, economic case for producing industrial goods with renewable electricity, and for phasing out fossil fuels. This report shows that electrical technologies can efficiently produce the heat needed to manufacture any product. Many of these alternative electrical approaches are already cost-effective today and are increasingly being deployed in other countries.

Nevertheless we cannot rely on the market alone to decarbonise industry at the speed required to avert catastrophic climate change.

The viability of many Australian manufacturers is under threat from today's high energy prices. In many cases the impact is exacerbated by old and inefficient equipment. There is a risk that businesses respond by simply moving production overseas, and this risk is heightened by investors' growing wariness of carbon exposure (Section A1).

The brighter prospect for Australia is that manufacturers embrace the renewable energy era, by investing in efficient electrical heating processes, powered by renewable energy.

There is a clear role for governments to help Australian industry steer a successful course through this transitional period. This requires that several substantial barriers are addressed.

## Barriers to the rapid electrification of Australian industry with renewable energy

Existing fossil fuel-dependent manufacturing processes are deeply entrenched. Electrical technologies must compete with processes that have been used for decades, in some cases centuries. These traditional processes are well understood by manufacturers, as well as their supply chain. Suppliers and consultants who service and support industrial processes have understandable vested interests in maintaining the status quo. A specialist in gas boilers is unlikely to recommend a heat pump.

Electrical alternatives are, in general, much less understood in Australia and there is far less experience in their use. Australian manufacturers are unsure how the technologies will perform, operationally and financially. This lack of knowledge adds to the perceived risk of switching from current processes.

Apart from these institutional and knowledge barriers, existing processing systems represent sunk costs. If existing systems have not yet exceeded their operating life, there are financial disincentives to deploying new capital investment.[i]

These obstacles, while significant, are surmountable.

Companies frequently make new investments, innovate and take risks. One problem is the current absence of clear incentives to take action. Both the market and policy environment fail to sufficiently penalise greenhouse gas emissions, or to reward low-carbon approaches. Markets are also failing to send a clear enough signal about the risk of continuing with high-carbon strategies (Section A1). Other countries are addressing this with a carbon price, and in our view Australia will have to follow suit.

Below we propose some actions and policies to overcome these barriers and hasten the implementation of electrical heating technologies, powered by renewable electricity.

## 1. Seize the opportunity

***Action:*** *Large corporations to set ambitious emissions reduction targets and invest in electrical heating technologies powered by renewables.*

***Action:*** *SMEs to explore opportunities to reduce costs by switching to renewable energy and electrical heating technologies.*

Australian manufacturing has a tremendous opportunity to thrive in a low-carbon world. We recommend that large Australian corporations set ambitious emissions reduction targets, following the example hundreds of international companies that have signed up to robust climate policy through initiatives such as the Science Based Targets initiative (Section A1). Such targets will improve their standing with investors concerned about the financial risk of high-carbon strategies.

*i* This barrier is lower in Australia than some other countries due to recent weak investment in manufacturing. Many of our industrial facilities are old enough to need replacing, and this creates an opportunity to switch to modern equipment.

With emissions reduction targets in place, Australian manufacturers will have an incentive to invest in electrical heating technologies powered by renewables. This will not only reassure their investors and customers, but enable them to reduce their energy bills.

Small and medium-sized enterprises are unlikely to have the same power to shape the future, and are more reliant on governments to create incentives to invest in electrical heating technologies. They can however, make a start by exploring opportunities to reduce costs by switching to renewable energy and technologies such as heat pumps, infrared and induction heating.

## 2. Develop industrial strategy consistent with a zero emissions target

***Action:*** *Governments to develop an industrial strategy with dual aim:*

1. *Stimulate growth in Australian low-carbon manufacturing, capitalising on our unique renewable energy resources*
2. *Rapidly reduce industrial emissions to zero, with a focus on industrial heat processes.*

Most states and territories have zero emissions targets. The Australian Government has also agreed to this target by signing the Paris Climate Agreement, whose achievement will require that global net emissions of $CO_2$ eventually decrease to zero.[106]

To support this target we urgently need national and state emissions reductions strategies in all sectors. No such strategy exists for industry, and emissions from the sector have risen over the last 10 years.[107]

Governments should put in place a coordinated strategy with the explicit aim of decarbonising industry, eventually to zero or near zero emissions. A second aim of the strategy should be the expansion of Australian manufacturing, capitalising on our unique renewable energy resources. This dual strategy will send a clear signal to domestic and international manufacturers and investors that Australia welcomes zero carbon industry.

The actions we recommend below will have a larger impact if they are part of this coherent national plan. The aim should be to promote the adoption of any sustainable approach to eliminating fossil fuels, not just electrical heating technologies. The strategy should also be flexible, adapting over time as we learn what works best.

Industry's transition to renewable energy and clean technology needs to be at the heart of economic and industrial policy in all jurisdictions. We will not succeed while energy remains solely under the environment portfolio – it must be a central concern of departments with responsibility for business, manufacturing, employment and innovation.

The role of industrial energy efficiency must be considered in the light of the zero emissions goal. Energy efficiency improvements reduce emissions, but to a smaller degree than renewable energy. Also, by investing in efficiency improvements we can inadvertently further entrench fossil-fuel-based systems. Switching to renewable energy is essential to reaching our emissions goals, and energy efficiency improvement will play an important supporting role (See Box A2.3, page 25).

## 3. Set sustainable procurement standards and targets

***Action***: *Governments and large corporations to support low-carbon goods through procurement standards and targets.*

Public and private procurement policies can play a central role in reducing risk for leaders in zero carbon production.

Section A1 describes how many of the world's largest corporations, such as Mars, IKEA and Unilever, are determined to reduce the embedded emissions of the products they sell and are working with their supply chains to achieve this.

Government procurement is also important. State and territory governments should use their considerable spending power to support their emissions reduction targets. This includes procuring products and materials with lower embedded emissions.

This is especially important for projects with local content requirements. Whenever governments stipulate that products are made locally they should demand a higher sustainability standard. Such a policy would be consistent with the twin aims of the industrial strategy we propose above.

We are already starting to see government policies that enable this approach. For example, the Victorian Government's sustainable procurement policy aims to minimise greenhouse gas emissions through performance standards on larger projects (greater than $20 million).[108]

Support through procurement is especially important for low-carbon materials, such as steel, that currently cost more to produce. But this need not be an expensive policy. For example, even if steel were 25% more expensive, the increase in the cost of products which use steel, such as cars and buildings, is likely to be less than 1%.[109]

## 4. Invest in research and commercialisation

***Action:*** *Increase government spending on research and commercialisation of renewable heating technologies, with the aim of establishing Australia as a global leader.*

While many of the technologies profiled in this report are mature, their full potential has yet to be realised. For example, the 'single-shot' induction technique profiled in 'How to electrify aluminium casting' has not yet been used commercially. Some other technologies need to be developed further. For example, while heat pumps are likely to be capable of supplying heat at 200°C or more, commercially-available equipment does not exceed 165°C.

We need more industrial research in these areas to develop and commercialise new technologies. Governments can help by financing pilot projects for non-mature technologies with significant growth potential.

There is already some funding for this type of project, especially from the Australian Renewable Energy Agency (ARENA), but it is not enough. Australian Government spending on research and development is one of the lowest in the OECD.[110] If we are to become a home of low-carbon innovation and manufacturing, we need to substantially increase spending on research and development. We should show the same ambition as the Swedish Government which is investing A$80 million in hydrogen-based steel production (Box A1.1, page 13).

## 5. Tackle the information deficit

***Action:*** *Governments to create an information and advice service, helping manufacturers move away from fossil fuels. Using this service should be mandatory for large users of energy.*

***Action:*** *Peak bodies, such as AI Group and Manufacturing Australia, to explain to members the business advantages of switching to renewable energy and decarbonising.*

***Action:*** *Universities and research bodies to increase study of low-carbon approaches to manufacturing and ensure knowledge transfer to industry.*

***Action:*** *Engineers Australia to build capacity in the use of electrical heating technologies and renewable energy.*

Across industry, academia and energy consultancies there is a low level of understanding of most of the electrical heating technologies profiled in this report. Many companies are also confused about renewable electricity, believing incorrectly that it is more expensive.[111]

Lack of information is perhaps the biggest barrier to electrifying industrial heat processes, and there is a clear role for governments and others to address this.

## Mandatory energy information and audit service

We propose the establishment of a government service for analysing fuel switching to renewable energy for industrial heat processes. This service would provide information on:

- the government's vision and strategy for a flourishing low-carbon manufacturing sector
- the benefits and potential cost-savings of renewable energy, and advice on finding an advantageous power purchase agreement.
- the risks of maintaining a high-carbon strategy in relation to investors, carbon tariffs, legal liability, changes in policy, supply-chain pressure etc.
- using renewable energy in industrial heat processes, including specific electrical heating technologies. This would include information about research, support schemes and international case studies of manufacturers who have successfully switched
- reducing electricity costs through demand management, consuming energy when it is cheap and reducing consumption at times of peak demand.

This service would also offer low-cost energy audits. These audits would assess the energy used by a process and propose not just energy efficiency but fuel-switching possibilities and potential cost savings. The analysis would be carried out by registered, independent consultants who are required to consider all options, including fuel switching. Using this service could be a pre-requisite for getting a grant of the type discussed below.

The service would also provide energy management tools to help understand energy use and evaluate alternatives. This software would deliver detailed and precise energy analysis by exploiting a relatively new range of technologies, such as big data analytics, the industrial internet of things, sensors and energy simulation software.

This service would be mandatory for large users of energy, in a similar way to the federal Energy Efficiency Opportunities program which ran from 2007 until 2014. Since the closure of this program Australia is very unusual among developed countries in not having mandatory audits for large energy users.[112]

The service would be co-designed with industry groups and companies, to ensure it is tailored to the needs of Australian businesses, its practicality and usefulness to businesses of all sizes.

## Peak bodies and academia

Industry peak bodies, like the Australian Industry Group, also have a role in sharing information with members, particularly in explaining how they can reduce electricity bills through PPAs and demand management. Industry groups also have a role in communicating the growing global pressures to decarbonise and the business advantages of doing so.

Industry groups and others could consider replicating the service provided by the Business Renewables Centre at the Rocky Mountain Institute in the US. The Business Renewables Centre makes it easier for corporations to enter the renewable energy market by sharing information on PPAs and tools for assessing energy contracts.[113]

There is role for academia too. In Australia there is a lack of academic knowledge about industrial production of common materials and the alternative technologies described in this report. There are, for example, no Bachelor degrees and only one postgraduate degree dedicated to manufacturing processes.[114]

Industrial research in Australia is focused on futuristic techniques and materials like 3D printing, nanotechnology, biotechnology and graphene. These are all important, but they are not going to replace our need for commonplace materials such as paper, steel and glass.

Engineers Australia can also play a leading role by encouraging and developing professional knowledge and capacity in designing processes that deploy electrical heating technologies and renewable energy. This is consistent with their chartered purpose to "...advance the science and practice of engineering for the benefit of the community".[115]

## 6. Offer financial incentives

***Action:*** *Governments to establish substantial financial incentive – grants, loans and tax credits – for manufacturers investing in new renewable heat processes and switching from fossil fuels.*

Manufacturers not only understand gas-fired processes, they have invested in them. The newer technologies profiled in this report entail both cost and risk. One way to overcome this is through financial assistance in the form of grants, loans or tax credits.

In theory the Clean Energy Finance Corporation could provide finance for the technologies presented in this report. In reality little of their investment is for improving industrial processes. Other programs have specifically targeted manufacturers. For example the federal Clean Technology Food and Foundries Investment Program ran for five years until 2017 supporting purchases of equipment to reduce the carbon intensity of production. Grants for fuel switching to renewable heat are uncommon, though one small example is Sustainability Victoria's gas efficiency grants which award up to $50,000 for projects including switching from gas to renewable electricity.

We recommend a financial assistance program available to all manufacturers planning to:

i) switch from fossil fuels to renewable energy for an industrial heat process

ii) reduce overall energy use by fuel switching

iii) source most electricity from renewable sources (if switching to electrical heating.

The size of these grants could be connected to emissions avoided.

**Table A5.1 Recommended actions to develop zero carbon industry in Australia**

| Action area | | Recommended action | Responsible |
|---|---|---|---|
| **1** | Manufacturers' opportunity | Where possible, manufacturers to set ambitious emissions reduction targets and invest in electrical heating technologies powered by renewables. | Large businesses |
| **2** | Zero carbon industry strategy | Implement an industrial strategy to rapidly reduce industrial emissions to zero and promote growth in Australian low-carbon manufacturing, | Federal and state governments |
| **3** | Sustainable procurement | Support low-carbon goods through procurement standards and targets. | Federal and state governments<br>Large corporations |
| **4** | Research and commercialisation | Substantially increase spending on research and commercialisation of renewable heating technologies. | Federal and state governments |
| **5** | Information provision | Set up information and advice service to help manufacturers move away from fossil fuels<br>Help manufacturers understand business advantages of switching to renewable energy and decarbonising<br>Increase study of low-carbon approaches to manufacturing and ensure knowledge transfer to industry.<br>Build engineering capacity in use of electrical heating technologies and renewable energy | Federal/state governments<br>Industry groups<br>Universities and research bodies<br>Engineers Australia |
| **6** | Financial incentives | Establish substantial financial incentives – grants, loans and tax credits – for manufacturers investing in new renewable heat processes and switching from fossil fuels | Federal and state governments |
| **7** | Carbon price | Impose a price on carbon which includes domestic and imported manufactured goods<br>Call for coordinated international action on the embedded carbon in manufactured goods | Federal Government |

## 7. Introduce a price on carbon

***Action:*** *Federal Government to put a price on carbon which includes domestics and imported manufactured goods.*

***Action:*** *Federal Government to propose and support coordinated international action to reduce the embedded carbon in manufactured goods – such as global carbon pricing or an agreed set of standards.*

It is well-established that the most efficient way of achieving emissions reductions across the economy is to put a price on carbon, either via a tax or an emissions trading scheme. By failing to do this Australia is making the zero-carbon transition more expensive than it needs to be. And, as discussed in Section A1, there is a high risk of other countries imposing carbon tariffs on Australia's manufactured exports.

The revenue from a carbon price can be used to fund the government grants and information services recommended above.

> ***"There is widespread recognition in the business community that domestic policy settings will have to tighten in the near future, and that this will inevitably include a form of emissions trading and a carbon price signal."*** [116]
>
> ***Peter Castellas, CEO, Carbon Market Institute.***

# Part B

## Electrical heating technologies in action

**Part B** provides more detailed technical information on electrical heating technologies and their potential applications.

**Sections B1 to B5** describe five electrical heating technologies with the most potential to contribute to an electrified industry:

- Electric heat pumps
- Electromagnetic heating – infrared, induction, microwaves and radio-frequency heating
- Electric resistance heating
- Electric furnaces – resistance, arc and plasma
- Hydrogen produced by electrolysis
- Heat storage – sensible and phase change

# B1 Industrial Heat Pumps

- Heat pumps are a widely-used technology that produce 3-7 times more thermal energy than they use as electrical energy.
- Heat pumps can save money for manufacturers currently using gas-fired heat processes, up to 160°C.
- Heat pumps can play an important role in Australian manufacturing in industries such as food, chemical and paper.
- They have the potential to replace 95 PJ of fossil fuel combustion, eliminating nearly 5 million tonnes of emissions.

An electric heat pump is a technology for producing hot air, hot water or steam. It does this very efficiently by extracting thermal energy from a convenient source of heat. It is particularly useful for reusing heat wasted by many industrial processes.

The first large-scale heat pumps were installed in the 1950s, and they are now a well-established technology. Thousands of industrial units are in service around the world, particularly in Japan and Europe. Heat pumps have the potential to replace hundreds of thousands of industrial gas-fired boiler systems, saving energy costs and reducing emissions.

## Energy advantage of heat pumps

Heat pumps achieve remarkable efficiencies of 300-700%. This means that for every unit of electricity they consume, they produce 3 to 7 units of heat. The efficiency of a heat pump is measured by its 'coefficient of performance' (COP). The COP is the ratio between the electrical energy used by the heat pump and the heat they produce (or their cooling capacity). A heat pump which is 400% efficient has a COP of 4. Some heat pumps can be used simultaneously for heating and cooling, and their combined COP for both services can be as high as 10 (ten units of heating/cooling for each unit of electricity).

The efficiency of heat pumps gives them a great advantage over gas boiler systems. As explained in Section A2 ('Centralised Gas Boilers', page 22) the efficiency of gas boilers is rarely better than 80%, and in practice is often less than 50% due to heat losses.

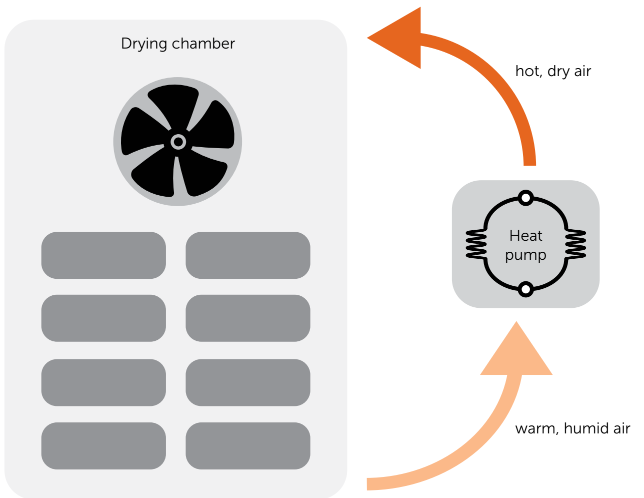
Heat pumps can reuse heat that would otherwise be wasted. They can extract close to 100% of the thermal energy in exhausted heat. Unlike conventional heat exchangers, heat pumps can extract latent heat, which accounts for most of the energy in warm humid air, by condensing water vapour.

For example, Austrian brick maker, Wienerberger is piloting the use of heat pumps to recover heat lost from drying operations (Figure B1.1). Bricks are dried by placing them in a chamber into which hot dry air is pumped. As the bricks dry, moist air is released from the chamber, taking with it most of the initial heat input – a tremendous waste. Wienerberger has found that by using heat pumps it can reduce the energy consumption of brick drying by 80%.

Common sources of industrial waste heat include:

- Drying processes (food, timber, bricks) which release warm, humid air
- Waste heat from refrigeration systems
- Pasteurisation – this involves rapid heating then cooling of a liquid. A heat pump can provide both services simultaneously, with a potential efficiency as high as 1000%.

**Figure B1.1 Heat pumps can reuse heat in warm, humid air expelled from industrial drying processes.**

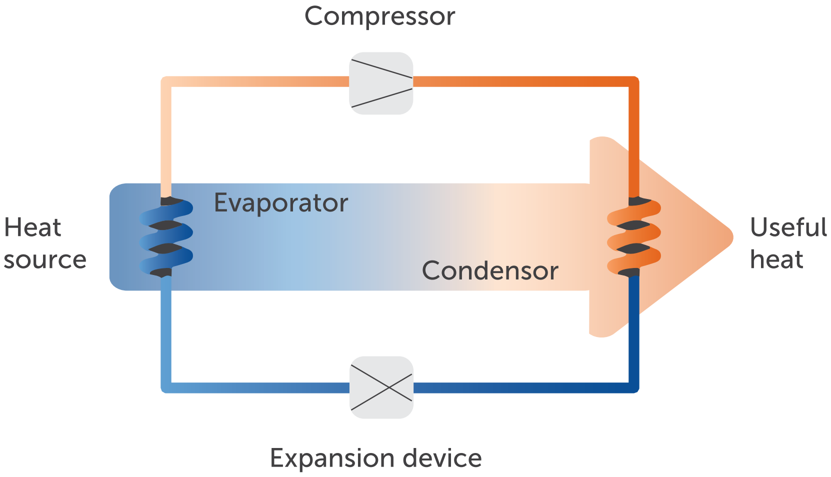


## Box B1.1 How a heat pump works

Heat pumps take a low temperature heat source and transfer its thermal energy to a higher-temperature heat output. Potential heat sources include the outside air or the ground, or waste heat from industrial processes. A heat pump is the key component in everyday appliances such as fridges, freezers and reverse-cycle air conditioners.

Heat pumps create heat by compressing and expanding a refrigerant fluid. They exploit the property of the refrigerant to heat up when compressed (like in a bicycle pump), and cool when expanded (like an aerosol can). A heat pump moves a refrigerant between four key parts: compressor, condenser, expansion device and evaporator. This cycle is illustrated in Figure B1.2.

Figure B1.2 Simplified diagram of a heat pump




**Compressor:** compresses working fluid causing temperature to increase (electrically powered).

**Condensor:** gas condensed to liquid - releasing heat

**Expansion device:** reduces pressure of gas

**Evaporator:** low pressure refrigerant evaporated, absorbing heat from external source

**Heat source:** waste heat or external air, water or ground

## Box B1.2 Mechanical vapour recompression

Mechanical vapour recompression (MVR) is a special type of heat pump that compresses the vapour form of the fluid being processed (usually water), rather than a refrigerant. Compressing the vapour makes it hotter. MVR systems usually compress water vapour at 70-80°C and deliver steam between 110°C and 150°C, in some cases up to 200°C. Their performance is particularly impressive with COPs of 10 to 30.

Common MVR applications involve the removal of water or water vapour in drying, dehumidification, distillation and concentration processes, and the recovery of heat for immediate reuse. An MVR system is modelled in C3: How to electrify milk powder. Other potential industrial applications include:

- de-watering mixtures such as landfill leachate, oil emulsions and saline, acidic or other corrosive solutions
- concentrating liquids such as fruit juices, milk, black liquor (in pulp and paper industry)
- distilling of alcohol and organic chemicals;
- re-injecting low pressure steam into a high-pressure system.

## How heat pumps reduce energy costs

Heat pumps enable energy and costs savings due to their remarkable efficiencies – represented by their coefficient of performance. These operational savings mean the capital cost of installing heat pumps can be quickly paid back (Table B1.2 and Table B1.3).

As a rule of thumb a heat pump with a COP of 4 will be cheaper to run than a gas boiler where the price of electricity is less than 4.5 times the price of gas. Heat pumps are even more cost-effective when they can be used for simultaneous heating and cooling – for example in the pasteurisation of milk. The example below compares energy costs under one scenario for the task of heating water by 50°C.

### Comparing a boiler and heat pump – heating water by 50°C

Many industrial processes require hot water. Heating 1 tonne of water from 40°C to 90°C requires 58.1 kilowatt hours of energy (equivalent to 209 megajoules). Table B1.1 compares the operational energy cost of this task using a gas boiler and a heat pump. In this example the boiler has an efficiency of 80% and uses gas costing A$12/GJ (4.3 c/kwh). The heat pump has an efficiency of 400% and uses electricity costing 12 c/kwh. Under these assumptions, the heating task costs 44% less using a heat pump.

The precise savings depend heavily on the cost of energy. Figure B1.3 shows that heating water will be cheaper using a heat pump under for a broad range of energy costs, and this advantage is likely to grow as the cost of renewable energy fall. The direct energy savings could be much larger as many industrial gas boiler systems are less than 50% efficient once losses from steam distribution systems are taken into account.

**Table B1.1 Comparative cost of heating 1 tonne of water from 40°C to 90°C**

| | Gas boiler (80% efficient) | Electric heat pump (COP of 4) |
|---|---|---|
| **Efficiency** | 80% | 400% |
| **Cost of gas/electricity** | $12/GJ (4.3 c/kwh) | 12 c/kwh |
| **Required energy input (kWh)** | 72.6 | 14.5 |
| **Cost of heating 1T water by 50°C** | $3.14 | $1.74 |
| **Saving with heat pump** | | 44% |

Figure B1.3: Comparative cost of raising temperature of 1 tonne of water by 50°C for a range of energy prices. (Comparison between heat pump with CoP of 4 and a gas boiler with 80% efficiency.)

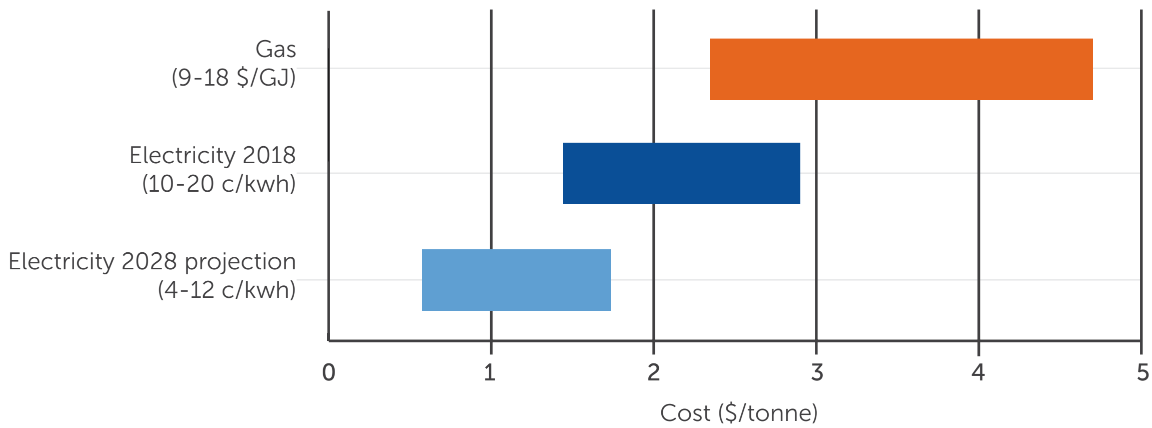


**Table B1.2 Replacing a gas boiler with a heat pump could pay for itself in less than 2 years.**

| System | Heating Capacity (MW) | Cost ($/kW) | Capital cost ($) | Cost of energy | Annual cost of operation* ($) | Payback period (years) |
|---|---|---|---|---|---|---|
| Gas boiler (85% efficiency) | 2 | 120 | 240,000 | $13/GJ (gas) | 660,706 | 1.7 |
| Heat pump (COP of 4) | 1.6 | 520 | 832,000 | 12 c/kWh (elec) | 312,000 | |

**6000 hours per year.*

## Additional economic benefits of a heat pump

The major cost savings discussed above can be significantly enhanced by considering the additional benefits of a heat pump, which include:

- improved ability to recover waste heat, including latent heat
- better reliability – reducing maintenance costs and plant downtime. Heat pumps can run trouble-free for 15 years or more.
- better heating control leading to improved product quality
- increased plant output
- increased space on the factory floor due to smaller footprint of heat pumps and their potential to reduce space occupied by steam distribution systems.

## Costs of purchase, installation and maintenance

A heat pump system costs around $500-1000 per kilowatt of heating capacity for heat pumps with capacity below 500 kW, and around $275-500 per kilowatt for systems of 1 MW and above. For example, the Mayekawa EcoSirocco costs A$75,000 for a unit with 120kW of heating capacity. Installation is an extra 25-100% of the purchase price, depending on numerous site-specific factors.

The total cost might be two or even three times the up-front cost of an equivalent gas boiler, however the heat pump can pay for itself in just a few years thanks to cheaper running costs.

Table B1.2 compares the capital and operating costs of a gas boiler and a heat pump. The heating capacity of the heat pump is lower as it minimises distribution losses. The heat pump costs over three times more than the gas boiler to buy and install. However, due to lower running costs, the heat pump pays for itself in less than two years. In some case heat pumps will be even more cost effective as they can replace costly steam distribution systems along with the central gas boiler.

Heat pumps have the added advantage that they can be installed in a modular fashion. Manufacturers can choose to replace just the most inefficient parts of the boiler/distribution system rather than needing to shut-down and replace the entire boiler/steam system in one go.

# The growing potential of heat pumps

Most heat pumps in use today supply temperatures below 100°C. The efficiency, flexibility and reliability of heat pumps have improved considerably in recent years. Heat pumps are now available that can supply steam or hot water up to 165°C, or hot air up to 120°C. This means they can provide sufficient heat for a wide range of manufacturing processes, including food production, industrial washing and drying products such as timber, brick and paper.

Within a decade heat pump manufacturers expect to commercialise industrial systems capable of reaching 200°C[118]. The heating capacity of single modules is also growing, with several available in the megawatt range. For example, Sabroe's NS 355 HP, with a capacity of 12.5 MW, can produce more than 200,000 litres of hot water every hour

Today there are hundreds of industrial heat pumps available to manufacturers. Figure B1.4 shows a selection of high-temperature and high-capacity systems. Most of the leading manufacturers are based in Europe or Japan. Some are large engineering firms like Bosch and Kobe Steel, and others are specialist manufacturers like Viking and Mayekawa.

## Current use across the world

Heat pumps have a potential role in industrial processes where hot air, hot water or steam is required including most food production processes, such as pasteurisation, fermentation, distillation, washing and drying.

The International Energy Agency has collected more than 100 detailed examples of industrial heat pump installations and their performance.[119] Table B1.3 presents some of these successful installations in the printing, chemicals, glass, metals and electronics industries. For example, Hokkaido Bioethanol installed a heat pump to recover heat from the distillation of ethanol. The heat pump captures heat at 65°C and returns it to the distillation process as steam at 120°C with a COP of 3.5. The company has reduced energy consumption by 40% and running costs by 54%.

All the installations in Table B1.3 have achieved impressive energy and cost savings, and short payback periods. The International Energy Agency reports that the typical payback period for a new heat pump is between 2 and 7 years.

## The opportunity for heat pumps in Australian industry

So far there are very few industrial heat pumps installed in Australia.[120] Despite this heat pumps have huge potential to replace gas and other fossil fuels in most processes requiring hot air, water or steam up to about 160°C. They could provide most of the heat energy required by the food, paper, wood and textiles industries. Heat pumps could displace one third of the energy used by chemical sectors to generate steam.[121]

In total heat pumps could eliminate the need for **95 GJ** of fossil fuels used for industrial heat – 15% of the total. When powered by renewable energy this would eliminate nearly 5 million tonnes of greenhouse gas emissions. (Figure B1.5).

Opportunities to use heat pumps include:

- replacing all or part of boiler steam systems
- in combination with mechanical vapour recompression to produce steam
- installing multiple heat pumps in series to achieve higher temperature uplift with greater efficiency. For example, one heat pumps heats water from 40 to 70°C and a second from 70 to 95°C
- in combination with heat storage so that excess heat can be reused later
- to heat a material towards its temperature target, with another system doing the rest of the work
- for processes that require lower temperatures than the main process
- to replace the end-sections of long heat distribution pipes with high heat losses.

The principal barriers to the wider application of heat pumps by Australian industry is the lack of local expertise and awareness within industry. However, experience in other countries such as Japan and Korea shows that this barrier can be overcome through government support including investment incentives, demonstration projects and information provision (Section A5).[122]

The 'How to' guides in Part C include three detailed examples of food manufacturing processes which could convert to heat pumps: milk powder, beer and prepared food.

## Further reading on heat pumps

- *High temperature heat pumps for the Australian Food industry:* Opportunities assessment. Australian Alliance for Energy Productivity, 2017.
- *Application of Industrial Heat Pumps. Annex 35.* International Energy Agency, 2015.
- In*dustrial Heat Pumps. Annex 48.* International Energy Agency, due 2019.

### Box 1.3 Refrigerants and global warming

Heat pumps create heat by compressing and expanding a refrigerant fluid. This refrigerant's characteristics must include a high latent heat when in gaseous form, and good ability to transfer this heat.

Two significant classes of refrigerant, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), have mostly been phased out due to their role in destroying the earth's ozone layer. CFCs and HFCs have been replaced by hydrofluorocarbons (HFCs).

HFCs do not deplete ozone, but many of them do have a very high global warming potential – often thousands of times higher than $CO_2$. For this reason all governments have agreed to drastically reduce use of HFCs by mid-century.[117]

This report promotes heat pumps that use refrigerants with low global warming potential. This includes natural refrigerants such as $CO_2$, ammonia and water, as well as some newly-developed HFCs. There is a shift in the industry towards such refrigerants.

Figure B1.4 Commercially-available industrial heat pumps

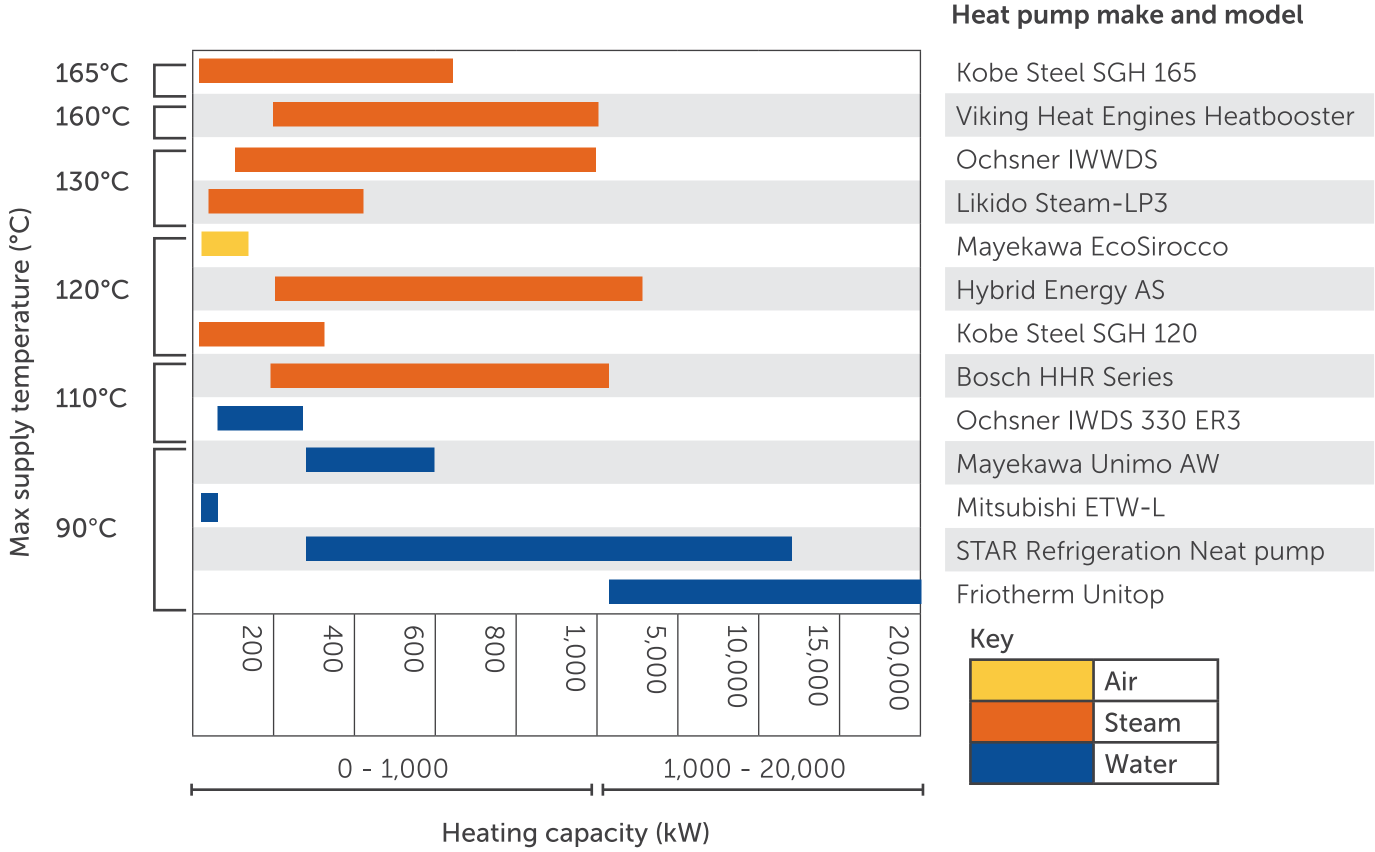



Figure B1.5 The annual potential of heat pumps to replace fossil fuels and reduce emissions in Australian industry

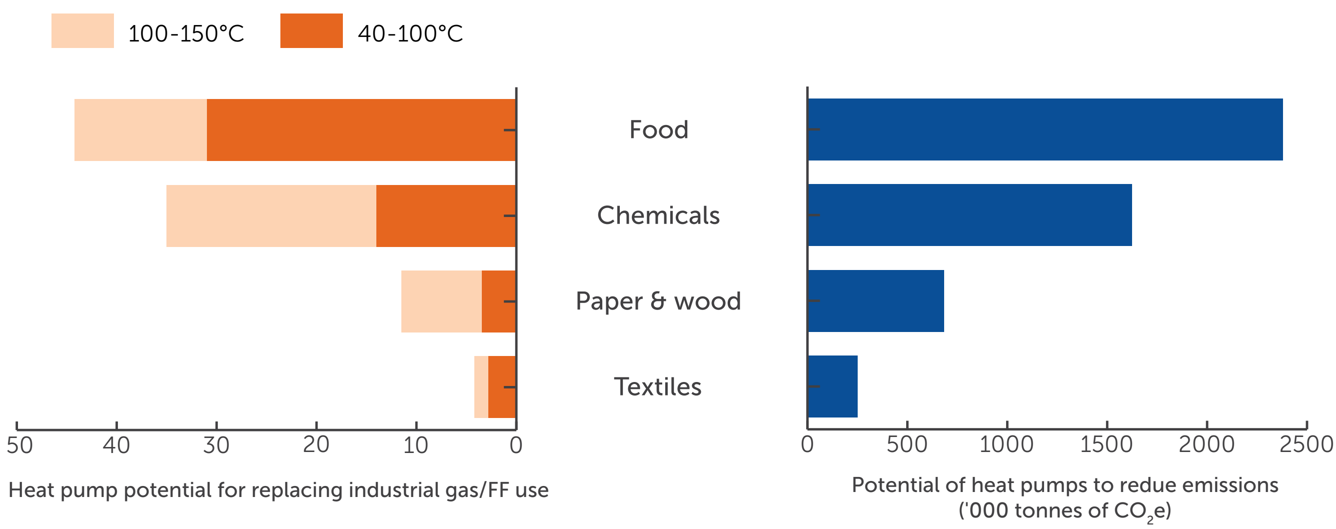


**Table B1.3 Examples of electric heat pumps replacing fossil fuelled systems**[123]

| Sector/product | Company/Location | Heat pump make | Heating capacity (kw) | Temperature uplift | Coefficient of performance | Energy/cost saving | Heat pump application |
|---|---|---|---|---|---|---|---|
| Food - chocolate | Nestle, UK | Star Neatpump | 1,250 | 5°C > 60°C | 6 (combined heating & cooling) | Saving $200,000 in energy costs | Simultaneous cooling and hot water for chocolate production. |
| Food – frozen noodles | Shikoku Island, Japan | | 144 | 83°C > 98°C<br>10°C > 3°C | 3.0 (heating)<br>2.1 (cooling) | | Hot water for boiling noodles, and cold water for the cooling process before freezing. |
| Food – milk powder | Arla Arinco, Denmark | Industri Montage | 1,250 | 40°C > 85°C | 4.6 | Payback – 1.5 yrs | Preheats air to 85°C for drying milk powder. A gas boiler completes the temperature uplift to 150°C. |
| Food - French fries | McCain, Netherlands | Grasso 65 | 500 | > 70°C | 5-8 | Payback – 4 yrs<br>Energy saving 70% | Recovers and recirculates heat from drying french fries before cooking. Provides most of the heat for drying |
| Food & drink - Beer | Mohrenbrauerei, Austria | COFELY Kältetechnik | 370 | > 77°C | | Payback 5.7 yrs<br>Energy saving 18% | Reuses waste heat from chillers to supply all process and space heating. |
| Auto -painting | Hino Motors, Japan | HEM-150 II | 566 | | 5.1 (heating)<br>4.1 (cooling) | Payback 3-4 yrs<br>Cost saving 63% | Simultaneous heating and cooling for drying paint on car parts. |
| Timber - Softwood timber | Germany | | 180 | 65°C > 90°C | 4.5 | Payback - 4 yrs | Recovers waste heat from the biomass power plant to dry timber. |
| Paper – packaging material | Smurfit Kappa, Netherlands | Bronswerk Heat Transfer and IBK | | 64°C > 115°C | | | Recovers heat from moist air released from paper-drying to produce steam at 115°C, which is used at different steps in production. |
| Chemicals - Bioethanol distillation | Hokkaido Bioethanol, Japan | Kobe Steel | 9,250 | 65 > 120°C (steam) | 3.5 | Cost saving 54% | Recovers warm air from the distillation process and returns it as steam. |
| Electronics - transformer casings | Minami Electric, Japan | | 110 | 20°C > 80~120°C | 4~6.5 | Energy cost saving 12% | Pre-heats air to 80-120°C for drying casings. A gas burner completes the temperature uplift to 170°C. |

# B2 Electromagnetic heating

- Electromagnetic heating technologies include infrared, induction and microwaves.
- Electromagnetic heating technologies perform heating tasks with high efficiency, often reducing energy requirements by 50% or more.
- They also complete many heating tasks several times more quickly than gas-fired ovens, increasing productivity.

Electromagnetic heating technologies use wavelengths in the electromagnetic spectrum to process and manufacture a wide range of products. The most important examples are infrared, induction, microwaves, radio waves and ultraviolet. Although industry has used these technologies for decades, we have only scratched the surface of their true potential.

The major advantage of electromagnetic technologies is they generate heat within a target material. This is more efficient than fossil fuel heating that first heats a medium, usually air, which then heats the material through convection. Energy use can often be cut in half by switching to electromagnetic heating.[124]

Beyond efficiency, electromagnetic technologies have several additional advantages:

- **Rapid heating** – allowing for faster processing and minimising heat losses
- **Greater ability to control** – producing a more consistent output
- **Less material waste** – as there is no contact with combustion gases and other substances, there is less contamination, thereby reducing material wastage[125]
- **Compact size** – taking up less space on the factory floor
- **Safety** – producing less noise and on-site pollution.

The three electromagnetic heating technologies considered in this report are infrared, induction and dielectric.

### Table B2.1 Electromagnetic heating technologies[141]

| Frequency | 50 Hz - 500 kHz | 10-100 MHz | 200-3000 MHz | 30-400 THz | | 1-30 PHz |
|---|---|---|---|---|---|---|
| Wavelength | | | | | | |
| | Induction | Radio | Microwave | Infrared | Visible light | Ultra-violet |
| Max temp °C | 3000 | 2000 | 2000 | 2200 | | N/A |
| Power density (kW/m²) | 50,000 | 100 | 500 | 300 | | 100 |
| Efficiency | 50-90% | 80% | 80% | 60-90% | | |
| Application | Rapid internal heating of metals. | Rapid internal heating of large volumes. | Rapid internal heating of large volumes. | Very rapid heating of surfaces and thin material. | | Non-thermal curing of paints and coatings. |

**Power density signifies the rate of energy transfer to an amount of material. Increasing power density enables increases in productivity*

## Infrared

Infrared systems emit infrared radiation that heats an object. This is how the sun warms the earth. Electrical infrared systems have been used in industrial heat processes since the 1930s.

Infrared heating is an excellent technology for heating surfaces, a task it carries out many times faster than a gas oven (Table B2.1). Radiant energy heats material directly, in contrast to a gas convection oven which heats the air around material to a higher temperature than the target temperature for the material. Infrared works best with objects with a simple shape and flat surface, although with smart positioning of emitters and reflectors more complex objects such as car wheels can be heated successfully. Infrared is less suitable for heating large masses of material.

Infrared systems are designed according to the temperature requirement and the ability of the target material to absorb infrared radiation. In general, shorter infrared wavelengths correspond to higher power densities and can reach very high temperatures of over 2,000°C (Table B2.2). The temperature and intensity of infrared systems can be adjusted for different products, and can even heat different sections of an object to different temperatures. For example, infrared can be calibrated to heat the surface of a coated object while passing unabsorbed through the coating itself.

### Advantages of infrared

**Infrared heating is fast and efficient**

Infrared heaters convert a very high proportion of electrical energy into radiant energy – 80 to 95% for short and medium wavelength infrared (Table B2.2).

This radiant energy heats material directly, leading to very high overall efficiencies. In the case study below of preheating aluminium billets, the infrared system uses 65% less energy than the gas-fired system it replaced.

Infrared also heats objects rapidly. Table B2.1 shows that the heating time for some common materials is 7 to 40 times faster than gas convection ovens. This enables fasting processing times, another key advantage of infrared heating.[126] Other advantages of infrared compared to gas-fired furnaces are:

**Fast response** – heats up and cools down in seconds, many times faster than gas convection systems.

**Low cost** – often several times cheaper than a convection system or other heating system. Infrared heaters usually cost less than $1000 per kilowatt.

**Compact size** – for example an infrared dryer will be less than 1 metre long compared to 10-30 metres for a typical convection system.[127]

**Precision** – ability to control temperature and target a precise area. (+/-0.5C compared to +/-5C for gas oven)

**Modular design** – easy to integrate into existing production systems.

**Clean products** – circulating air in convection ovens can cause contamination of the product. This doesn't happen with infrared.

**Low maintenance** – long life and little maintenance except scheduled cleaning of reflectors and replacement of emitters

**Worker safety** – reduces heat, reduces emissions and eliminates risk of carbon monoxide poisoning.

**Table B2.1 Time to heat surfaces of different materials to 150°C- gas convection oven vs electric infrared with power density of 20 kW/m2 [142]**

| | Steel (0.13 cm thick) | Aluminium (0.13 cm thick) | Plastic (0.64 cm thick) | Wood (0.64 cm thick) |
|---|---|---|---|---|
| | *Time taken to reach 150°C (seconds)* | | | |
| **Gas convection (at 220°C*)** | 210 | 138 | 460 | 365 |
| **Electric infrared** | 30 | 20 | 14 | 8 |

**A gas oven must be heated to 220°C in order to heat its contents to 150°C.*

## Table B2.2 Characteristics of infrared at different wavelengths

| | Wavelength (µm) | Emitting temperature | Power density (kw/m2) | Response time | Efficiency* | Applications |
|---|---|---|---|---|---|---|
| Near infrared | 0.76—1.2 | 1800-2,500°C | 160-300 | <1 sec | 85-95% | Drying coatings, paper, textiles. Deeper penetration for baking, roasting etc |
| Medium infrared | 1.2-3 | 800-1,800°C | 40-160 | <30 sec | 80-85% | Efficient surface heating of glass, plastic, water. |
| Far infrared | 3-10 | 400-600°C | 10-40 | 5 minutes | 50-60% | Food processing. Space heating in buildings such as factories. |

*Conversion of electrical energy into radiant heat.*

### Box B2.1 Infrared case studies

#### Queen City Forging - heating billets[143 144]

Queen City Forging in Ohio, US makes components for transport and agricultural equipment.

The company heats aluminium billets to 425°C prior to hot-forging. Previously this preheating was achieved using convection gas-fired furnaces. By switching to an infrared heating system the company has reduced costs and energy use, while increasing throughput and quality.

**Energy savings:** new system uses 65% less energy (gas system used 968 kWh/T, infrared system 323 kWh/T).

**Cost savings:** 40-50%

**Production speed:** increased four-fold, because:

- Preheating time decreased from 6 hours to 18 minutes
- Heat treatment time reduced from 10 hours to 1 hour
- Reduction in downtime due to less maintenance.

**Product quality:** infrared heating improved the product's consistency and its structural and mechanical properties.

*Infrared Heating Technologies, LLC. Copyright Heraeus*

#### Outdoor South – curing paint[145]

Outdoor South is a US metal fabricator that makes painted cargo racks. In the past the company cured the paint by placing the racks in a gas-fired oven for several hours at 120°C. They have now replaced this batch process with continuous infrared processing. This cures the paint in only 4 minutes.

**Production speed:** increased eight-fold.

**Product quality:** Paint finish improved and less prone to blistering.

**Cost savings**: Initial investment paid back in less than a year, largely due to faster production.

## Applications of infrared

Infrared heat is suitable for many industrial heat processes (Table B2.3). It is particularly useful for drying and for curing paints and coatings, such as those used to improve the performance of lithium ion and alkaline batteries. Such coatings are usually baked at 150-200°C. Using a convection oven this would require heating the air to around 400°C, whereas infrared heats the coating directly. Infrared can reduce curing times from several hours to just a few minutes.

This report's 'How to' guide on recycled paper (Section C4) shows that infrared can be used to dry paper, replacing the traditional steam-drying paper.

Infrared ovens have potential role in many food production processes, and can be three times more efficient than gas ovens.[128] One of their advantages is that they can heat the surface of a food (eg a pie crust) without cooking it through. As well as the food production processes listed in Table B2.3, infrared systems can be used for frying, roasting, baking, thawing, blanching and pasteurization.

Some industries are already familiar with infrared heating. It is often used to manufacture products that must be heated in a vacuum, such as solar cells and electronic circuits. Infrared is also vital for curing, joining and preheating some plastic and composite materials such as thermoplastics for large car body parts or wind turbine blades made of fibreglass composite.

Many more manufacturers could benefit from the advantages of infrared heating. The case studies in Box B2.1 outline two examples where infrared heating replaced a gas-fired system, leading to significant savings in energy and money, as well as improved product quality.

**Table B2.3: Industrial process applications of infrared heating**

| | Curing | Drying | Gluing | Laminating | Melting | Preheating | Shrinking | Soldering | Sterilising | Tempering |
|---|---|---|---|---|---|---|---|---|---|---|
| **Automotive** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| **Ceramics** | ✓ | ✓ | ✓ | | | ✓ | | | | ✓ |
| **Electronics** | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | | |
| **Flooring** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ |
| **Food** | | ✓ | | | ✓ | ✓ | | | ✓ | ✓ |
| **Glass** | | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| **Metal** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| **Packaging** | | ✓ | ✓ | ✓ | | ✓ | ✓ | | | |
| **Paper** | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | | |
| **Photovoltaics** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |
| **Plastics** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| **Powder coating** | ✓ | ✓ | | | ✓ | ✓ | | | | |
| **Rubber** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| **Semiconductors** | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ |
| **Textiles** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| **Wood** | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | | |

## Induction

Induction heating is a fast, efficient, repeatable, non-contact method of heating metals and other electrically-conductive materials. The target material is placed within a metal coil which carries a high-frequency electric current. This induces an electromagnetic field around the material and an electric current within it, generating heat (Figure B2.1). Many of the advantages of induction come from its ability to generate internal heat, minimising energy losses and improving control.

Induction has been used in industry since the 1930s and is now increasingly used for domestic cooking. Induction heating is particularly suitable for processes involving electrically-conducting metals such as steel, aluminium, copper, zinc, lead and brass. It can achieve very high temperatures (up to 3,000°C) and its controllability makes it ideal for integrating into automated production lines.

Induction can be used to heat objects of almost any shape and size. Lower frequencies are used for thicker materials requiring deep heat penetration, while higher frequencies (up to about 500 kHz) are used for smaller parts or shallow penetration.

### Advantages of induction heating

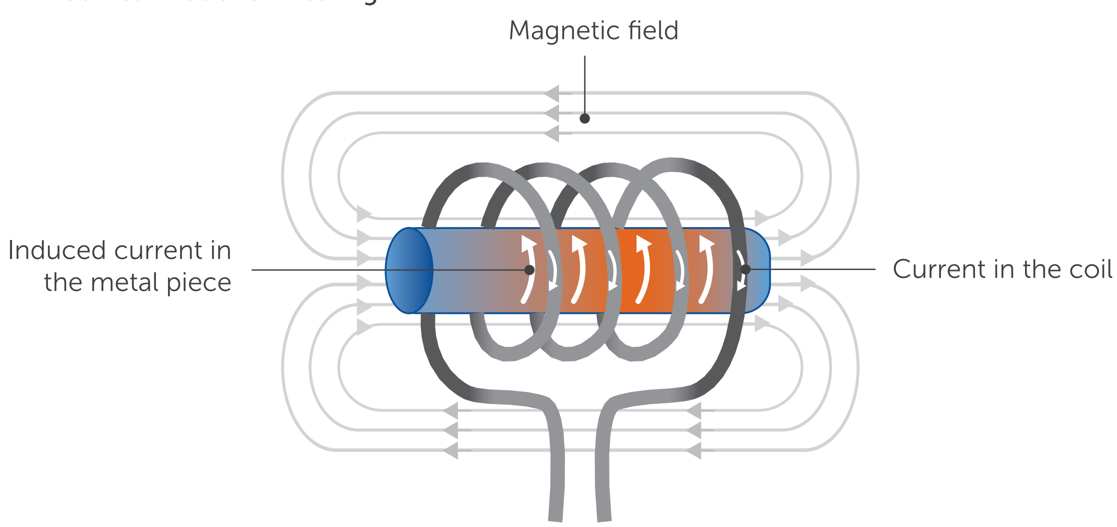
Induction heating is more efficient at heating metal than either gas-fired or other types of electric furnace. For example, to melt a tonne of iron a gas-fired furnace requires at least 900 kWh, including auxiliary equipment.[129]

A crucible induction furnace can do the same job using 490 kWh per tonne – only 25% more than the theoretical minimum of 390 kWh per tonne.[130]

Induction heating has several other advantages, all of which can contribute to cost savings (Box B2.3):

- **Faster processing** – induction can reduce processing time to several minutes or less.
- **Faster start-up** – induction systems deliver 100% of power instantly, and require no warm-up period. This can reduce melting batch time by 1-2 hours.
- **Higher yields** – gas-fired furnaces cause oxidisation of metal surfaces – called 'scale'. This results in material losses of 3-5%. Induction heating reduces scale losses to 1% or less.[131]
- **Better quality output** – due to more precise temperature control and better mixing of molten metal.
- **Control and automation** – induction systems can improve productivity by being easier to control and monitor.
- **Lower maintenance** – induction systems require less maintenance.
- **Health and safety** – induction is quiet, produces no on-site emissions and wastes little heat, reducing the risk of burns
- **Compactness** – induction furnaces are compact and require no space for fuel storage and handling.

Figure B2.1: Electrical induction heating



## Applications of induction heating

### Heat treating and pre-heating

Metal products are often heat-treated to give them desired characteristics such as durability. Common heat-treating procedures include hardening, tempering and annealing (Box B2.2). Induction is the fastest way to carry out these processes, often taking a few seconds whereas a gas furnace would take hours. A single induction coil can carry out both hardening and tempering, where two separate gas-fired furnaces would be required. Induction can also precisely target heat at particular sections of products such as gears, crankshafts, valves and drill bits.

Induction is used to pre-heat metal prior to forging, forming, rolling and extruding. It can also be used for metal joining processes such as welding, brazing and curing adhesives and sealants for car components such as doors and hoods.

### Box B2.2: Applications of induction in metal processing

**Melting** – induction furnaces can melt large volumes of metal prior to casting.

**Hardening** – heating followed by rapid cooling to increase hardness and durability.

**Tempering** – optimising properties such as toughness and ductility in workpieces that have already been hardened.

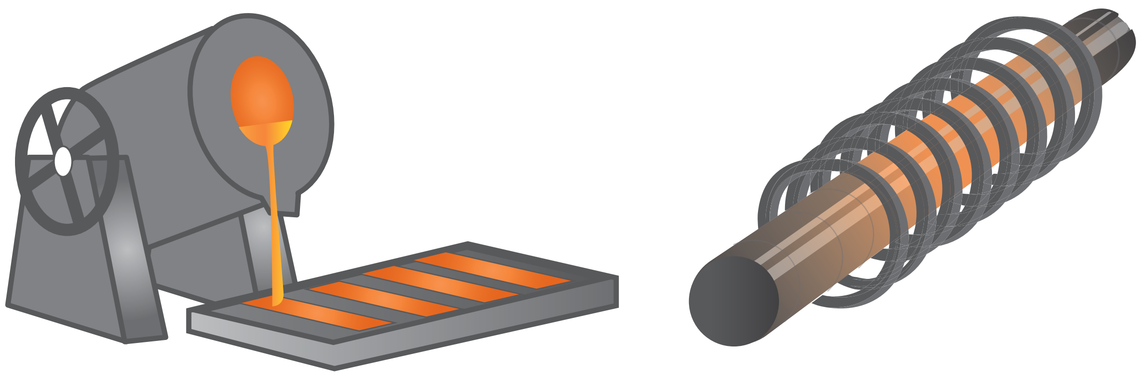
**Annealing** – reducing hardness, improving ductility and relieving internal stresses.

**Brazing** – joining two pieces of metal using a filler metal.

**Welding** – joining metal parts by heating and then pressing together.

**Pre-heating** – heating to a high temperature (below melting point) prior to forging, forming, rolling and extruding.

Figure B2.2 Two principal types of induction heating. Left-hand side: Induction furnace for melting large volumes of metal. Right-hand side: induction coil for heat treating metal pieces or melting small volumes.



## Melting metal with induction

Refined or recycled metals normally need to be melted before being fabricated into a useful product. Melting metal is an energy-intensive process, traditionally achieved in a fossil fuel-fired furnace. Such furnaces are often less than 20% efficient,[132] and even the very best are less than 50% efficient.

Induction furnaces melt metal by inducing an electric current within the material. The electric current not only generates heat, but creates a stirring motion which keeps the molten metal at a constant temperature. This enables homogenisation and a higher quality product. With fossil fuel furnaces this stirring must be generated by mechanical means.

There are two main types of induction furnaces for melting: channel induction furnaces and crucible induction furnaces. Channel induction furnaces are used to melt and hold molten non-ferrous metals such as aluminium, brass, copper and zinc. They can be designed to handle any capacity up to 200 tonnes, with 80-90% efficiency.[133]

However, channel induction furnaces are less suitable for metals with higher melting points such as steel and cast iron. Melting of these metals can be carried out with a crucible induction furnace, with a working efficiency of 80%.[134] Crucible induction furnaces are more flexible in that they are available in small modular size and can be completely emptied, enabling a manufacturer to switch materials more easily.

Induction coils can also be used to melt small amounts of metal. This raises the possibility of 'single-shot' processes where just enough metal is melted to cast a single part. Single-shot induction melting is explored in C5: 'How to electrify aluminium casting'.

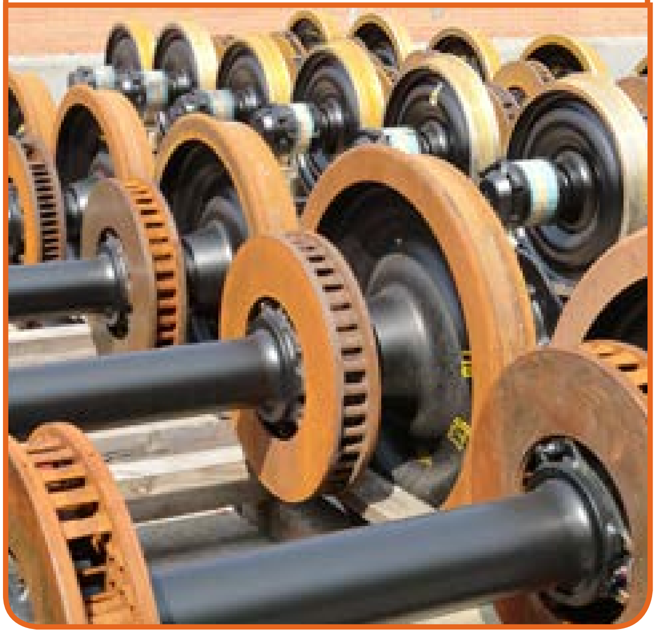
### Box B2.3 Induction case study[146]

This case study concerns a US manufacturer of bearings for use in wheel axles, drive units and traction motors of railway vehicles. The company previously hardened these bearings by heat-treating in a gas-fired furnace. This heat-treating process acted as a bottleneck, hampering efforts to increase production.

In response the company installed five 2,500 kW induction heat-treating devices costing a total of $US 600,000.

The new induction system reduced energy inputs, labour requirements and material losses, leading to huge cost savings of up to 30% per tonne. These savings meant that the initial investment was paid back in just one year.

**Operating labour savings:** 50%
**Maintenance savings:** 50%
**Scrap reduction:** 75%
**Cost saving per tonne:** 25-30%
**Payback period:** 1 year



## Dielectric heating

In dielectric heating systems a material is placed in a high-frequency electromagnetic field, causing the molecules in the material to agitate rapidly. Like induction heating the basic advantage of dielectric systems is the generation of heat within the material. Unlike induction, dielectric heating works well with materials which do not conduct electricity such as paper, cardboard, textiles and wood. Such materials are also poor conductors of heat which makes other heating techniques, such as hot air and infrared, slow and inefficient.

Dielectric heating has high power density and heats products rapidly. It is an efficient alternative for heating bulky material with a small surface to volume ratio, such as a stack of bricks or timber. Conventional furnaces heat bulky material slowly and unevenly because the heat must travel from the surface to their interior via conduction (Figure B2.3).

### Microwaves and radio-frequency

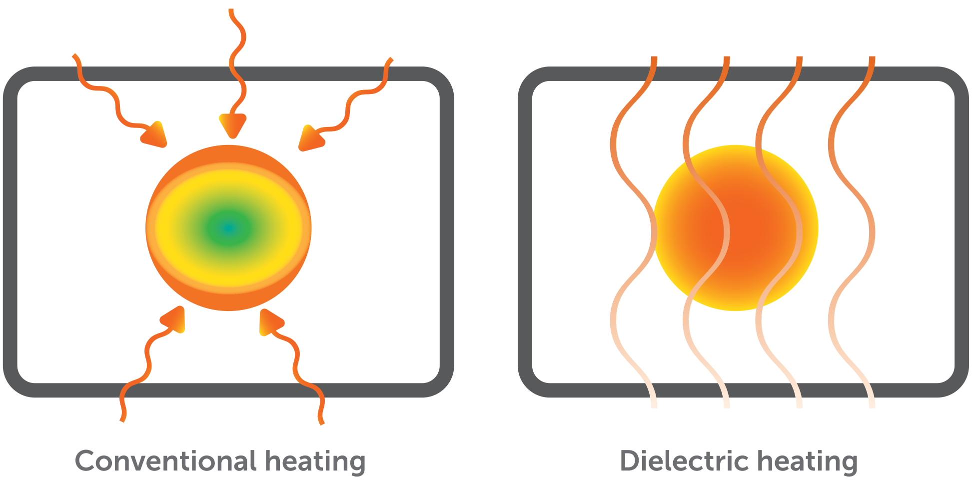
There are two types of dielectric heating – microwaves and radio-frequency. Microwave frequencies are in the 900-3000 MHz range with an associated wavelength of 10 to 30 centimetres.[i] Radio frequency installations operate in the 10-30 MHz range with a wavelength of 10 to 30 metres. Industry has used both technologies since the 1940s.

Radio-frequency systems heat material more uniformly and with greater depth of penetration, and work best with objects of a regular, simple shape. Microwave systems are more expensive but are better suited to materials with an irregular shape.

### Advantages of dielectric heating

The key advantage of dielectric heating is its ability to heat large volumes of material efficiently, as demonstrated in C6: 'How to electrify bricks'. With dielectric heating electricity is consumed only when the load is present and in proportion to the load, and there are no thermal losses from heating air or equipment.

**Figure B2.3 Dielectric heating compared to conventional heating. When bulk material is heated in a conventional oven or kiln, the heat travels slowly and unevenly from the outer edges to the centre. Dielectric heating is faster and more even because the heat is generated within the material.**




*i In practice most microwaves operate at either 915 MHz or 2450 MHz.*

Dielectric heating can also automatically adjust power output according to requirements. For example, as a product dries the energy required reduces.[135] Other advantages are:

- Faster processing times – see Box B2.4
- Instant start-up – full power is available in seconds
- Uniform heating throughout a mass of material
- Reduced equipment size – dielectric heaters are smaller than convection ovens required to do the same work
- Lower temperatures than other drying techniques.

## Applications of dielectric heating

Dielectric heating is particularly effective for drying, because water is an excellent absorber of microwaves and radio-frequency energy. Conventional drying processes are slow especially for poor thermal conductors such as brick and wood. Furthermore the surface of the material may become overly-dry resulting in cracking. With dielectric heating, drying rates are greatly increased and the likelihood of cracking greatly reduced.[136]

Table B2.5 shows that dielectric heating is suitable for processing many materials including paper, cardboard, textiles and wood, glues and plastics. It can also be used for a wide-range of heat processes including drying, sintering, calcining, cooking, curing and pre-heating.

It can also be used to speed up chemical reactions, and many experts believe microwave-enhanced organic synthesis has a particularly promising future in the production of plastics, biodiesel, chemicals and pharmaceuticals.[137]

Box 2.4 presents an example of using radio-frequency to improve the process for curing glues in engineered wood products, and C6: 'How to electrify bricks' shows how microwaves can be used to fire bricks.

**Table B2.5 Industrial process applications of dielectric heating**

| | Drying | Heating | Separation | Enhancing chemical reactions | Vulcanisation |
|---|---|---|---|---|---|
| Biodiesel | | | ✓ | | |
| Ceramics | ✓ | | | ✓ | |
| Chemicals | ✓ | ✓ | ✓ | ✓ | |
| Food | ✓ | ✓ | | | |
| Iron ore | ✓ | | | | |
| Plastics | ✓ | ✓ | | ✓ | |
| Paper | ✓ | ✓ | | | |
| Pharmaceuticals | ✓ | ✓ | | ✓ | |
| Rubber | | ✓ | ✓ | | ✓ |
| Textiles | ✓ | ✓ | | | |
| Timber | ✓ | ✓ | | | |

### Box B2.4 Dielectric case study

Beyond Zero Emissions' report, *Rethinking Cement*, promoted the benefits of timber construction. Building with engineered wood products (EWPs) such as cross laminated timber and glue laminated timber (glulam) reduces demand for concrete and steel and sequesters carbon.

Most EWPs are made from separate timber pieces held together with strong adhesive. This glue must cure before it sets properly. Some Australian manufacturers, such as Hyne Timber, cure glue by heating the EWPs in a gas-fired kiln for up to 8 hours.

**Fast and efficient curing with radio-frequency**

In Europe EWP manufacturers increasingly use radio-frequency heating to cure glue.[138] Danish company Kallesøe Machinery makes equipment which uses radio-frequency heating to cure and set EWP glues in less than 20 minutes,[139] many times quicker than any alternative curing process. A single 200 MW Kallesøe machine can process more than Hyne Timber's annual glulam output in just one month.[140]

Radio-frequency curing is also extremely energy efficient as it heats only the glue, without heating the wood at all. Compared to curing in a gas-fired kiln, it uses less than 10% of the energy.

**Table B2.6 Comparison of processing time and energy input for setting adhesive in glulam.**

| Curing process | Energy per 1m³ (kWh) | Processing time per batch |
|---|---|---|
| Gas-fired kiln* | 200 + | 8 hours |
| Radio-frequency[Δ] | 6-11 | 18-26 minutes |

**Energy estimate based on Wood Solutions' Environmental Product Declaration for Glued Laminated Timber*
*Δ RF energy depends on amount of glue in the product and moisture content in the timber*

Figure B2.4 Kallasøe timber press

## Ultraviolet processing

Many consumer products are coated to improve durability, provide protection or enhance appearance. Most of these coatings are dried and cured in gas-fired ovens. Ultraviolet processing is an alternative, room-temperature method of curing coatings.

UV processing is used to cure:

- coatings applied to wood, metals, paper, plastics, vinyl flooring, and wires
- inks as part of printing operations
- adhesives used in packaging and plastics
- polymers used to print on circuit boards and other electronic parts.[147]

These systems require special UV-curable coatings and a custom-made lamp system. UV coatings are more expensive than traditional solvent-based coatings but this extra cost is offset by several benefits:

- lower energy use – typically 75% less than thermal gas-fired systems
- faster processing – curing in seconds, rather than minutes or hours
- near-elimination of toxic volatile organic compounds emitted by solvent-based coatings
- better control over end result.[148]

## Potential of electromagnetic heating in Australian industry

Electromagnetic heating technologies have broad potential across many industries. Their value is in their ability to generate heat directly within the target material, meaning they can significantly reduce heat losses.

We estimate that electromagnetic heating technologies could displace 32 PJ of fossil fuel energy in Australian manufacturing. When powered by renewable energy this would eliminate nearly 2 million tonnes of greenhouse gas emissions.

This is inevitably a rough estimate due to the number of potential applications, and the fact that for many processes several different electric heating technologies could be employed. For example to dry food a manufacturer could use infrared, microwaves or an industrial heat pump.

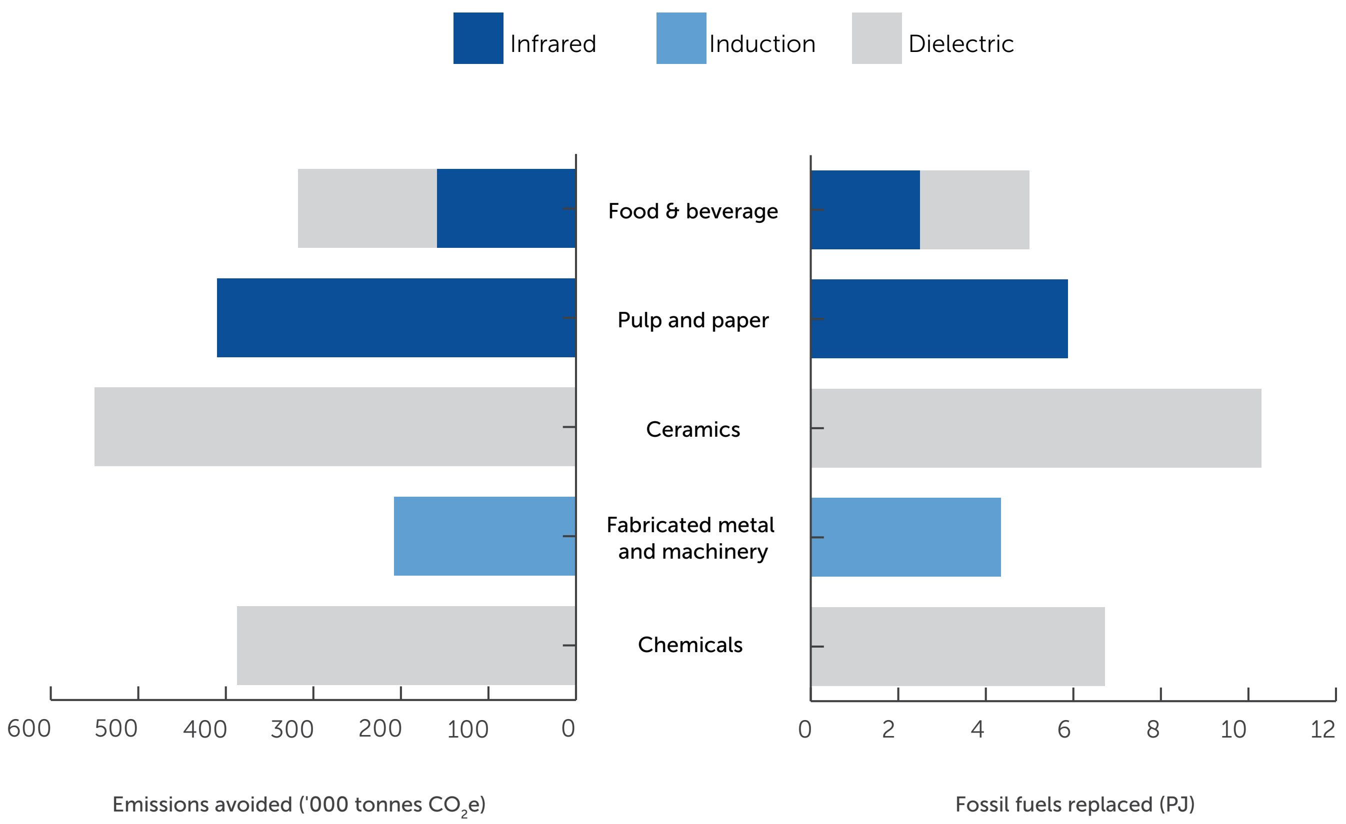
Part C explores three major opportunities for electromagnetic heating:

- Infrared for drying paper
- Microwaves for firing brick and other ceramics
- Induction for melting metal and heat-treating metal equipment.

These opportunities account for more than half of the potential illustrated in Figure B2.4. In addition we estimate that dielectric and infrared heating could together displace 10% of fossil fuels in the food industry, for processes such as cooking and pasteurisation. The true potential is much greater, though for lower temperature processes industrial heat pumps will often have a cost advantage.

Microwave technology could also replace 4% of the energy used in the chemicals industry, representing a further 385,000 tonnes of greenhouse gas emission savings.

Figure B2.4 The annual potential of electromagnetic heating to replace fossil fuels and reduce emissions in Australian industry



# B3 Electric furnaces

- Electrical resistance heating offers a simple alternative to most types of industrial gas-fired heating systems.
- Electric glass melting furnaces can provide the basis of all-electric glass-making.
- Electric arc furnaces will be a crucial part of a future zero carbon steel industry.
- Plasma arc furnaces offer new possibilities for electrifying high-temperature processes, such as cement-making.

Industry uses an enormous variety of ovens, furnaces and kilns – enclosed chambers heated to a high temperature. Ovens are used for cooking, drying, curing and various heat-treatment processes. Furnaces service a diverse range of high-temperature processes (hotter than an oven) up to 3,000°C. A kiln is a type of oven or furnace for burning, baking, or drying something, especially firing ceramics or calcining minerals.

Many types of industrial oven, furnace and kiln can be powered either by a fuel or electricity (just as a domestic oven can be gas or electric). This section outlines some significant types of electric heating technologies that can replace a fossil fuel oven, kiln or furnace.

## Electrical resistance heating could replace most gas-fired furnaces

The simplest and oldest electricity-based method of heating is resistance heating. This involves generating heat by passing an electric current through a resistive heating element. There are two types of electrical resistance heating:

- direct resistance, where the resistive heating element is also the target material
- indirect resistance heating, where the resistive heating element transfers its heat to the target material via radiation and convection. Electric ovens and boilers work this way (Figure B3.1).

Resistance heating is useful because of its simplicity and efficiency, which can approach 100%.[149] Other advantages include greater controllability, lower maintenance and absence of emissions from combustion. Resistance heating is used in for both low and high-temperature applications in various sectors including food, textiles, printing, chemicals, glass and plastics. It is also used for some processes that require higher temperatures than achievable with natural gas, such as carbon fibre production.

Indirect resistance provides a straightforward alternative to many gas-fired heating systems because it delivers heat in a similar way. For example, any gas-fired oven for baking food or firing ceramics could operate just as well using electrical resistance heating. In fact, electrical resistance furnaces used to be even more common in industry before natural gas became readily available in Australia (early 1970s).

Electrical resistance boilers could replace the type of centralised gas-fired steam systems described in Section A1. Electric boilers can produce hot water or steam (up to 220°C), are available in any size (up to 100 MW) and are almost 100% efficient.[150] Some manufacturers in Europe already operate electric boilers flexibly to take advantage of low-cost intermittent power supply from renewables.[151]

Electrical resistance could even power high-volume, high-temperature processes such as calcining. Australian company Calix is developing an electric version of its flash calciner, which can process limestone, clay and other minerals, by heating them to around 1,000°C.

Electric resistance lacks some of the benefits of other electric heating technologies, such as the spectacular efficiencies of heat pumps or the speed of induction. But its importance is its ability to replace an extremely wide range of gas-fired ovens, furnaces and kilns – Table B3.1 shows some examples.

Figure B3.1 Indirect electrical resistance furnace.

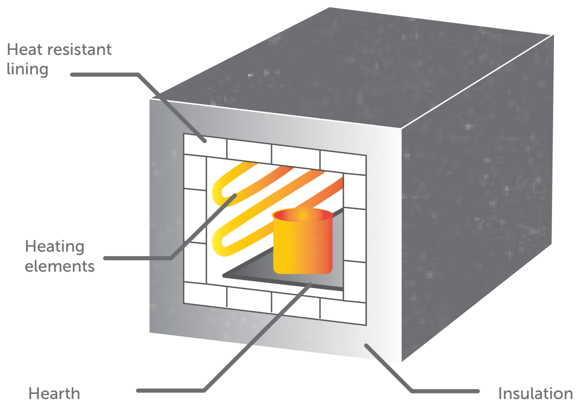


**Table B3.1 Example electric resistance equipment for high-temperature, energy-intensive processes**

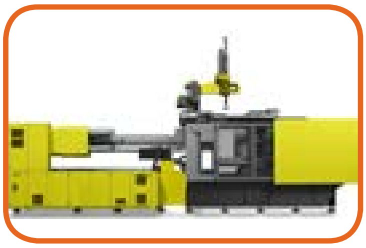


Image: Koh Wei Teck / CC BY-SA 4.0

**Plastic injection moulder**

Application: Making plastic objects

Max temperature: 200°C

Power capacity: 100 kW

**Car kiln**

Application: Firing ceramics

Max temperature: 1,300°C

Power capacity: 42 kW

**Carbon Fibre furnace (Furnace Engineering)**

Application: Producing carbon fibre

Max temperature: 1,800°C

Capacity: up to 50 tonnes per year

**Nabertherm TS**

Application: Salt-bath furnace for heat treating metals

Max temperature: 1,000°C

Power capacity: 20-120 kW

## Electric glass melting furnace

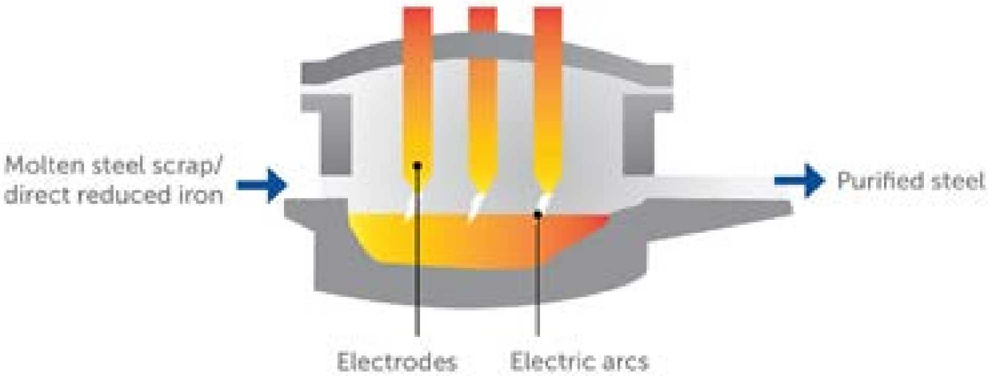
**Efficient, high-volume electric glass melting furnaces are already available.**

All-electric furnaces have been to make glass more than a century.[152] However, most glass melting furnaces are fuelled primarily by gas, with supplementary electrical resistance heating to boost the temperature. However all-electric industrial glass melting furnaces are available. Several companies supply all-electric melting furnaces, with production capacities up to 100 tonnes of glass per day.[153]

Electric glass melting furnaces use direct resistance heating – the glass heats as an electrical current passes through it. This makes them highly efficient as the heat doesn't have to be transferred. Today's efficient melt furnaces use about a third less energy than the most efficient fossil fuel fired furnace.

This report's 'how to' on glass explains how we can eliminate fossil fuel use from glass-making using electric glass melting furnaces and other electrical equipment (Section C7).

Figure B3.2 Electric arc furnace for recycling steel or making steel from direct reduced iron




## Electric arc furnaces

**Electric arc furnaces are vital for all-electric steel production.**

An electric arc furnace is a century-old technology which uses electricity to melt metal. Their most common use is to melt steel for recycling, and these furnaces produce about one quarter of world steel output. Recycling steel in an electric arc furnace requires only 10% of the energy required to produce primary steel.[154]

Electric arc furnaces are also used to convert *direct-reduced iron* into steel. This is important because, as this report's 'how to' on steel shows, production of direct-reduced iron can be electrified. This gives us a ground-breaking all-electric route to steel ('How to electrify steel'– Section C9.)

Electric arc furnaces melt steel by generating an electric arc[i] from a graphite electrode to the metal load (Figure B3.2). It is a scalable technology, with furnaces available in capacities up to about 1 million tonnes per year. They can be rapidly started and stopped, allowing a manufacturer to vary production according to demand.

Other types of electric arc furnace include the indirect arc furnace, common in the production of copper alloys, and the submerged arc furnace used to produce various metals such as silicon and iron alloys.

## Plasma arc furnace

**We could electrify high-temperature, high-volume operations like cement production using plasma arc furnaces.**

A plasma arc furnace is a special type of electric arc heating which can generate temperatures as high as 5,000°C.[ii] The heat is produced by an electric arc created when a powerful electric current is passed through certain gases such as argon.

Industrial plasma arc furnaces have been in use for more than 30 years, originally for welding and cutting. Today their main applications are incinerating hazardous wastes and processing metals such as titanium and tungsten.

As with combustion heating, plasma arcs produce a hot gas, in a way manufacturers will be familiar with. High temperatures are generated very quickly and can be precisely controlled. Plasma arcs also have better efficiency (85%) and power density than combustion heating.

Plasma arc furnaces offer new possibilities for electrifying high-temperature, high-volume processes that are otherwise difficult to electrify. For example, a plasma-fired cement kiln with a power rating of approximately 20-25 MW could produce 30 tonnes per hour.[155] This would be an energy intensive piece of kit, but with much lower power requirements than some other equipment such as a 100 MW electric arc furnace, or a 500 MW aluminium smelter.

*i An electric arc occurs when an electrical current jumps between electrodes. As the current passes through air (or another gas) it produces a plasma discharge, generating heat and light. Lightning is a natural form of electric arc.*

*ii Plasma is ionised gas which conducts electricity. It is the fourth state of matter other than solid, liquid and gas.*

Swedish cement company Cementa (part of HeidelbergCement Group) is currently investigating the potential of plasma arc furnaces to electrify cement kilns.[156]

Other potential applications of plasma arc furnaces include:

- Calcination processes including limestone calcination for pulp and paper industry and flash calcination to produce metakaolin.
- Beneficial processing of wastes from metal works such as aluminium dross and zinc leach by-product.
- Alumina production from bauxite
- Manufacturing carbon black.

## Potential of electric furnaces in Australian industry

Electric resistance heating, electric arcs and plasma furnaces have huge industrial potential. In fact *most* fossil fuel-fired ovens, furnaces and kilns could be replaced with an electric alternative. Electric resistance kilns can deliver a service temperature of up to 1,600°C, hot enough for most industrial processes.[157] For the few processes which require higher temperatures plasma arc furnaces present a viable solution.

It is estimated that electric ovens, furnaces and kilns could displace **140 PJ of fossil fuel** energy in Australian manufacturing, avoiding over 10 million tonnes of carbon dioxide (Figure B3.3). This is a high-level estimate, focussing on four areas:

- **Chemicals** – direct resistance heating could power 50% of this sector. The greatest part of this is the generation of higher temperature steam (150°C-210°C). Steam generation uses 60% of the energy in the chemicals sector.[158]
- **Cement and non-metallics minerals –** production of many minerals, including lime, metakaolin and magnesium oxide, involves heat processes below 1,100°C. These processes can be carried using electrical resistance heating. Cement kilns, which operate at 1,450°C could be electrified using plasma arc furnaces. This report assumes electrification of 70% of non-metallic minerals, and 30% electrification of the cement industry.

  The potential to electrify existing cement kilns is actually much higher but, as our *Rethinking Cement* report shows, Australia should be retiring cement kilns and switching to low-carbon cements such as geopolymers.
- **Glass –** all glass manufacturing could be electrified with electric furnaces and electric annealing lehrs. We explain this in more detail in 'How to electrify glass' (Section C7).
- **Food –** There are many opportunities to use electrical resistance in the food sector such as electric ovens and electric pasteurisation. Also electric boilers could provide hot water or steam where there is insufficient waste heat to justify a heat pump. This report assumes 25% of the fossil fuels in the food sector could be replaced with electrical resistance, although it will compete in this space with electric heat pumps.

## Potential in new or expanded industries

Electric furnaces also have a role to play in the growth of new industries. For example, an electric version of Calix's Direct Separation Reactor could be used to produce metakaolin from clay. Metakaolin will be a key raw material for the low-carbon cement industry of the future.[159]

This report also highlights the potential role of electric furnaces to support growth in three manufacturing sectors:

- Electric arc furnaces processing direct reduced iron as part of a zero carbon steel industry. A 20 MT/a industry would require 8,000 GWh/year of EAF power or 29 petajoules. (displacing part of Australian emissions from steel and others from overseas). See 'How to electrify steel' (Section C9).
- Recycling plastic – Australia could increase domestic recycling of plastics ten-fold from 5% now to 50%. This expanded plastics recycling industry would be powered by electric melting and extrusion machines. See 'How to electrify plastic' (Section C8).
- A high-tech carbon fibre industry supporting the renewable economy. See Box B3.1.

Figure B3.3 Potential of electric furnaces to replace fossil fuels and reduce emissions in Australian industry

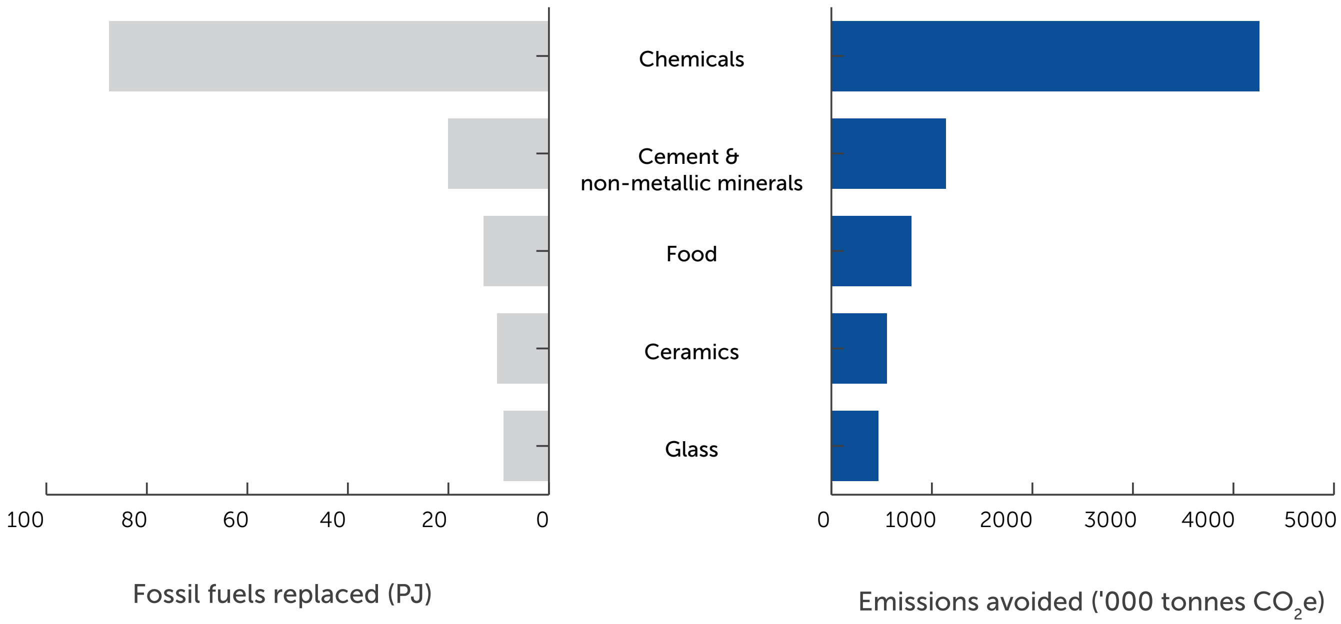



Figure B3.4 Electric submerged arc furnace producing high grade silicon used in solar cells

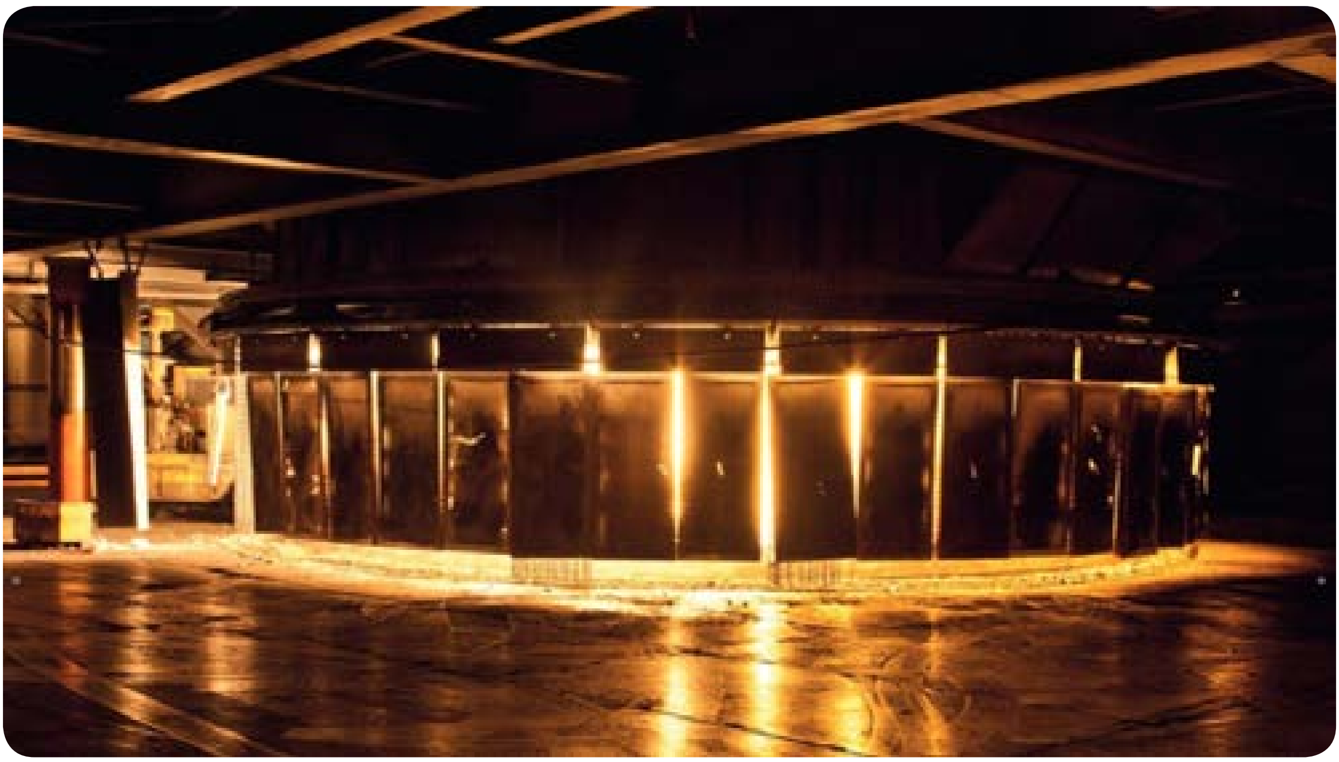


*Image courtesy of Simcoa Operations, Kemerton Western Australia.*

## Box B3.1 Carbon fibre is helping the wind industry build larger turbines.

Carbon fibre is a material for the low emissions future. It is 35% and 60% lighter than aluminium and steel, for comparable strength and stiffness.[160] This combination of low weight and high strength contributes to fuel efficiency in cars, aircraft and spacecraft. The wind power industry is also increasingly using carbon fibre to make lighter turbine blades which extract energy from wind more efficiently.

The potential of carbon fibre is yet to be fully realised, and researchers are working to reduce its production cost and develop new carbon fibre-based products. Potential future applications include concrete reinforcement, hydrogen gas storage and buildings.

### Carbon fibre and energy

One drawback of carbon fibre is that its production is energy intensive. The precursor material, usually an organic polymer, must be heated and stretched in a series of ovens and furnaces, requiring temperatures of up to 2,200°C. Using today's production technology, one tonne of carbon fibre requires an energy input of between 200,000 and 300,000 kWh,[161] 20 times more than steel and several times more than aluminium.[162]

This high energy requirement typically accounts for one third of the cost of making carbon fibre.[163] The resulting high embodied emissions diminish the environmental benefit of carbon composites. A car with light-weight carbon fibre parts must normally be driven many thousands of kilometres before its greater fuel efficiency has offset its higher embodied emissions.[164]

### Carbon fibre and renewable electricity

However, carbon fibre could be carbon neutral. All the energy-intensive steps in production – polymerisation; spinning; oxidation; and carbonisation – are already carried out in electrically powered reactors, ovens and furnaces. All that is needed is to supply this electricity from renewable sources.

Carbon fibre composites are therefore another energy-intensive material that it makes sense to make in Australia with our cheap, abundant renewable energy.  By combining this natural resource with our world-leading technical know-how, Australia could become a global centre for carbon fibre production and manufacturing.

#### Carbon Nexus

Carbon Nexus is a carbon fibre and carbon composites research facility at Deakin University in Geelong, Victoria. The facility aims to reduce production costs and energy inputs, improve performance, investigate renewable feedstocks and develop novel carbon fibre processes, products and composites.

Manufacturers are able use Carbon Nexus to develop and test carbon fibre materials and processes, as well as train their staff in production processes.

The Carbon Fibre furnaces at the centre, made in Melbourne by Furnace Engineering, use 30% less energy than machines currently used in the carbon fibre industry.

Rimac Concept One - an electric vehicle with carbon fibre body

*Norbert Aepli, Switzerland [CC BY 4.0 (https://creativecommons.org/licenses/by/4.0)], from Wikimedia Commons*

# B4 Renewable hydrogen

- We have been converting electricity into hydrogen through electrolysis on an industrial scale for over 100 years.
- Renewable hydrogen, and the synthetic hydrocarbons we can make from it, provide zero-carbon fuel.
- Renewable hydrogen can be used to fuel heat processes, or as a replacement for fossil fuels in the manufacture of steel and ammonia.

Renewable electricity can be converted into hydrogen through the electrolysis of water ($H_2O$). This involves passing an electric current through water, causing it to split into oxygen and hydrogen. Renewable hydrogen can also be combined with carbon to synthesise a range of hydrocarbons, including substitute natural gas.

Renewable hydrogen and synthetic fuels will play significant roles in decarbonising industry.

## Renewable hydrogen can replace natural gas as an industrial fuel

Hydrogen can be burned to fuel industrial heating processes in a similar way to natural gas. It burns at a higher temperature than natural gas, and generates 2.5 times more thermal energy per kilogram. The only by-product of burning hydrogen is water.

The technical differences in burning hydrogen (such as exposure of system components to higher temperatures) are easily manageable, and industrial burner systems adapted to hydrogen combustion are already commercially available (eg Maxon's Wide-Range Industrial Burner).[165] It is also possible to modify existing gas heating systems to allow them to burn pure hydrogen.[166]

***Our ability to convert electricity into hydrogen and hydrocarbons shows we can use electricity (indirectly) to fuel any industrial heat process***.[i]

## Hydrogen as an industrial feedstock and chemical

Hydrogen is also an important industrial feedstock and chemical, which can displace significant quantities of fossil fuels.

**Zero carbon steel -** Hydrogen can completely replace fossil fuels in steel-making. The standard blast-furnace process of converting iron ore into iron uses large amounts of coke (made from coal). The coke is not only a fuel but plays a vital role as a reducing agent – that is, it reacts with the iron ore, reducing it to iron.

Direct reduction is a well-established alternative way to make steel without coal. Hydrogen can be both fuel and reducing agent in the production of iron through direct reduction.ii This eliminates the need for coal, coke or any other fossil fuel. Direct reduction using hydrogen has already been proven at an industrial scale and is explored in 'How to electrify steel'. (Section C9)

**Renewable ammonia -** Another exciting opportunity for renewable hydrogen is in the manufacture of ammonia (a compound of hydrogen and nitrogen). Ammonia is one of the world's most important industrial chemicals and is the basis for all nitrogen fertilisers. Ammonia may soon become even more important because it provides a practical means of storing and transporting hydrogen, and could become a major energy export for Australia. (See 'How to electrify ammonia' Section C10).

**Hydrogen as an industrial chemical -** Hydrogen is an important chemical in many industries such as pharmaceuticals, glass-making and electronics. It also vital to the production of important industrial chemicals such as olefins, ethylene and propylene.

More than 95% of industrial hydrogen is extracted from a fossil fuel, usually through reforming natural gas.167 Hydrogen produced through electrolysis provides a zero-carbon alternative.

*i Renewable hydrogen and zero carbon synthetic fuels are useful where they can eliminate natural gas use. It is sometimes suggested that these fuels should be used just to supplement existing natural gas provision. This is not a sensible approach as it only prolongs the use of a fossil fuel which is unsustainable.*

*ii Hydrogen is also used as a reductant in the production of tungsten, molybdenum and some precious metals.*

### Box B4.1 Electrolyser technologies

There are three principal types of electrolyser.

**Alkaline electrolysers –** the cheapest and currently most suitable for large-scale electrolysis (> 50 MW). Their effectiveness has been proven over a century of use – Norway built an enormous 135MW alkaline electrolyser in the 1920s).

The best alkaline electrolysers can operate with an efficiency of 74-87% (45 to 53 kWh/ per kilogram of hydrogen). They offer a large degree of flexibility as they can operate between 20 and 100% of design capacity allowing them to handle a fluctuating power supply.[168] An alkaline electrolyser can operate for 30 years or longer, though their central component (cell stacks) must be replaced every 8 to 10 years.

**Polymer electrolyte membrane (PEM) electrolysers –** have been available commercially for 40 years but have only started to become mainstream in the last few years. The efficiency of PEM electrolysers is similar to alkaline electrolysers but with the advantage of starting up and powering down very rapidly (in seconds). This enables them to be coupled closely with intermittent renewable energy and respond to fast-changing electricity prices. Their drawbacks include shorter life expectancy and higher cost compared to alkaline electrolysers. This makes them less suitable for large systems, although PEM electrolysers on the 5-10MW scale are now being built. Some experts think that in 10 years' time PEM will be the cheapest and most efficient electrolyser technology.[169]

**Solid oxide electrolysers –** electrolyse water (steam) at high-temperatures (500°C to 800°C) which in theory enables an improvement in efficiency, although this technology is still at the development stage. If some challenges can be overcome, solid oxide electrolysers have the potential to become the dominant electrolyser technology in 10 years or more. In this case they would be particularly suitable for Australian conditions where some or all of the high temperature required could be provided by solar thermal energy.[170]

## Renewable hydrogen is getting cheaper

It is now possible to make hydrogen at a competitive cost by using a large electrolyser in a location with very good renewable energy resources. The costs can be reduced by using excess renewable energy. Once the electricity system is based largely on solar and wind energy, there will be periods of surplus generation when electricity is cheap or even free. Energy company Uniper is proving this at a site in northern Germany, using free electricity from local wind power to make substitute natural gas. Uniper sees manufacturers as one potential customer for this renewable fuel.

Figure B4.2 below, which is based on International Energy Agency calculations, shows the cost of hydrogen using lowest cost renewable electricity in Australia in 2018 and 2028. The grey rectangle represents the cost range of hydrogen from conventional production which involves reforming natural gas. At current natural gas prices, Australian hydrogen is in the upper half part of this cost range.

The graph shows renewable hydrogen can be cost-competitive where renewable energy is available to power electrolysers most of the time – at least 4,500 hours per year. This means siting the ammonia plant in a location with excellent potential to generate both solar PV and wind power. Much of Australia meets this criterion, and some sites in Western Australia can generate solar or wind power for over 6,000 hours per year. [171]

The orange line shows that, with today's renewables prices, large-scale production hydrogen from electrolysis is already cost-competitive – below A$4 per kilogram. The blue line shows that in 10 years' time, with a renewables price of 4 c/kWh, electrolysis may be the cheapest way to make hydrogen in Australia – below A$2.5 per kilogram. As we have seen in Section A4, a renewables price of 4 c/kwh or less is only a few years away in Australia.

These cost estimates assume large-scale production. Small-scale electrolysers built in Australia today cost around A$1,500 per kilowatt. By scaling up we reduce this cost dramatically. For example, Norwegian company NEL Hydrogen is planning to build a 400 MW electrolyser for just A$584 per kilowatt.[172]

## Power to methane (Substitute Natural Gas)

Hydrogen from an electrolyser can be combined with a source of carbon dioxide or carbon monoxide to make methane ($CH_4$) – sometimes called Substitute Natural Gas (SNG) (Figure B4.4). The methanation reactions which achieve this also produce water and heat. Carbon-neutral SNG is possible as long as the source of carbon is organic (not fossil fuels). Potential organic sources of carbon are air, bioethanol and anaerobic digestion plants.

Carbon neutral SNG could be an alternative renewable fuel which requires no modification of equipment. SNG production is already commercialised on a small scale. The largest facility is the Audi e-gas plant in Germany. This generates hydrogen using a 6 MW electrolyser running on intermittent renewable electricity, and reacts it with carbon dioxide from a waste-biogas plant to make SNG with an overall efficiency (electricity > heat) of 54%.[173]

Much higher efficiencies may be feasible. The EU's Helmeth project reused the heat of methanation to drive a high temperature (solid oxide) electrolyser.[174] By combining the two processes the research team achieved an efficiency of 76% and believe that 80-85% is possible (that is, a better average efficiency than power to hydrogen).[175]

### Other hydrocarbons and organic chemicals

In addition to methane, hydrogen and carbon can be combined to manufacture a wide range of hydrocarbons and organic chemicals that are normally made from fossil fuels. The simplest of these is methanol ($CH_3OH$) which is the source of several important organic compounds, such as formaldehyde. Icelandic company CRI produces renewable methanol from renewable hydrogen and carbon dioxide from a geothermal power plant.

Producing hydrogen-based methanol provides a route to low-carbon versions of other important industrial chemicals. Methanol is the key ingredients of substances such as ethylene, propylene and benzene which are the primary buildings blocks of most plastics and other organic chemicals, including those required to make carbon fibre.

Figure B4.2: Cost of hydrogen from electrolysis for different hours of operation.

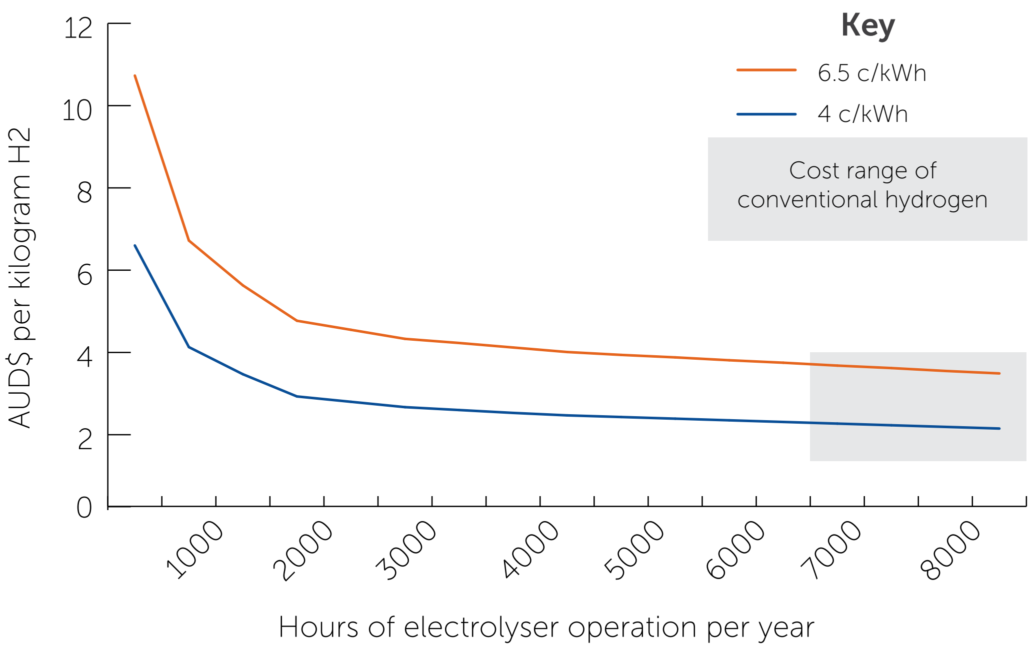



*Figure B4.2 adapted from IEA's Renewable Energy for Industry[176].*
*Assumptions: Lifetime: 30 years; Discount rate: 7%; Inflation: 3%; Operating hours: 6135 (70%); Maintenance: 1.5% of CAPEX; Cell stack replacement: every 10 years at cost of 40% of CAPEX.*

## Potential of hydrogen in Australian industry

Renewable hydrogen can replace at least **142 PJ** of fossil fuel use in Australia, avoiding over 10 million tonnes of emissions (Figure B4.3). This includes replacing:

- 43 PJ of natural gas as feedstock for ammonia production
- 65 PJ of coal and coke for primary steel manufacture.

These quantities relate to current domestic production. But the future potential of renewable hydrogen is many times greater. Australia has an opportunity to develop a significant export industry manufacturing and exporting hydrogen and ammonia as zero-carbon fuels. A second enticing prospect is to develop the world's first zero-carbon steel industry.

We have made a conservative assumption that renewable hydrogen replaces 34 PJ of natural gas as a fuel for industrial heat processes. The most likely use of hydrogen as a fuel is in those industries which are harder to electrify, such as cement and alumina. Again the true potential may be much larger, especially if electrolysing hydrogen becomes cheap at times of excess renewable energy.

### Challenges using hydrogen

**Water use -** Each kilogram of hydrogen requires 9-10 kilograms of pure water. Where hydrogen is burned at the same site as its manufacture this water can be recovered, as hydrogen produces water when burned. Sea water can also be used if it is purified (C10: How to electrify ammonia).

**Storage –** Hydrogen molecules are very small, making it hard to store as it leaks easily. Most industrial uses of hydrogen will require temporary storage. Options include high-pressure gas tanks (350 - 700 bar), metallic hydride tanks or conversion to ammonia.

**Safety -** Hydrogen explodes more easily than most fuels. Industries that use hydrogen understand how to manage this risk.

Figure B4.3 The annual potential of renewable hydrogen to replace fossil fuels in Australian industry

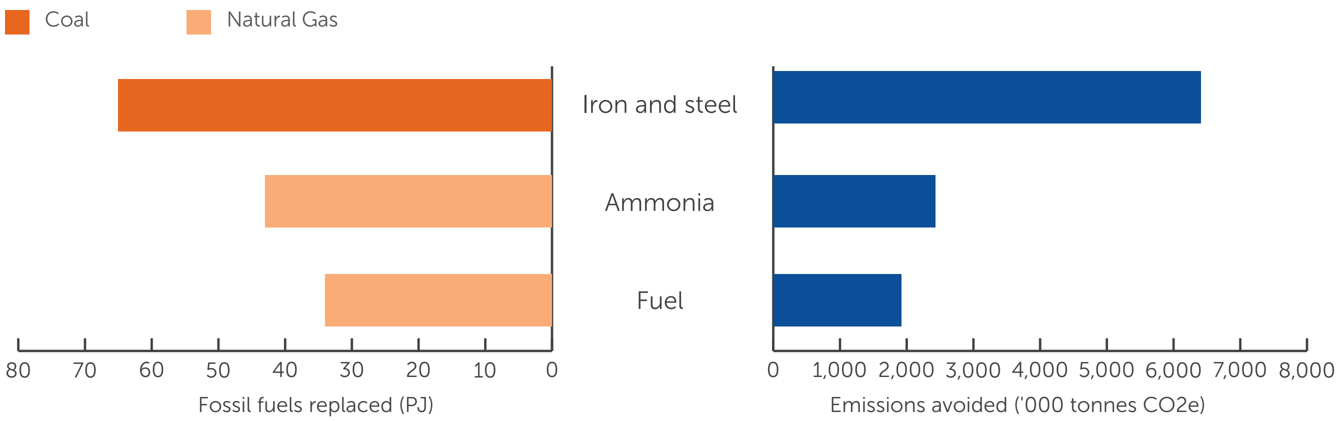
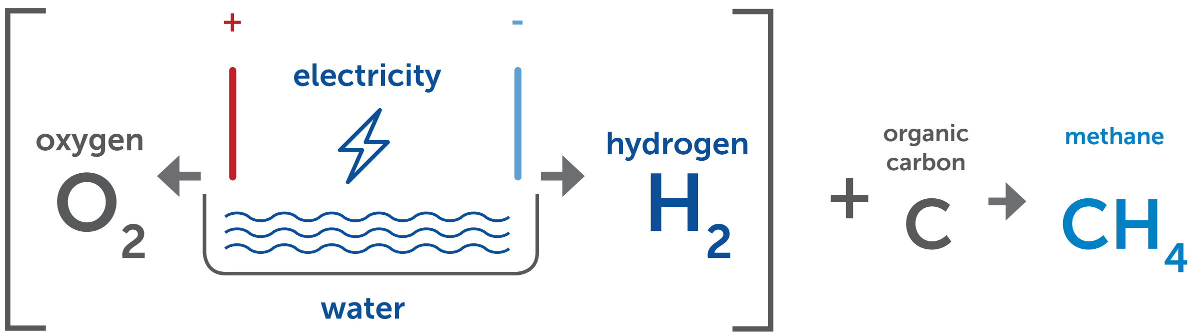



Figure B4.4 Electrolysing water produces renewable hydrogen. Hydrocarbons such as methane can be made by combining hydrogen with an organic source of carbon



# B5 Heat Storage

## Storing electricity as heat

In a 100% renewable energy grid, there will be times when wind and/or solar are producing more electricity than required. At these times the cost of electricity will fall dramatically. Sometimes consumers may even be paid to use electricity, as already happens in California and Germany.[177]

The periodic availability of free or cheap energy presents a new option for manufacturers – storing electricity as heat. There are two types of commercialised heat storage system:

- **Sensible heat[i] storage –** heat is stored using thermal capacity of a material such as water, molten salt, graphite, rock or concrete, and extracted when required. Siemens is building a sensible heat storage systems in Hamburg, Germany which will use excess wind electricity to heat 1,000 tonnes of crushed basalt. The system will store 518 GJ thermal energy which is intended for electricity generation.[178]
- **Phase-change material heat storage –** a solid material, such as a salt or metal, is heated until it is liquid. Heat is extracted by exploiting the latent energy released when the material changes back to its solid state. Examples include the 1414 technology described below, and the EU's Amadeus project which is using a silicon-boron material to store temperatures up to 2,000°C.[179]

### Application of thermal storage systems in electrified industry

Thermal energy storage could be attractive to manufacturers with electrified heat processes. A manufacturer, or co-located group of manufacturers, would store thermal energy when electricity costs were low or when their own solar panels were generating. They would then access the stored heat when electricity prices rose or when the sun stopped shining.

Thermal energy storage would enable a manufacturer to avoid paying peak electricity prices, and to be financially rewarded for relieving pressure on the electricity grid at times of high demand.

It could therefore allow a manufacturer to continue operating economically regardless of the energy market and weather.

Another advantage of storing electricity in this way is that heat storage systems are cheaper to buy than electric batteries. This means thermal storage systems can store energy for a cost of A$50-80 per kWh of storage capacity, compared to more than A$250 per kWh for lithium ion batteries.

### Box B5.1 1414 Degrees – a unique energy storage system[180]

1414 Degrees, a company based in Adelaide, has developed a unique phase-change material heat storage system. The company's Thermal Energy Storage System (TESS) takes electricity and stores it as heat in molten silicon. (Silicon's melting point of 1414°C gives the company its name.)

When required, heat is passed through an energy recovery system and a turbine to provide heat or electricity as required. The heat can be stored for a week, or even longer, though faster cycles are more economic.

The company has designed the TESS-IND series for industries whose energy use is dominated by heat, such as food and drink, agribusiness and paper manufacturing.

In combined heat and power mode a 10MWh TESS-IND module has a capacity of 170 kW electrical and 360 kW heat. The heat can produce steam at 150°C to 200°C. In heat-only mode, TESS-IND can heat air up to 700°C – hot enough to heat-treat or melt some metals such as aluminium.

1414 Degrees has successfully trialled prototypes and is now starting commercial demonstrations with several companies, including Austcor, a NSW-based packaging manufacturer. Austcor will use heat provided by a TESS-IND installation to generate steam, reducing its consumption of natural gas.

*i Sensible heat is the energy required to increase a materials temperature.*

## Box B.2 Concentrated Solar PV

Concentrated solar PV combines two technologies – solar PV and concentrated solar. The appeal of this technology is its ability to generate both electricity and heat, with a very high level of efficiency (80%).

Concentrated solar PV systems consist of a field of mirrors which concentrate sunlight onto highly-efficient PV panels. These panels convert 30-35% of the concentrated light into electricity – twice as efficient as the average PV panel. To prevent them from over-heating the panels must be continually cooled with water. This creates a source of useful hot water, typically up to 100°C.

Australian company RayGen has developed a concentrated solar PV system, called PV Ultra, which produces twice as much heat as electricity (See Box: RayGen). A PV Ultra system with a capacity of 3 MW (1MW of electricity and 2 MW of heat) requires a 4.4m2 solar panel and 200 sun-tracking mirrors in a field of 2.4 hectares. This is about the same surface area as a 1MW solar PV plant, which produces no useful heat. PV Ultra produces about three times more energy per hectare than traditional solar PV.

### Applications in manufacturing

Concentrated solar PV is an attractive renewable energy technology for manufacturers requiring electricity and heat. The low-grade heat (typically less than 100°C) can be stored or used directly in low-grade processes (eg cooking, sterilisation) and in pre-heating boilers for higher grade thermal processes. Suitable applications include brewing, horticulture and much of the food industry. Manufacturers requiring higher temperature water or steam (up to 160°C) can either increase the operating water pressure, or use concentrated solar PV in combination with a high temperature heat pump.

For a given electrical generation capacity concentrated solar PV currently costs more than an ordinary PV installation. But its ability to deliver heat at below the cost of gas means that for some manufacturers concentrated solar PV could have a shorter payback period.

Sites installing concentrated solar PV would need:

- sufficient space adjacent to their facility, or nearby
- the capacity to store heat
- to be in a location with high 'direct normal irradiation' - ie cloudless sunshine (most of Australia).

**RayGen - PV Ultra**

Australian company RayGen, based in Melbourne, is leading the world in the commercialisation of tower-mounted concentrated solar PV. The company has developed a system called PV Ultra which requires just 4m$^2$ of PV panels and 2,500m$^2$ of mirrors to generate 1 MW of electricity, plus at least 2 MW of heat. A 1 MW array of traditional solar PV needs 5,000m$^2$ of panels.

The effectiveness of PV Ultra has been demonstrated over several years at two pilot sites. The first installation supplies heat and electricity to a mushroom farm in Newbridge, Victoria. RayGen has also successfully installed a 250 kW PV Ultra system at an automotive tape manufacturing site near Beijing, China.

# Part C
## How to electrify guides

# Part C How to electrify guides

Part C contains 10 theoretical case studies. Each of these 'How to' guides focuses on an industrial product that is usually manufactured using fossil fuels.

The guides propose all-electric manufacturing systems, which could replace conventional processes, removing the need for fossil fuels. These alternative systems apply one or more of the electrical technologies described in Sections B1-B4.

The all-electric systems presented in Part C are unlikely to be the only way to eliminate fossil fuel, but are intended to inspire manufacturers to re-think industrial heat processes for the low-carbon era. Each 'How to' guide:

- quantifies and compares the energy requirements of the conventional and electric process systems
- compares operational energy costs of the two systems
- where available, presents information on costs of purchase and installation.

This cost comparison uses the prices for gas and renewable electricity set out in Section A4. For the conventional system we use low, medium and high gas prices within the range projected in Section A4. For renewable electricity prices we use typical prices in 2018 and projected prices in 2028 for both on-site generation and off-site generation.

**Table C.1 'How to electrify' guides in Part C show how common industrial material could be made without fossil fuels.**

| Product | Electrical heating technology | Energy saving |
|---|---|---|
| **Prepared food** | Heat pumps and infrared | 49% |
| **Beer** | Heat pumps | 69% |
| **Milk powder** | Heat pumps | 66% |
| **Paper** | Infrared | 24% |
| **Aluminium casting** | Induction | 50% |
| **Brick** | Microwaves | 50% |
| **Glass** | Electrical resistance | 30% |
| **Plastic** | Electrical resistance | 95% |
| **Steel** | Renewable hydrogen and electric arc furnace | 18% |
| **Ammonia** | Renewable hydrogen | 4% |

# C1 How to electrify prepared meals

- Prepared meals require an average energy input of 2,469 kWh per tonne of product, with most of the energy supplied by gas-fired boilers.
- An all-electric system could replace these boilers, reducing energy use by 49%.
- This efficiency is achieved through the use of heat pumps with combined heating and cooling capability, and infrared ovens.

Demand for prepared meals[i] is increasing, as busier lifestyles reduce the time people have for cooking. The Australian prepared meals industry generates revenues of $607 million a year and is growing by 3.7% annually.[181] Prepared food manufactures, such as McCain Foods, Simplot Australia and Patties Foods cook ingredients, package the final product and sell it to grocery wholesalers, supermarkets and other food outlets.

## Conventional prepared food manufacturing

This 'How to' uses real data from a manufacturing facility in Australia capable of producing over 50 tonnes per day of food.[ii] The facility makes prepared meals and pizzas in the following steps:

1. **Food preparation –** Processing and mixing of raw ingredients such as meats, potatoes, vegetables, pasta flour, water, eggs and flavouring ingredients.
2. **Cooking –** Raw food is boiled or steamed in large steam-injected kettles. This process, known as blanching, destroys enzymes that can cause chemical changes that negatively affect flavour and colour. Raw meat products are typically cooked using gas-fired commercial woks.
3. **Filling and Packaging –** Once the food is cooked it is put into trays. The food trays then move to the packaging station and a partial vacuum is created to ensure that the container is airtight.
4. **Freezing and storage prior to transportation –** The packaged food is sent to a cold air-blasted freezer where it is cooled rapidly from 70°C to below freezing within 90 minutes. This prevents bacterial growth and makes the food safe for storage and consumption.
5. **Cleaning –** Hot water for cleaning the plant is generated using a second gas-fired boiler.

### Existing energy input and equipment

At this example facility, the most significant equipment in terms of energy use is:

1. A 4 MW gas-fired boiler providing steam at 180°C to the cooking kettles. This boiler operates at only 50% of capacity (2 MW) and uses a heat economiser to achieve an efficiency of 82%.
2. A 200 kW gas-fired oil heater providing hot oil for cooking at 240°C
3. A 50 kW gas-fired boiler providing hot water for cleaning at 90°C
4. Two gas-fired pizza ovens (400kW and 300kW) to cook pizzas at 200°C.
5. Six refrigeration compressors ranging in size from 220kW to 465kW provide cooling for the blast chillers (-30°C) and cool rooms (-18°C).

The energy consumption of this equipment is summarised in Figure C1.1. The current system requires 2,469 kWh to prepare one tonne of food.

*i Defined as a complete meal prepared by manufacturers that the consumer is only required to reheat.*

*ii The research for this 'How to' was led by Michelle Brownlie, Associate Sustainability Engineer at WSP.*

## All-electric prepared food manufacturing

An all-electric foods preparation system can halve the amount of energy required (Figure C1.1). This approach relies on electric heat pumps and infrared ovens, both of which are three times more efficient than the existing gas-fired systems.

The heat pumps recover the large amount of waste heat expelled from the refrigeration compressors, and operate with an average effective efficiency of 300% (a coefficient of performance of 3 – see Section B1, page 50). Two of the heat pumps have cooling capability, reducing demand on the refrigeration units by 1.5%.

The key components of the all-electric system are outlined below.

**Heat pumps 1 & 2 –** The main 4 MW gas boiler can be replaced with two 1 MW heat pumps. These heat pumps use only 29% of the energy of the existing boiler. This impressive efficiency gain is achieved because the heat pumps:

1. reuse warm air expelled by the condensers of the refrigeration system at 25-30°C.
2. deliver steam at 110°C, the temperature required to cook the raw food. The current system, like many central boilers, over-heats the steam to 180°C.
3. operate with an effective efficiency of 300% (COP of 3), compared to only 82% for the current boiler.

The heat pumps' combined heating capacity of 2 MW is sufficient because the existing 4 MW boiler is twice as large as it needs to be. Several commercial heat pumps, such as the Hybrid Energy AS, have the required capacity and capability (Section B1).

**Heat pump 3 –** The 50 kW gas-fired hot water boiler can be replaced with a 60 kW heat pump capable of providing heating and cooling simultaneously. This heat pump reuses waste heat from the refrigeration system, as well as providing 40 kW of cooling capacity. It operates with a combined coefficient of performance of 4.5.

**Heat pump 4 –** The oil heater can also be replaced with a 60 kW heat pump capable of providing heating and cooling simultaneously. The heat pump reuses waste heat from the refrigeration system and raises the temperature of the oil to 90°C. An electrical resistance heater is then used to boost the temperature up to 240°C.

**Infrared pizza ovens –** The gas-fired pizza ovens can be replaced by commercially-available infrared ovens. Infrared ovens are faster and three times more efficient.[182] (Section B2 on infrared heating.)

Figure C1.1 Stages, temperature and energy requirements for producing 1 tonne of prepared foods

### Existing system

| Equipment | Energy (kWh) | |
|---|---|---|
| | Gas | Elec |
| 4 MW Boiler | 1,267 | - |
| 200 kW Oil heater | 97 | - |
| 50 kW Hot water heater | 15 | - |
| Pizza ovens | 341 | - |
| Processing equipment, filling & packing lines | - | 355 |
| Refirgeration Compressors | - | 394 |

### Process Stage

| Process Stage |
|---|
| Steaming raw food 180°C 110°C |
| Cooking food product 240°C |
| Cleaning 90°C |
| Cooking pizzas 200°C |
| Processing and packing |
| Refrigeration |

### All-electric system

| Equipment | Energy (kWh) |
|---|---|
| Heat pumps 1 & 2 (2 x 1 MW) | 373 |
| Heat pump 3 (60 kW) | 4 |
| Electrical reistance oil heater | 24 |
| Heat pump 4 (60 kW) | 5 |
| Infrared pizza ovens | 115 |
| Processing equipment, filling and packing lines | 355 |
| Refrigeration compressors plus heat pumps 3 & 4 | 388 |

| Existing system | | All-electric system |
|---|---|---|
| 2,469 kWh | Total Energy | 1,264 kWh |

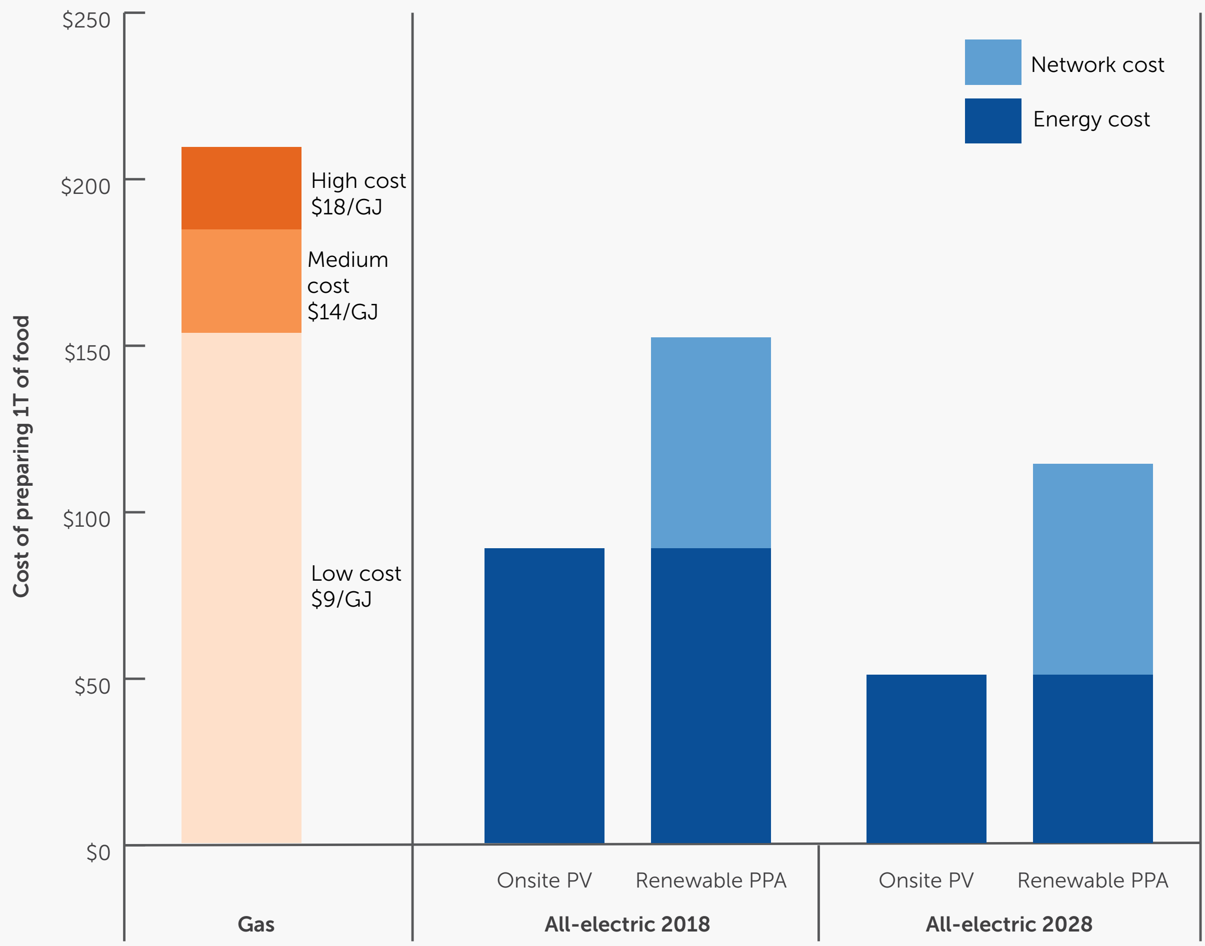
## Comparing operational energy costs

By fully electrifying the production of prepared food we can reduce energy consumption by 50%. Figure C1.2 below compares the energy costs of production in the current system and the all-electric system. The comparison uses gas and electricity prices set out in Section A4.

Figure C1.2 shows that an all-electric system, powered by renewable energy, is already cost-competitive with the current gas-fired system, even with a low cost of gas. For example, at current renewable PPA prices, one tonne of food can be prepared for $152. This is cheaper than the current system even with a low cost of gas (at $9/GJ = $153 per tonne). If electricity were produced with on-site solar PV, the all-electric system would beat gas on cost for all plausible gas prices.

The cost advantage to renewable electricity will grow steeply in the next few years. By 2028 the energy cost of the all-electric system will be around half the cost or less of the current gas-dependent system.

Figure C1.2 Comparative operational energy costs to prepare 1 tonne of food.



# C2 How to electrify beer

- The relatively low temperatures required in brewing (60 to 100°C) presents an excellent opportunity for energy and cost savings through the use of electric heat pumps.
- By fully electrifying brewing we can reduce thermal energy input by 69%.

Australians drink 5 million litres of beer every day. That's a pot for every adult.[i]

Brewers require heat for mashing, boiling, pasteurisation and packaging. The operating temperature range of these processes, 60 to 100°C, presents excellent opportunities for energy and cost savings through the use of electric heat pumps.

Large breweries require an energy input of 32 to 45 kWh per hectolitre of beer (1 hectolitre = 100 litres). Craft breweries, whose market share is growing, can use at least twice this amount.

Around one quarter of energy used in brewing is electricity used to handle grain, mix and pump product, operate packaging systems and power refrigeration systems. This 'How to' guide focuses on the remaining three-quarters of energy for running thermal processes. This heat is normally supplied by burning natural gas and amounts to 28 to 40 kWh per hectolitre.[183]

## The manufacturing process

Beer is made from just four primary ingredients: barley, hops, yeast and water. The main process steps involved in brewing are:

- **Mashing –** malted barley is mixed with water and other minor ingredients, and heated to 70-85°C to extract flavour. The liquid stream produced is known as wort.
- **Separation –** the wort is separated from the grain in a vessel called a Lauter tun.
- **Boiling –** hops are added and the mix is heated to boiling point (100°C). Modern breweries have improved energy efficiency by limiting evaporation. The wort is then filtered and cooled ready for fermentation.
- **Fermentation –** yeast is added to the wort, initiating the fermentation process which takes several days. Fermentation releases heat, so cooling jackets and coils are used to maintain the correct temperature.
- **Clarification and cooling –** the fermented product is cooled, clarified and filtered to remove yeast and other components in preparation for filling.
- **Filling and pasteurisation –** beer is poured into a keg, bottle or can, before being pasteurised at 60°C.
- **Final packaging –** the beer is prepared for sale by labelling, cartoning and palletising.

Thermal energy is required for mashing, boiling and pasteurisation, as well as to provide hot water for cleaning and other services. The total thermal energy requirement varies widely between breweries. In our comparison we assume an efficient brewery consuming 28 kWh of thermal energy at the brewhouse per hectolitre. This energy is supplied by a central gas-fired boiler operating at 85% efficiency, giving a total requirement of 33 kWh per hectolitre (Figure C2.1).

## All-electric beer production

Fully electrified beer production involves replacing gas boilers with heat pumps. In our example this enables a 69% reduction in the thermal energy input of brewing.

The proposed all-electric system uses heat pumps to provide heat for boiling, mashing, pasteurisation and cleaning. These heat pumps will recover heat from the wort boiling and the cooling steps in the brewing process.

*i The research for this 'How to' was led by Andrew Gelbart, a process engineer who has spent the majority of his career in design and manufacturing in the food industry .*

Table C2.1 outlines the four heat pumps required in a large all-electric brewery capable of producing 500,000 hectolitres per year or 100 hectolitres per hour. Heat pumps 3 and 4 will operate with very high effective efficiencies of 400 to 500% (COP of 4-5), due to the relatively low temperature required for mashing, pasteurisation and cleaning. The two heat pumps for boiling will operate at a lower coefficient of performance of 1.8 due to the higher temperature uplift required.

The heat pumps will be integrated into the brewery and distributed at the points of consumption. This will allow a brewery to eliminate steam distribution piping and the associated heat losses.

A further advantage of heat pumps is that they can each be sized according to need. A brewery of any size could install heat pumps according to requirements.

**Table C2.1 Four heat pumps required in a large all-electric brewery.**

| | Power rating (kW) | Output temperature | Process stage | Coefficient of performance | Thermal output (kW) |
|---|---|---|---|---|---|
| **Heat pump 1** | 500 | 110°C | Boiling | 1.8 | 900 |
| **Heat pump 2** | 500 | 110°C | Boiling | 1.8 | 900 |
| **Heat pump 3** | 120 | 60°C | Pasteurisation | 5 | 600 |
| **Heat pump 4** | 400 | 80°C | Mashing & cleaning | 4 | 1,600 |

Figure C2.1 Stages, temperature and heating energy requirements for producing 1 hectolitre of beer.[184]

| Conventional systems: Equipment | Conventional systems: Energy (kWh) Gas | Process Stage | All-electric system: Equipment | All-electric system: Energy (kWh) |
|---|---|---|---|---|
| Centralised gas boiler system | 2.9 | Mashing 70°C-85°C | Heat pump 4 | 0.62 |
| | 12.9 | Boiling 100°C | Heat pump 1 & 2 | 6.1 |
| | 5.2 | Pasteurisation 60°C | Heat pump 3 | 0.9 |
| | 12 | Cleaning & production supoort 60°C-90°C | Heat pump 4 | 2.6 |
| 33 kWh | | Total Energy | 10.2 kWh | |

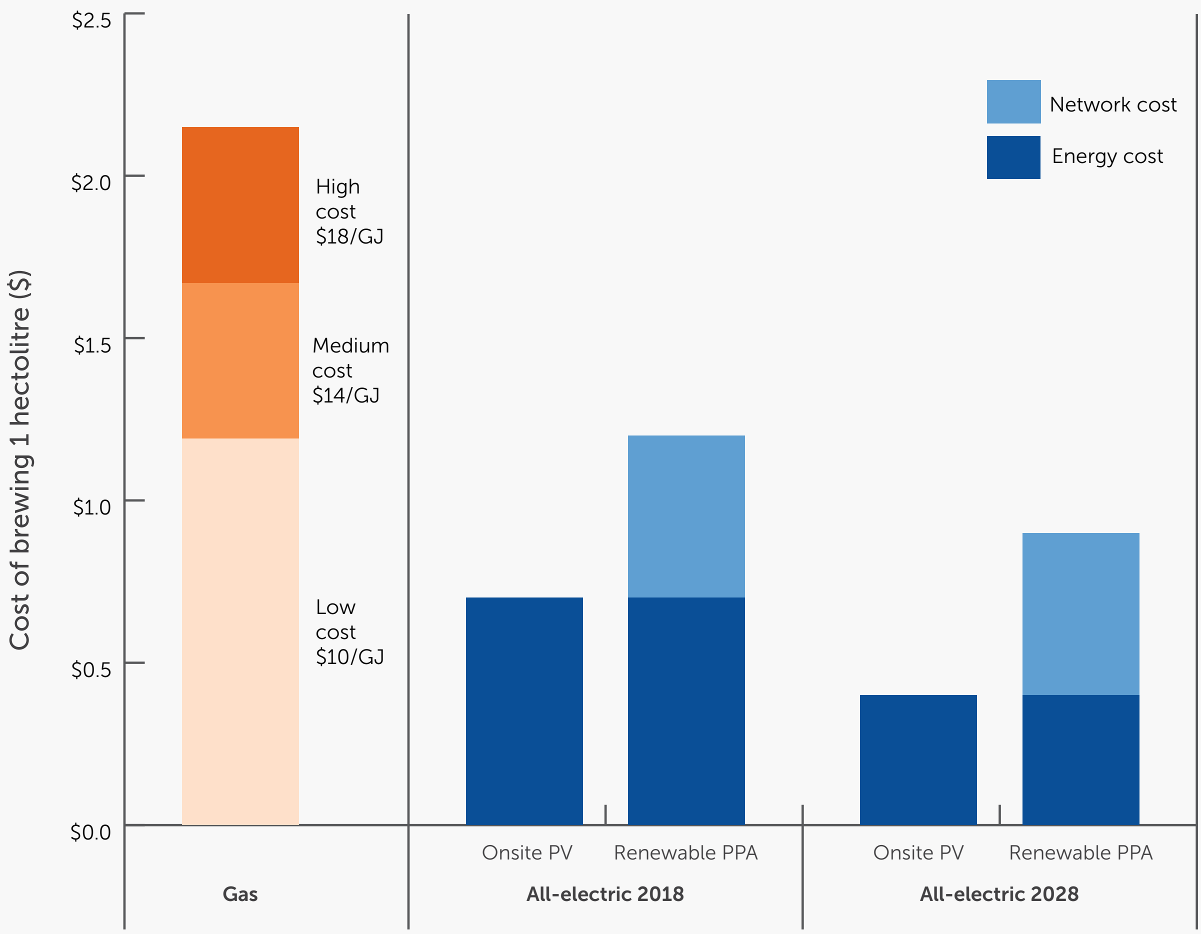
## Comparing thermal energy costs

Figure C2.2 below compares the energy costs of production in conventional brewing and an all-electric system using heat pumps. The comparison uses gas and electricity prices set out in Section A4.

Figure C2.2 shows that an all-electric system, powered by renewable energy, is already cost-competitive with the current gas-fired system, even with a low cost of gas. If electricity were produced with on-site solar PV, the all-electric system would beat gas on cost for all plausible gas prices.

The cost advantage to renewable electricity will grow steeply in the next few years. By 2028 the cost of thermal energy in brewing could be less than the half the cost of the current gas-dependent system.

Figure C2.2 Comparative thermal energy costs of brewing 1 hectolitre of beer.



# C3 How to electrify milk powder

- An all-electric milk powder production system could reduce energy use by 66%.
- This electric system uses:
  - reverse osmosis to remove 20% of the water prior to heating and evaporation.
  - two highly-efficient heat pumps which reuse waste heat for pre-heating, pasteurisation and drying.
- All-electric milk powder manufacturing would be cheaper to run than standard production.

More than a third of Australia's annual national milk production of 9 billion litres is used to make milk powder.[185] Australia produces 322,000 tonnes of milk powder per year, more than 80% of which is exported.[186]

Milk powder manufacturing plants are a significant investment, so tend to be large and few in number. The main manufacturers are Fonterra, Camperdown Dairy International, Devondale Murray Goulburn and the Midfield Group.

## Standard milk powder production process

Milk powder production involves the removal of water from milk, until the moisture content is 5% or less. About 80% of the water is removed by boiling the milk under reduced pressure at low temperature in the evaporation process. The resulting concentrated milk is then sprayed in a fine mist into hot air to remove further moisture and produce a dry powder. The evaporation and drying processes are usually serviced by a central gas-fired boiler which generates high pressure steam. Natural gas typically supplies more than 90% of the process energy.

In recent decades efficiency improvements have reduced the energy required for a tonne of milk powder from about 12 GJ to 5-6 GJ for world-leading facilities.[187] The Australian average is reportedly 8.3 GJ.[188]

One of the main efficiency improvements has been the combined use of Mechanical Vapour Recompression (MVR) and Thermal Vapour Recompression (TVR). These technologies recompress low pressure vapour to a slightly higher pressure and temperature, with an overall heat pump COP of 30-50. MVRs are electrical whereas TVRs are powered by steam.

## Production steps

1. **Separation.** Cream and butterfat are separated from milk in a centrifuge.
2. **Pre-heating and pasteurisation.** Milk is briefly heated to between 75-120°C through steam injection.
3. **Evaporation.** 80% of the water in milk is removed as vapour by boiling in MVR and TVR systems. The pressure is reduced so that the boiling point is only 57-68°C and heat damage to the milk is avoided.
4. **Drying.** Milk concentrate is converted into a fine mist which is sprayed into the top of a tower of hot air (heated by steam). The heated mist dehydrates as it falls and is collected at the bottom of tower as a powder.
5. **Cooling & final drying.** The partially dried powder exits through a series of fluidised beds, completing the drying process and cooling the powder from 80°C to 35°C.

## All-electric milk powder production

Here we present one approach to the complete electrification of a milk powder plant (Figure C3.2).[i] The process steps are similar to the standard process, except for the introduction of reverse osmosis. The heating, evaporating and drying processes are carried out by the four electrical technologies described below.

A large part of the energy savings in this all-electric system result from the application of process integration techniques developed at the University of Waikato. We have also achieved efficiencies by reusing waste heat and exploiting the high efficiency of heat pumps, and by eliminating the energy wasted by a gas boiler.

The alternative system involves the integration of the equipment described below, as part of a system capable of producing 5 tonnes of milk powder per hour (a medium-size factory).

1. **Reverse osmosis –** a recently commercialised membrane technology which partially removes water from milk. By raising the solid content from 10% to about 30% it reduces the demand on both the pre-heater and the evaporator.
2. **Heat pump 1 –** a heat pump capable of providing heating and cooling simultaneously. The cooling capacity of 80 kW is used to refrigerate the milk and operate cool stores, and providing waste heat at 35-40°C. The heating capacity of 120 kW reuses this waste heat, producing hot water at 85°C for heating milk, and additional hot water at 55°C for washing. The heat pump achieves a combined COP for heating and cooling of 4.6.
3. **Mechanical Vapour Recompression –** Instead of MVR followed by TVR we have introduced a two-stage, low-energy system of mechanical vapour recompression.[189]
   a. Stage 1 - Pre-heating for heat treatment and flashing releases water vapour at 85°C. Under low pressure, the milk boils at 68°C with an MVR pulling and pressurising the water vapour to a condensing temperature of 73°C to boil off more water from the milk in Stage 1. Some vapour may also be diverted to pre-heat incoming milk.
   b. Stage 2 – Milk concentrate at 40% solid content enters at low pressure into Stage 2 with a water boiling point of 56°C. A second MVR raises the vapour from Stage 2 to a condensing temperature of 61°C. The solid component increases to 53%.
4. **Heat pump 2 –** a heat pump which recovers waste heat from the dryer exhaust at 75°C, producing hot air at 140°C with a COP of 2.5. The heat pump has a heating capacity of 2,560 $KW_{th}$ while consuming 1,025 $kW_e$.
5. **High-temperature electric air heater –** the heater takes air at 140°C from heat pump 2, and directly heats air to 210°C via hot elements using 1,435 kWe.

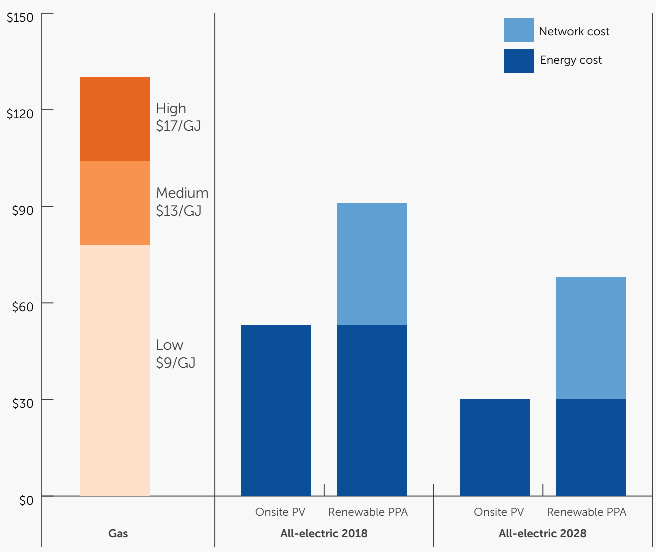
## Comparing operational energy costs

By fully electrifying milk powder production we can reduce thermal energy input by 61%. Figure C3.1 below compares the energy costs of production in conventional brewing and an all-electric system. The comparison uses gas and electricity prices set out in Section 4.

Figure C3.1 shows that an all-electric system, powered by renewable energy, is already cost-competitive with the current gas-fired system, even with a low cost of gas. If electricity were produced with on-site solar PV, the all-electric system would beat gas on cost for all plausible gas prices.

The cost advantage to renewable electricity will grow steeply in the next few years. By 2028 the all-electric system will be cheaper to run than the conventional gas-fired system for any plausible cost of gas.

### Figure C3.1 Comparative energy costs of producing 1 tonne of milk powder




*i This all-electric alternative is based on various papers by the Energy Research Centre, School of Engineering, University of Waikato.*

Figure C3.2 Stages, temperature and energy requirements for producing 1 tonne of milk powder

| Existing system | | | Process Stage | All-electric system | |
|---|---|---|---|---|---|
| **Equipment** | **Energy (kWh) Gas** | **Energy (kWh) Elec** | | **Equipment** | **Energy (kWh)** |
| Centrifuge | 3 | 13 | **Separation** 8°C | Centrifuge | 13 |
| N/A | - | - | **Reverse osmosis** | Reverse osmosis pumps | 35 |
| Steam boiler | 388 | - | **Pre-heating** 75-120°C | Heat pump 1 | 47 |
| Mechanical & thermal vapour recompression | 133 | 90 | **Evaporation** 57-68°C | Mechanical vapour recompression | 27 |
| Steam boiler | 1,139[190] | 50 | **Drying** 210°C | Heat pump 2<br>Electric air heater | 205<br>287 |
| Fluidised beds | 111 | 45 | **Cooling** | Fluidised beds | 148 |
| 1,972 kWh | | | **Total Energy** | 762 kWh | |

# C4 How to electrify recycled paper

- Recycled paper has just 1% of the climate impact of virgin paper
- 81% of the energy required to make recycled newsprint is for drying the paper
- Electric infrared heaters can dry paper, saving time, money and energy compared to conventional steam drying[ii]

The prevalence of computers and screens has failed to dampen our enthusiasm for paper. On average each Australian uses twice their body weight in paper each year – 150 kilograms.[191] Just over half of this is print paper such as newsprint and the rest is for various industrial, domestic uses such as packaging and tissues.

The Australian paper and pulp industry is dominated by a few large companies, such as Australian Paper, Norske Skog and VISY. The industry employs 12,500 people in NSW, Queensland, Tasmania and Victoria.[192]

## Paper production and energy

Making paper is a complex multi-step process, which consists essentially of two stages: 1) pulping and 2) conversion of pulp into paper. The most common method of pulping is the Kraft process, in which wood chips are broken down in a hot chemical solution. Virgin paper made via the Kraft process requires 5,000-7,000 kWh of energy per tonne,[193] a similar energy requirement to virgin steel.

Many paper mills are able to be partly self-sufficient in energy by using wood wastes or the by-products of pulping. For example, Australian Paper's mill in Maryvale derives 53% of its energy from biomass.[194] Despite this, paper mills are major consumers of fossil fuels, and the Maryvale facility is Victoria's largest user of natural gas.[195]

## Recycled newsprint

This 'How to' focuses on the final drying stage in producing recycled newsprint. Newsprint is the type of paper used for newspapers and magazines. Recycled paper requires less than half the energy input of virgin paper, and also reduces consumption of wood, water and other chemicals. A recent life-cycle analysis found that recycled paper has just 1% of the climate impact of virgin paper.[196]

Production of newsprint paper from recycled pulp paper requires 2,262 kWh per tonne (63% less than virgin newsprint requirement of 6,138 kWh).[197] Most of this energy is used to remove water after pulping, particularly drying sheets of newsprint. When newsprint enters the final drying stage, it contains about 50% water, and this must be reduced to 6%.[198]

In the conventional process, the drying stage consumes 1,824 kWh per tonne of product – 81% of the energy required to make recycled newsprint (Figure C4.2).

## Conventional paper drying

When wet paper enters the drying chamber it is passed around a long series of hollow cylinders heated internally by steam. The steam is supplied from a central boiler system (at 120-125°C).[199] The hot cylinders heat and dry the paper through evaporation. Moist air is removed from the drying chamber and replaced with warm dry air. Heat is extracted from the moist air and used to pre-heat the dry air.

The drying chamber is often a bottleneck in paper production.[200] Expanding the chamber is not always an option because it takes up a lot of space.

## Drying paper with electric infrared

Infrared is an efficient way to dry thin material, as it targets heat at an object's surface (Section B2). Electric infrared is already widely used for drying coated paper,[i] and gas-fired infrared is used to dry regular paper, usually in combination with conventional steam dryers.[201]

*i Paper coated in a compound or polymer to add weight or a surface gloss, or give water resistance.*
*ii Much of research for this 'How to' was carried out by Azadeh Keshavarzmohammadian, a mechanical engineer.*

A US study found that using 100% electric infrared to dry paper could save energy, time and money, compared to conventional steam drying.[202] The study assessed a theoretical facility producing newsprint at a high rate of 26 tonnes per hour. A conventional steam drying system with this capacity would involve 48 steam-heated cylinders. To dry one tonne of paper the cylinders would be fed 947 kWh of steam – equating to 1263 kWh of natural gas (assuming 75% efficiency).

An alternative all-electric set-up would comprise 47,000 individual infrared emitters,[ii] each with 0.45 kW capacity (21 MW in total). In this system the wet paper passes around metal cylinders and is exposed every few metres to infrared radiation. The wavelength of the infrared, and the gap between paper and infrared emitter, are optimised to maximise evaporation and prevent charring. The paper passes through alternate sections of infrared radiation and cool-down in which fans remove humid air and replace it with dry air (Figure C4.1).

Figure C4.2 shows that an infrared system could reduce energy used for drying paper by 24%.

Non-energy benefits of infrared drying include:

- increased production speed
- lower maintenance and labour costs
- reduced amount and size of equipment (see 'Comparing operating costs' below).

Figure C4.1 Drying paper with infrared heating

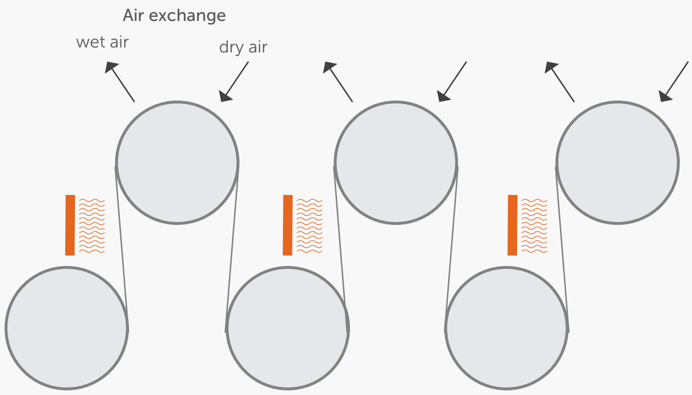



Figure C4.2 Comparison of energy uses in drying 1 tonne of paper

| | Conventional steam drying: Energy (kWh) – Natural gas & bioenergy | Conventional steam drying: Energy (kWh) – Electricity | Electric infrared drying: Electricity (kWh) |
|---|---|---|---|
| Motor & pumps | - | 521 | 539 |
| Fans | - | 40 | 40 |
| Steam generation | 1,263* | - | - |
| Infrared heating | - | - | 811 |
| Total Energy | 1,824 kWh | | 1,390 kWh |

ii Commercially-available flat ceramic short-wave infrared emitters with an efficiency of 96%.
* Assuming 75% efficient gas-fired steam system producing 947 kWh of steam energy

## Alternative approaches to electrified drying

There are at least two alternative approaches to electrified drying.

**Hybrid infrared system**

Electric infrared could be used in combination with conventional steam drying. In fact, it would be easy to retrofit an existing conventional steam dryer with infrared emitters. This type of hybrid drying system has several advantages:

- It could enable some paper mills to produce all their steam using thermal energy recovered from the pulping process but reduce or eliminate the use of supplementary natural gas
- Infrared is particularly useful towards the end of the drying section because the efficiency of evaporation declines significantly as the paper dries
- It speeds up drying. Brazilian company CoProcess, has found that retrofitting infrared increases productivity by 10-15%.[203]

**Heat pumps**

Another way to electrify paper drying would be to use heat pumps to supply the steam to a conventional steam system. The heat pump would make use of waste, humid air at 100°C to generate steam at 125°C required by the heated cylinders. A heat pump, such as Viking's HeatBooster, could perform this task with a coefficient of performance of around 4.5 – an effective efficiency of 450%.

## Comparing operating costs

Figure C4.3 shows operational energy costs of drying one tonne of paper for a conventional steam system and a fully-infrared alternative.

The figure shows that electric infrared can be the cheaper option across a range of energy prices. For example, if gas is $13 per gigajoule, drying newsprint would cost $115 per tonne of product.

Electric infrared beats this cost when electricity can be sourced at 8.25 c/kWh and below. Manufacturers can already get renewable electricity at this price through on-site generation. Within the next few years it will be also possible for large manufacturers to source renewable electricity at this price (including network costs)

## Comparing capital costs

One of the major benefits of an electric infrared drying system is the lower costs of purchase and installation. The US study[204] estimated these capital costs for each type of drying system:

- conventional steam drying – A$18.8 million
- infrared drying system – A$11.1 million.[i]

This shows that an infrared drying system will cost 40% less than a conventional system (Figure C4.4). Part of this saving is because of the equipment itself. The 21 MW infrared system would cost around $3.5 million to purchase and install – 20 % cheaper than the 48 steam cylinders required in a conventional system.

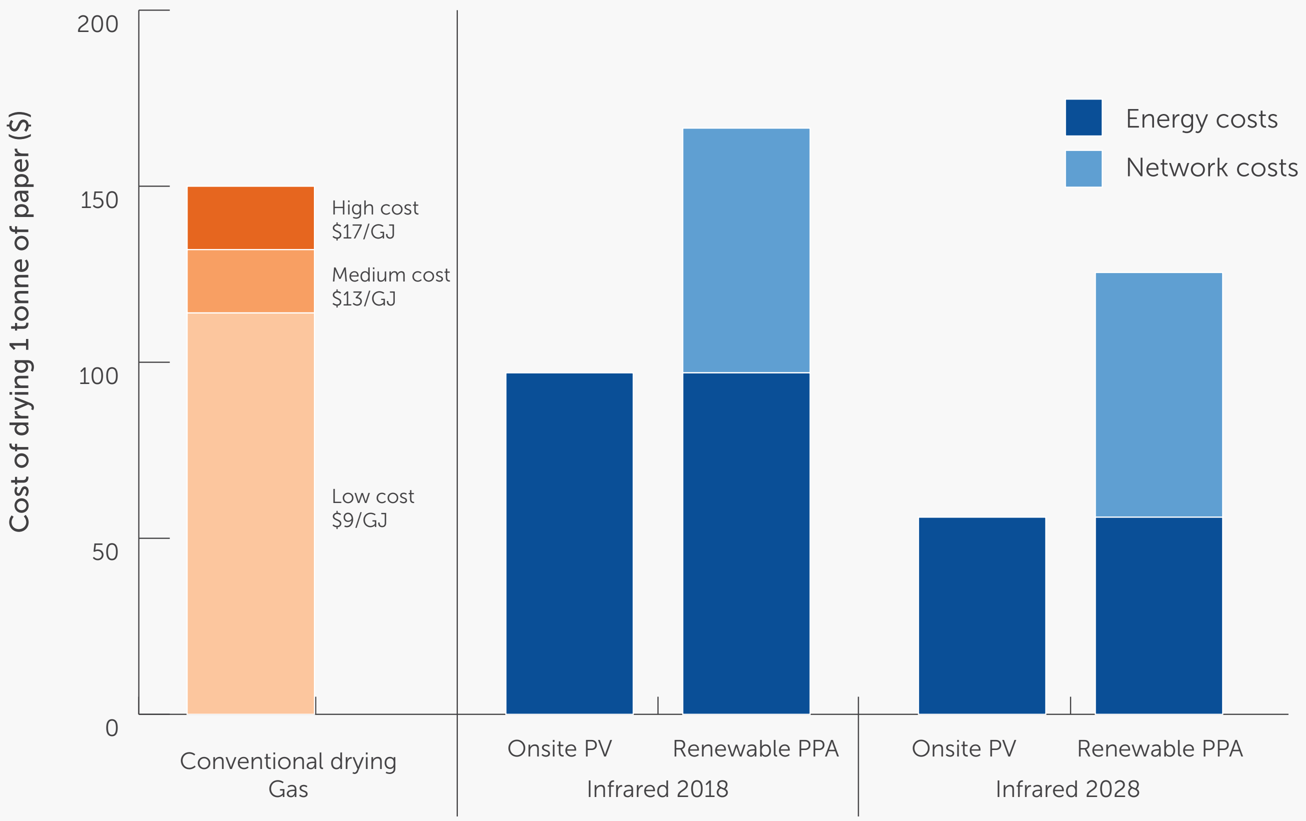
An even larger part of the savings is due to the smaller size of the infrared drying system. This smaller system needs less ancillary equipment and a smaller building to contain it. This leads to savings of 50% on the ancillary equipment and 44% on the building.

## Conclusion

This 'How to' shows how the use of renewable electricity could provide Australian paper manufacturers with both short-term and long-term benefits. The introduction of infrared, or hybrid infrared, systems for drying paper would significantly reduce a reliance on fossil fuels for this process. The capital output for such a system is less than for a conventional system, takes up less room, speeds up the process and increases efficiency. Infrared systems can also be retrofitted to conventional systems and will result in lower maintenance and labour costs, as well as increased production.

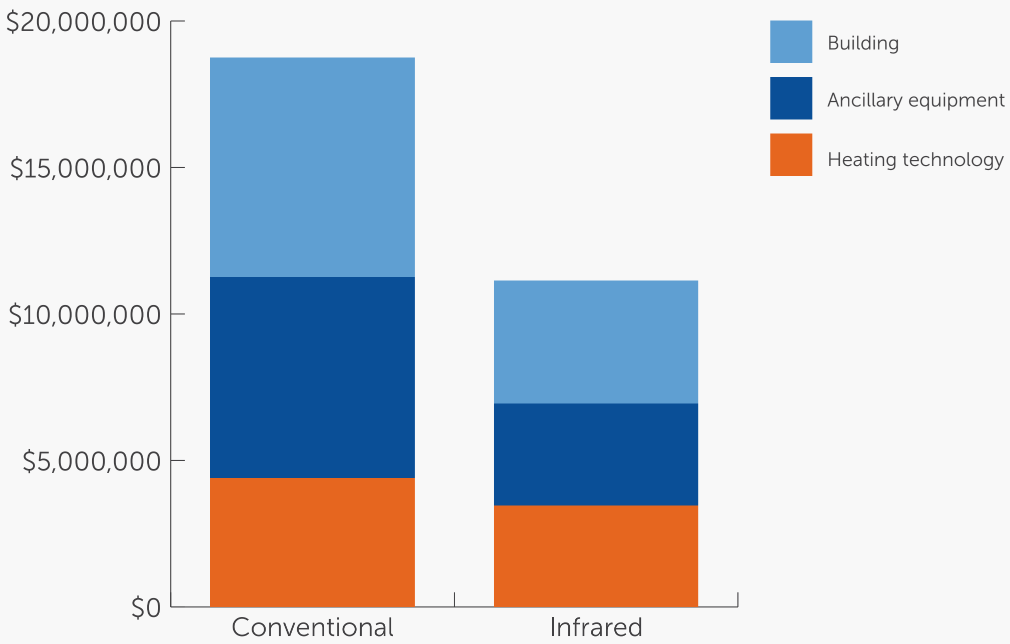
*i Converted from US dollars into Australian dollars.*

Figure C4.3 Operating costs of drying 1 tonne of paper – conventional vs infrared




*Conventional drying assumes constant price of 13 c/kWh for electrical component

Figure C4.4 Capital costs of 150,000 tonne/year paper drying system – conventional vs infrared



# C5 How to electrify aluminium casting

- Conventional gas-fired methods of melting metal prior to casting are less than 50% efficient and waste a significant amount of energy keeping metal hot.
- Induction heating is more efficient, eliminates the need to keep metal hot and reduces metal waste.
- Single-shot induction – rapid melting of just enough metal for each casting – could reduce energy input by 50% compared to the most efficient type of gas-fired furnace.

Complex metal components like car parts are often shaped through a process called casting. Casting involves melting a metal and then pouring or injecting it into a mould. This 'How to' focuses on melting aluminium and delivering it to a casting mould.[i] Melting metals takes a lot of energy and aluminium, which melts at 660°C, requires a theoretical minimum of 273 kWh per tonne (from room temperature).

The molten metal is usually held in a secondary furnace, with this holding stage consuming as much as 30% of the energy in the casting process.[205] The holding furnace is periodically 'tapped', releasing just enough molten metal for the castings. The metal is held under pressure in the mould as it cools and solidifies.

The inspiration for this 'How to' is the production of an aluminium part for Nissan's electric vehicles by Nissan Casting in Dandenong, Victoria (Box C5.1). It would be particularly apt if electric vehicles parts were made with renewable electricity. However the all-electric solutions presented here are suitable for most casting processes with aluminium and other metals.

Electrical induction can reduce both energy consumption and material losses in aluminium casting.

We present two alternative approaches:

1. *An induction furnace* – saving 37% of energy compared to a gas-fired tower furnace.
2. *A just-in-time 'single-shot' induction process* – saving 50% of energy compared to a gas-fired tower furnace.

## The standard gas-fired casting process

The standard process using a gas-fired furnace involves the following key steps:

1. **Melting –** aluminium ingots are tipped into the furnace melting chamber. Aluminium melts at 660°C, but the ingots are heated to 740-775°C to allow for some cooling later on.
2. **Holding –** the molten aluminium flows from the melting chamber to a holding chamber. Additional energy is needed to keep the aluminium hot until it is sent for casting.
3. **Transfer** *to casting machine – the molten metal is* tapped from the holding chamber into ladles at the die-casting machines. The ladles are heated to keep the metal molten.

Steps 1 and 2 are carried out by two common types of gas-fired furnace:

*Batch furnaces (crucible or reverberatory)* – this type of furnace melts metal in batches. They are periodically tapped and reloaded with a fresh cold batch. This is inherently inefficient as the furnace cools down between loads, and must be reheated along with the fresh load. The melting efficiency of gas-fired reverberatory furnaces is 30-45%, and crucible furnaces only 7-19%.[206]

*Tower furnaces* – these furnaces have a melting chamber at the base of a tower which is heated by a gas burner. The ingots are held in a section above the melting chamber where they are pre-heated before being dropped into the melting chamber. The tower furnace has a separate holding chamber filled from the melting chamber. This holding chamber is heated using exhaust gases from the melting chamber, as well as a supplementary burner. A tower furnace is a more modern, efficient alternative to a batch furnace and allows continuous melting of aluminium, so the furnace doesn't cool down.

*i Much of research for this 'How to' was carried out by Tom Burr, a mechanical engineer in the automotive sector.*

Figure C5.1 Using induction for aluminium casting leads to energy savings.

| Gas-fired | | Process Stage | All-electric system | |
|---|---|---|---|---|
| Reverberatory furnace | Tower furnace[212] | | Induction coreless furnace | Single-shot induction |
| 1.67 T | 1.63 T | **Initial metal mass** Aluminium required to produce 1T of finished castings, taking account of yield losses. | 1.60 T | 1.58 T |
| 1,332 kWh | 1,066 kWh | **1 Melting** 760°C | 700 kWh | 657 kWh (700°C) |
| 123 kWh | 123 kWh | **2 Holding** | *Not required* | *Not required* |
| 137 kWh | 137 kWh | **3 Transfer and holding**[211] | 137 kWh | *Not required* |
| **1,592 kWh** | **1,325 kWh** | **Total Energy** | **837 kWh** | **657 kWh** |

*Assumed melting efficiencies: Reverberatory furnace 37.5%; tower furnace 45%; coreless furnace 67.5%; single-shot induction 67.5%.*[213 214]

## Box C5.1: Nissan Casting Australia

Nissan Casting Australia in Dandenong, Victoria casts 2.5 million aluminium components for vehicles every year. One of these components is an inverter housing for the Nissan Leaf, the world's biggest-selling electric vehicle. The inverter housing comprises three separate castings all made at Nissan Australia: inverter case; water jacket and inverter cover. The role of the inverter is to convert low-voltage DC electricity from the battery to the high-voltage AC supply required by electric motors.

Nissan Casting has the capacity to produce enough castings to make 60,000 inverter housings every year, using up to several die-casting machines.

These casting machines are supplied with molten aluminium by a single gas-fired tower furnace commissioned in 2013. This tower furnace can melt three tonnes of aluminium per hour.

Figure C5.2 Second generation Nissan Leaf

*Photo: Qurren (talk)Taken with Canon PowerShot G9 X - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=62456370*

### Box C5.2: The relevance of yield losses

In the casting processes some proportion of the melted metal does not end up in the finished product. When calculating energy inputs into casting we must take account of these yield losses as they represent a waste of energy, and vary according to the process technique and furnace type. The main sources of yield loss are:

- Oxidisation which occurs during melting, holding, refining and casting when hot metal reacts with air. Oxidised aluminium (called dross) is a waste product and cannot be recovered at the foundry.
- Metal which enters the casting system but does not form part of the cast component. This excess metal must be removed in a process called fettling, and can weigh as much as the component itself. The metal itself is not wasted as it can be recycled through the furnace, but represents a waste of energy. Fettling losses are a function of the casting method and the geometry/size of the part being cast.
- Failed castings rejected due to problems such as shrinkage, cracking and porosity. These can also be recycled, but also represent a waste of energy.

Induction furnaces reduce yield losses by reducing the opportunities for the metal to oxidise.

**Table C5.1: Yield losses in different heating systems[207]**

| Cause of yield loss | | Gas-fired: Reverberatory furnace | Gas-fired: Tower furnace | Electrical induction: Induction coreless furnace | Electrical induction: Single-shot induction |
|---|---|---|---|---|---|
| Oxidisation | during melting | 4% | 1.5% | 1% | 1% |
| | during holding at furnace | 1.5% | 1.5% | - | - |
| | during holding at die-cast | 1% | 1% | 1% | - |
| Fettling | | 33% | 33% | 33% | 33% |
| Failed castings | | 5% | 5% | 5% | 5% |

## All-electric casting processes

As described in section 3, electrical induction transfers heat to metal more efficiently than fossil-fuel fired processes. We present below two methods of using electrical induction to improve the efficiency of aluminium casting. Both methods save energy by:

i. lowering the energy use per unit of cast metal
ii. reducing the amount of metal to be melted by limiting yield losses.

## Induction furnace

The most straightforward way to electrify the casting process is to use an induction furnace. Many foundries have already switched to induction furnaces due to their greater efficiency and lower on-site emissions.[208]

Figure C5.1 shows that an induction furnace melts aluminium with an efficiency of 67.5% - compared to 43% for a tower furnace and 37.5% for a reverberatory furnace. In fact the efficiency of the best induction furnaces can be as high as 76%.

A second advantage of an induction furnace is that it combines the melting and holding tasks, removing the need for a separate energy-intensive holding stage. The metal is sent directly to the casting stations where it is held locally in smaller amounts.

Melting in an induction furnace also leads to lower yield losses because, unlike gas-fired furnaces, there are no exhaust gases to contaminate the metal. Induction furnaces can also be designed so that a smaller surface area of the charge is exposed to air.

Overall using an induction furnace requires 837 kWh of electricity per tonne of successfully cast component – a 37% improvement on the tower furnace.

## Single-shot induction

A more innovative application of induction has even greater potential to save energy.[ii] Instead of melting large batches of metal, this process harnesses the power of induction to melt small quantities of metal very quickly – usually under 10 minutes.

Single-shot induction involves melting just enough metal for a single casting (For example, 1.44 kilograms for Nissan's water jacket described in Box C5.1). A cylindrical aluminium ingot is slotted into a small induction crucible of the same size. Once melted, the aluminium is immediately injected into the die casting system. This system reduces failed castings by ensuring molten metal flows slowly and smoothly into the mould, using computer-controlled injection.[209]

Single-shot induction uses only 657 kWh per tonne of successfully cast component – a 50% improvement on the most efficient gas-fired alternatives. It also reduces the amount of metal lost through scaling. Its main advantages are:

1. It exploits the greater efficiency of induction heating to melt metal.
2. It eliminates the requirement to hold molten metal. This stage can consume up to 30% of the energy in casting processes.
3. The speed of the process reduces losses from oxidisation leading to lower losses from scale oxidisation. It also reduces the risk of hydrogen porosity as hydrogen found in contaminates has less opportunity to dissolve into the liquid aluminium.
4. Melting the right amount of metal reduces waste during casting; it can smooth the casting process and no residual liquid needs to be held. Larger furnaces are often charged below their optimum load.[210]

Single-shot induction is a novel application of induction melting to the casting process. However it requires no advances in technology, as it relies on well-understood processes.

It does require the availability of single billets of the correct weight and alloy composition. Such billets are not generally available today, but would be if there were sufficient demand.

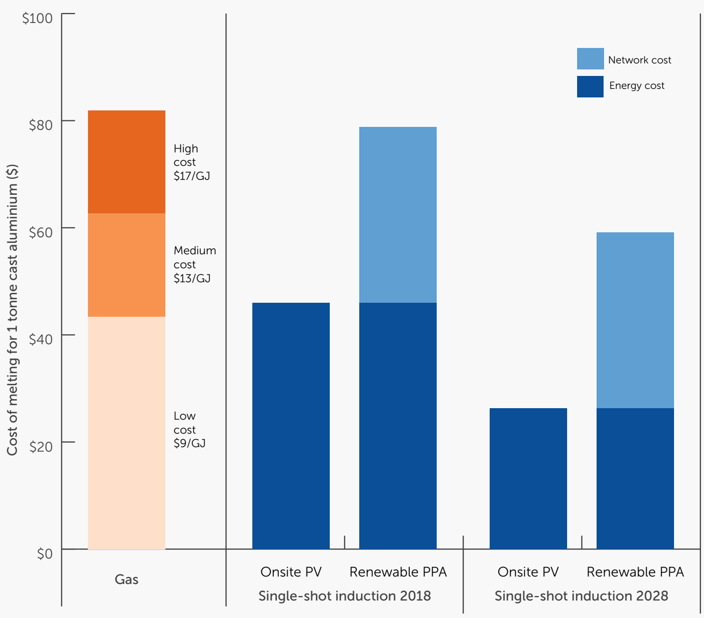
## Comparing energy costs

By fully electrifying the aluminium casting process we can significantly reduce energy consumption. Figure C5.3 below compares the energy costs of melting aluminium in a tower furnace and single-shot induction. This comparison uses gas and electricity prices set out in Section A4.

Figure C5.3 shows that single-shot induction, powered by renewable energy, is already cost-competitive with a tower furnace where a manufacturer is paying a high price for gas. If electricity were produced with on-site solar PV, the all-electric system would beat gas on cost for most plausible gas prices.

The cost-competitiveness of renewable electricity will grow steeply in the next few years. By 2028 the operational energy cost of single-shot induction will be less than the current gas-dependent system in nearly all circumstances.

**Figure C5.3 Comparative operational energy costs to cast 1 tonne of aluminium product**




*ii This approach is based on the Constrained Rapid Induction Melting Single Shot Up-casting (CRIMSON) process developed by researchers at Cranfield University in the UK.*

# C6 How to electrify bricks

- Bricks have high embodied energy, with more than 75% of heat energy used for the firing process.
- Microwave-assisted firing can reduce the energy consumption of brick firing by 50% and double production speed.
- Additional investment for a microwave-assisted kiln can typically be be paid off within a year thanks to lower operational costs.

Bricks are a building material made from fired clay. Clay-brick is a sustainable product which insulates, resists corrosion and fire and is extremely durable. Even when brick structures are demolished, individual bricks can be reused. Since ancient times bricks have been used to create structures, from the Egyptian pyramids to the classic Australian brick bungalow.

However, bricks have high embodied energy. Brick-making consumes on average 721 kWh per tonne, more than 75% of which is heat energy for the firing process.[215] Usually natural gas fuels the firing,[216] though some manufacturers also use biomass (Box C6.1).

## Conventional brick making

Most brick makers fire bricks in tunnel kilns up to 100 metres long. Bricks are moved very steadily through the kiln, heating up slowly to a maximum temperature of 1,040°C when they reach the firing zone. The bricks are then slowly cooled as they move towards the exit.

The whole firing process takes 40 to 70 hours, as the bricks are heated and cooled slowly, at no more than 40°C per hour. This gradual heating is partly because bricks are poor conductors of heat, and partly because faster heating can damage the brick by creating too great a difference between the temperature of the outer and inner parts.

Freshly-formed bricks must be partially dried before entering a kiln. Most of the energy for drying is supplied by heat expelled from the firing kiln. Additional energy for drying accounts for only 20% of the fuel energy in brick making.[217] This 'How to' focuses on the energy-intensive firing process.

### Box C6.1: Australia' own carbon-neutral bricks

Brickworks Building Products produces two brick brands certified as carbon-neutral under the Australian Government's National Carbon Offset Standard.

Daniel Robertson and Austral Bricks (Tasmania) are both manufactured at the Tasmanian Longford plant. Brickworks has achieved the certification by firing their kiln with sawdust, a by-product of the local timber industry. The company offsets the remaining embodied emissions by purchasing carbon offsets, related to Tasmanian habitat protection.

## Microwave-assisted firing of bricks

The time and energy required to fire bricks can be halved by using microwaves to supplement conventional kiln firing.

In a microwave-assisted kiln the bricks are heated simultaneously from the outside by conventional heating, and from the inside by microwave heating. This technique means the bricks can be heated rapidly and evenly, ensuring no damage occurs. Faster firing means less heat is wasted and energy efficiency is increased.

UK company, C-Tech Innovation built a microwave-assisted tunnel kiln to assess its capabilities.[218] The kiln combined conventional gas-firing with two 60 kW microwave emitters. C-Tech found that firing bricks in a microwave-assisted tunnel kiln reduced energy consumption by 50%. This huge reduction was achieved with microwaves supplying just 10% of the total firing energy (Figure C6.1).

An equally important benefit of microwave-assisted brick firing is its speed. In the UK project the time in the tunnel kiln was reduced from 46 hours to 16.75 hours – an increase in production speed of 174%. This rapid throughput means that, for any given capacity, a microwave-assisted kiln can be much smaller.[i] The quality of microwaved bricks is identical to bricks made the traditional way.

Another benefit of microwaves is that they can be retrofitted to an existing brick kiln. The technique can also be applied to almost any kiln-fired ceramic product, such as tiles and kitchenware.

The efficiency of microwave-assisted kilns relies on the presence of an external heat source to complement the internal microwave heating. C-Tech Innovation's pilot used conventional gas-firing for this external heating. One non-fossil fuel alternative is an electrical tunnel kiln, using resistance heating. Manufacturers, such as Deltech Furnaces in the US, can build tunnel kilns capable of firing brick.[219] Another option is to employ microwave heating in a kiln fired with wood waste (Box C6.1).

## Operating costs

Microwave-assisted firing can reduce the energy consumption of brick firing by 50%. Energy savings are particularly attractive to brick-makers as energy accounts for 23-38% of their production costs.[220]

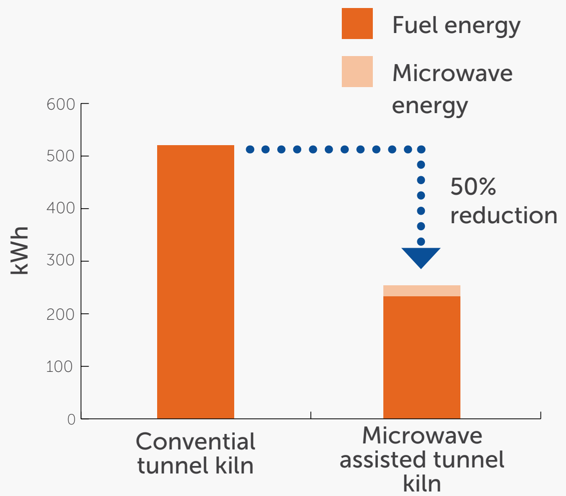
Figure C6.2 compares operating costs of a conventional gas-fired tunnel kiln with a microwave-assisted electric tunnel kiln. Whereas the conventional kiln uses 570 kWh of natural gas to fire one tonne of bricks, the microwave-assisted electric kiln uses just 285 kWh of electricity.

This reduction in energy means microwave-assisted electric brick kilns can be cheaper to run. Where on-site solar PV is available, the electricity costs are lower than for any plausible gas price. By 2028 microwave-assisted kilns, powered with a renewables PPA, are cheaper for all but the lowest price of gas.

### Microwave assistance with wood firing

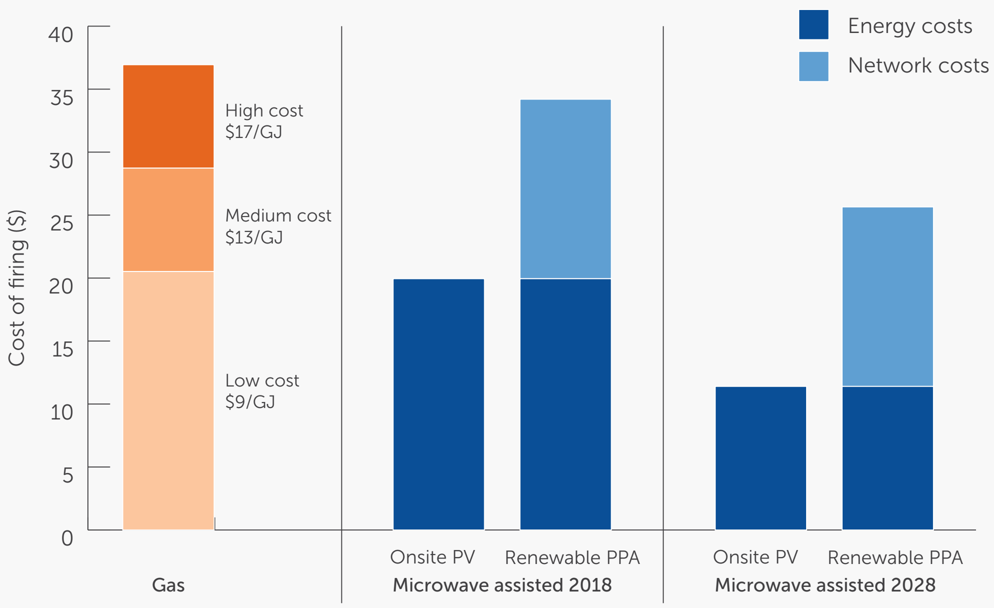
An even cheaper option is to retrofit microwaves to a tunnel kiln fired with wood-waste similar to the one used by Brickworks in Tasmania. A microwave-assisted wood-fired tunnel kiln could fire bricks for less than $18 per tonne – less than any other option. This assumes that wood firing costs $12 per gigajoule, though in some locations it will be much cheaper. As microwaves are only required to supply 10% of the firing energy, the operating cost is not particularly sensitive to the cost of electricity.

**Figure C6.1 Energy use in brick-firing: conventional vs microwave-assisted**




*i C-Tech's project broadly confirmed earlier studies in Canada. A more recent Danish study has also found that firing time in a batch kiln can be reduced by nearly 50%. Sheppard, L.M., 1988. Manufacturing Ceramics with Microwaves: the Potential for Economical Production. Am. Ceram. Soc. Bull., 67, pp.1656-1661*

Figure C6.2: Comparative operational energy costs for firing one tonne of bricks




## Capital costs

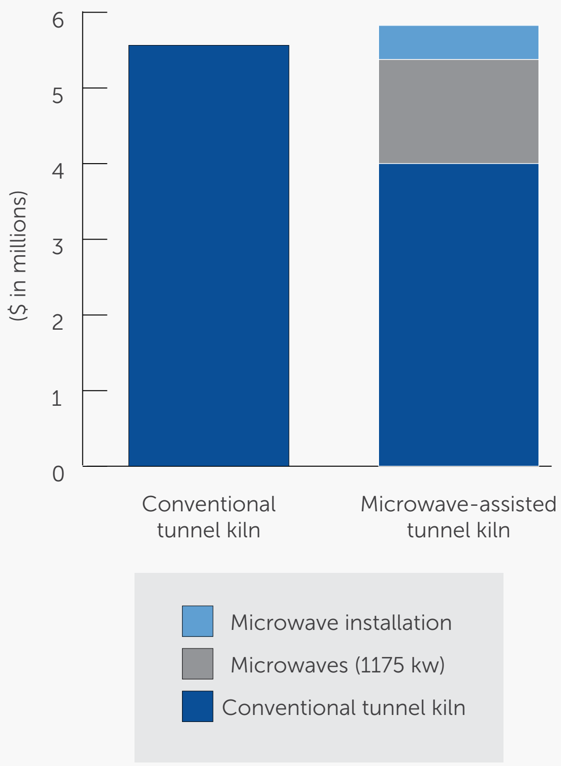
We have estimated the capital costs for two new-build tunnel kilns: conventional and microwave-assisted capable of firing 125,000 tonnes of brick per year, equivalent to 50 million bricks (Figure C6.3).[ii]

A conventional kiln with this capacity would be 100 metres long and cost about $5.6 million.

Due to its faster firing a microwave-assisted kiln of the same capacity can be half the size, and cost 28% less. This kiln will require 1,175 kW of microwave emitters at a cost of $600,000, plus 10% for installation. The total cost for the new microwave-assisted kiln is $5.8 million, a small increase on the conventional system.[221] This extra cost would be paid off in less than a year due to operational energy savings.

The microwave-assisted kiln provides an excellent example of electrifying production can double output and half energy consumption, enabling both industry efficiency and generating significant long-term savings.

Figure C6.3: Comparative capital costs of conventional brick kiln and microwave-assisted kiln.




*ii These costs are based on C-Tech Innovation's estimates and have been converted into 2018 Australian dollars.*

# C7 How to electrify plastic

- An important aspect of the global crisis of plastic waste is the sheer waste of energy it represents. Making plastic requires several times more energy than steel.
- An effective response to this crisis will include recycling far more and making new plastic from plants instead of fossil fuels. Electricity can power both solutions.
- Plastic recycling is already carried out in electric furnaces and consumes less than 5% of the energy required to make virgin plastic.

Over 90% of plastics are made by refining oil or natural gas. For example we require 2.2 tonnes of oil to make High Density Polyethylene (HDPE) used to make some plastic piping. Plastic production consumes about 5% of the world's annual oil output, about as much as the aviation sector.[222]

Making plastic is energy-intensive and produces more emissions per tonne of production than steel (Table C7.1). We are also increasingly aware of the problems of single-use and discarded plastic. About 95% of plastic packaging is used briefly, thrown away and not recycled.[223] Most of this plastic sits in landfills – a tremendous waste of resources. A third of plastic does not even make it to landfill, and every year millions of tonnes escape into rivers and oceans.[224] By 2050 there could be more plastic than fish in the sea.[225] If the plastic biodegrades or burns, fossil carbon enters the atmosphere, just as if we had burned the oil or gas from which it was made.

Despite these problems plastic has some benefits, and its excellent strength-to-weight ratio means it can even be a lower carbon option than alternatives. For example, a 1-litre plastic drink bottle has lower embodied energy and emissions than one made of glass or aluminium.[226] We will continue to depend on plastic for its usefulness and versatility, but we need to make fundamental changes to the way we produce it and treat it.

### Box C7.1 A sustainable, electric-powered future for plastic

A sustainable, zero carbon future for plastic will rely on four strategies[230]:

i. *Reducing consumption.* There is growing awareness of our wasteful use of plastic, especially single use plastics. A cross-party Australian Senate inquiry has recommended that all single-use plastics, such as coffee cups with plastic linings, be banned by 2023.[231]

ii. *Reusing*. Some plastic products, such as HDPE pipes, are durable and can be reused. The Ellen MacArthur Foundation estimates this applies to **20%** of plastic.

iii. *Recycling*. Most plastics can be recycled, though in 2017 Australia recycled only 12% of plastic.[232] We should aim to increase this to **55%**. This would require not only an effective recycling regime, but changes to the way some plastics are made to facilitate recycling.

iv. *Bio-based plastics.* The remaining demand for virgin plastic **(25%)** can be met with bio-based plastics which can be carbon negative. Most plastics can be made from natural polymers occurring in plants such as potatoes, tree bark and sugar cane.[233] Some bio-based plastics are already cost competitive with current fossil-based plastics.[234] For example, bio-ethylene and bio-propylene are already produced commercially from wood in Brazil and Europe.[235] Renewable plastics can also be manufactured from renewable hydrogen and waste sources of carbon dioxide.

This combination of strategies can eliminate the need for virgin fossil fuel-based plastics and the emissions associated with their manufacture. This approach is finding increasing favour with major corporations such as IKEA planning to use only recycled or bio-based plastics,[236] and chemicals companies like Dow, Dupont and BASF are investing heavily in bio-based plastics.[237]

**Table C7.1: Energy and emissions related to production of 1 tonne of different types of plastic (prior to forming into products)**

| Plastic | Example applications | Energy (kWh) | Production emissions (T $CO_2$e) |
|---|---|---|---|
| Polypropylene (PP) | Ice cream containers, crisp packets, plant pots | 23,056 | 2.0 |
| Polyethylene terephthalate (PET) | Food and drink containers | 22,972 | 3.0 |
| High density polyethylene (HDPE) | Films, pallets, bins, hoses and pipes | 21,111 | 1.9 |
| Polyvinyl chloride (PVC) | Pipes, garden hoses, floor coverings. | 16,444 | 1.9 |
| Polystyrene (PS) | Yoghurt pots, plastic cutlery, take away containers. | 25,000 | 3.4 |
| *Primary steel (for reference)* | | *5,489* | *1.8* |

## All-electric plastics industry

The sustainable strategy outlined in Box C7.1 will facilitate the electrification of the plastics industry. The production of bio-based plastics has the potential to be fully electrified,[227] and plastics recycling is already an electrified process. Recyclers prefer electric furnaces for their higher temperature control and lack of combustion gases. This means that to electrify the plastics industry we don't need to electrify oil refining – we can dispense with it altogether.

By recycling plastic we also save a lot of energy. Cryogrind is one of Australia's largest plastics recyclers, producing PVC pellets, from industrial plastic waste. Cryogrind's process of shredding, blending and extruding pellets uses 273 kWh per tonne of pellets – just 2% of the energy of virgin PVC. Newtecpoly produces a recycled hard plastic that can replace virgin HDPE, also uses about 2% of the energy of the equivalent virgin product (Box C7.2).

Bio-based plastics can even be carbon negative, as they store carbon dioxide captured by plants. New Zealand company *ecostore* produces a plastic bottle – *the Carbon Capture Pak* – made from sugarcane.[228] The plastic in these bottles is physically and chemically identical to conventional high-density polyethylene (HDPE). However, whereas conventional HDPE production releases nearly 2 tonnes of emissions, the sugarcane-based alternative is carbon negative. For every tonne of product, more than 2 tonnes of carbon dioxide are sequestered.[229]

Figure C7.1 Ecostore's Carbon Capture Pak carbon negative plastic bottle made from sugar cane.


### Box C7.2 Newtecpoly – Polywaste Technology

Newtecpoly is a Victorian manufacturer and plastics recycler. The company is a licensee of the PolyWaste technology – a low energy method of recycling plastic waste into products such as outdoor furniture, piping, pallets, posts and bottles.

PolyWaste's key innovation is the ability to recycle mixed waste plastics which otherwise go to landfill.[i] Most other plastic recycling processes are sensitive to contamination, and so require careful and costly separation of different plastic polymers. The PolyWaste technology also saves energy by melting the feed only once before producing plastic products.

As shown in Table C7.2 Newtecpoly requires approximately 540 kWh per tonne of product (based upon a high proportion of polyethylene in the feed). In comparison, one tonne of virgin HDPE requires 21,306 kWh and 2.2 tonnes of crude oil.

**Table C7.2: Newtecpoly process for producing 1 tonne recycled plastic**

| Process | Temp. | Electrical energy input (kWh) |
|---|---|---|
| Shredding | - | 0 |
| Water cooling | 10°C | 70 |
| Air compression | - | 20 |
| Melting | 190°C | 270 |
| Extrusion/moulding | | 120 |
| Lighting | | 60 |
| **Total energy** | | **540** |

*i Mixture can include high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), nylons, polyesters and polyethylene terephthalate (PET).*

# C8 How to electrify glass

- Natural gas supplies 75% of the energy in conventional container glass production.
- Switching to efficient electric equipment at each step in production could reduce energy inputs by 30%.
- Electric glass-making equipment is cheaper, produces fewer toxic emissions and leads to a higher quality product.

There are two main categories of glass – flat glass, for windows and mirrors, and container glass for bottles, jars and other vessels. Global production of each category is similar: 55 million tonnes of flat glass and 51 billion tonnes of container glass.[238] This How to focusses on container glass.

The Australian container glass industry is dominated by two companies.[239] Orora Packaging Australia has one facility in Adelaide,[240] and Owens-Illinois Australia has operations in Brisbane, Sydney, Adelaide and Melbourne.[241] The Australian wine industry is an important customer for both companies.

Natural gas supplies more than 75% of the energy in conventional container glass production.[242]

However, we show below that all-electric production is possible using equipment available today, without any major changes to the process.

## Conventional container glass manufacture

Container glass is made in the following steps:

1. ***Mixing –*** the raw materials for glass (mainly sand, soda ash, limestone, and often recycled glass) are mixed, crushed and transported using electrically-powered equipment.
2. ***Melting –*** the materials are melted by heating to 1550°C in a gas-fired regenerative end-port furnace.
3. ***Conditioning –*** molten glass is transferred from the furnace to the forehearth where it is heated evenly to the right temperature for forming.
4. ***Forming –*** the conditioned glass is sent to a forming machine, where it is cut to the right size and shaped into containers using compressed air and/or a mechanical plunger.
5. ***Annealing & cooling –*** The glass enters an oven (called an 'annealing lehr') where it is cooled in a controlled manner from 600°C to room temperature.
6. ***Finishing –*** coatings are applied to provide additional scratch resistance.
7. ***Packaging*** – containers are packaged, normally on pallets, for shipment.

## Energy input and equipment

The first five of these steps consume the vast majority of the energy in container glass production. On average one tonne requires 1,881 kWh (Figure C8.1), producing 450 kilograms of carbon dioxide emissions.[243]

This 'How to' focusses on the steps and equipment which are usually gas-fired: melting furnace; forehearth and annealing lehr.

### Melting furnace

The most energy-intensive step in glass-making is melting the raw materials. This accounts for around 75% of the energy requirement and 15% of the costs.[244] Most modern melting furnaces are gas-fired, with electric boosting contributing 5-20% of the heat, increasing efficiency and glass quality.[245]

Average container glass melting furnaces have a capacity of 200 tonnes per day, but can be as large as 450 tonnes per day. Typically 40-60% of furnace energy is wasted heating the structure of the furnace or through exhausted flue gas.[246] The glass industry has increased efficiency with innovations such as oxy-fuel firing, batch pre-heating and waste heat recovery. Modern container glass furnaces now have an efficiency of around 50%, with a maximum of 60%.[247] Further efficiency improvements to the conventional process are likely to be minimal.

In Figure C8.1 we have assumed a gas-fired furnace capable of melting 200 tonnes of glass per day with an efficiency of 55% against a theoretical minimum of 744 kWh.[248]

### Forehearth

To maintain an even temperature throughout the molten glass, forehearths heat and cool simultaneously, leading to heat loss and inefficiency. The forehearth consumes 6% of the energy in a typical container glass system, though in some systems it is as much as 30%.[249]

### Annealing lehr

In order to cool glass in a gradual and controlled manner the lehr initially applies heat. The lehr consumes 12% of energy in a typical glass plant, though in individual plants it can use as little as 2% or as much as 23%.

## All-electric glass production

Electric alternatives are available for all steps and equipment involved in container glass manufacture. An all-electric system could reduce energy inputs by 30% (Figure C8.1).

### Electric melting

Glass manufacturers have successfully operated all-electric glass melting furnaces since the 1920s. Today electric glass furnaces are mostly used to make special glass, such as glass for displays, tableware and cookware, and in the production of glass wool.[250] However, they perform equally well melting container glass.

Several manufacturers offer electric glass melters capable of melting over 100 tonnes of glass per day. UK company Electroglass has built a 280 tonne per day electric furnace. However, one advantage of electric glass melters is that, unlike gas-fired furnaces, efficiency is not strongly related to larger capacity, making smaller, modular installations more viable.

The biggest advantage of electric glass melters is their energy efficiency. The best achieve an efficiency of 87%,[251] enabling us to melt one tonne of glass with 855 kWh of electrical energy, 37% better than an average conventional gas-fired furnace.

Other advantages of all-electric melting are:

- ***Product quality*** – they produce a high-quality homogenous glass, which is why they are used for special glass.[252]
- ***Compactness*** – increased melting rate for a given furnace size.
- ***Reduced capital cost*** – electric furnaces have lower capital costs than conventional furnaces. However, they must be rebuilt or refurbished more often – every 2 to 7 years compared to 10 to 20 years for conventional furnaces.[253]

Figure C8.1: Comparison of energy inputs – conventional glass-making vs all-electric (200T/day furnace)[255]

| | | Conventional gas-fired | | All-electric |
|---|---|---|---|---|
| **Process stage** | **Temp** | Gas (kWh) | Electricity (kWh) | Electricity (kWh) |
| **Mixing** | Room temp | | 161 | 161 |
| **Melting** | 1550°C | 1,150 | 204 | 860 |
| **Conditioning & Forming** | 1100°C > 600°C | 105 | 26 | 104 |
| **Post-forming (annealing)** | 600°C > room temp | 210 | 25 | 183 |
| **Total** | | | **1,881** | **1,308** |

- ***Refurbishment time –*** an electric glass melter can be refurbished in 3 weeks, compared to 10 weeks for a gas-fired container furnace.
- ***Less maintenance –*** electric furnaces require less day-to-day maintenance due to their simpler operation.
- ***Lower toxic emissions*** – almost no harmful emissions of nitrogen oxides and sulphur oxides and lower evaporation of volatile chemicals.

All-electric glass manufacturing can also benefit from and contribute to grid demand management. A melter capable of 200 tonnes could reduce consumption by 30-40% for 4 hours, relieving pressure on the electricity system during periods of peak demand.[254]

### Electric forehearth and annealing lehr

Many glass-makers already use electric forehearths and annealing lehrs. Manufacturers of this equipment include Electroglass (electric forehearths) and CNUD and Pennekamp (electric annealing lehrs). In our example the electric forehearth is 26% more efficient and the electric annealing lehr 21% more efficient than their gas-fired equivalents.

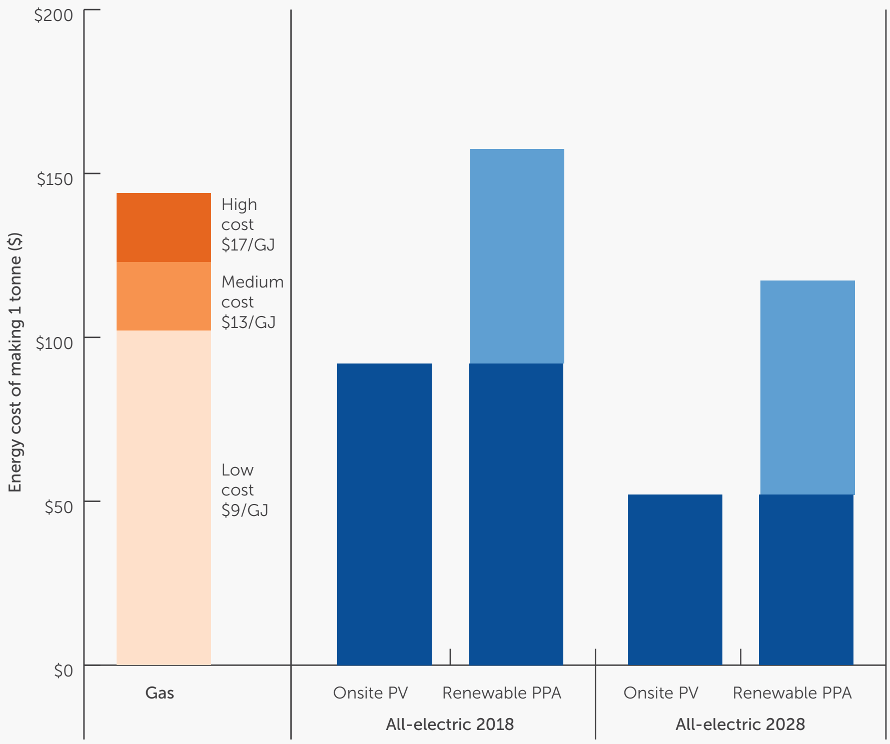
## Comparing operational energy costs

By fully electrifying container production we can reduce the overall energy input by 30%. Figure C8.2 below compares the energy costs of conventional container glass-making and an all-electric system. The comparison uses gas and electricity prices set out in Section A4.

Figure C8.2 shows that an all-electric system, powered by renewable energy, can be cost-competitive in 2018 where renewable electricity can be generated on-site, avoiding network costs.

By 2028 the all-electric system powered by off-site renewables will be cheaper than the conventional gas-fired system for gas prices above $12/GJ.

Figure C8.2 Comparative energy costs of producing 1 tonne of glass



# C9 How to electrify steel

- Steel is the second-most polluting industrial material after cement, largely due to the role of coal in steel production.
- Steel can be made without coal. Hydrogen-based steel production has already been demonstrated at a commercial-scale (the Circored process).
- By using renewable hydrogen as the chemical reductant and natural gas as the fuel source, we can reduce steel-related emissions by 90%, and energy use by 18%.
- Zero-carbon steel can be made by using renewable hydrogen for fuel or by electrifying Circored's heat processes.

Steel is one of the world's most important manufactured materials, used in machinery, vehicles, ships, buildings and infrastructure. World production of steel is currently 1.6 billion tonnes and this is expected to grow to 2 billion tonnes by 2030.[256]

Steel-making causes 6-7% of global emissions[257] – making it the second most polluting industrial material behind cement. Most of these emissions are related to the coal used in the production of steel. Indeed it's sometimes claimed, incorrectly, that steel cannot be made without coal.

This How to shows how zero-carbon steel can be made with renewable hydrogen. This process requires no coal at all, and reduces energy consumption by 9-18%. By combining our unparalleled resources in iron ore and renewable energy, Australia has an opportunity to become a pioneering producer of zero carbon steel.

### Box C9.1 Australia's role in the global steel industry

Australia manufactures a relatively small amount of steel – 5.3 million tonnes, or 0.3% of world output. Nevertheless we play a major role in the global industry as the largest exporter of the two key raw materials for steel production: iron ore and coking coal. In 2016 we exported 811 million tonnes of iron ore, 40% of the global total. We also have the world's largest reserves of iron ore.

Nearly half of Australia's coal exports are used to make steel.[265] The 172 million tonnes of coking coal exported in 2017 produced greenhouse emissions equivalent to more than 80% of all Australia's domestic emissions.[266] Our massive coking coal exports have helped drive the recent proliferation of polluting blast furnaces overseas, particularly in China, and hindered development of less polluting methods of making steel.[267]

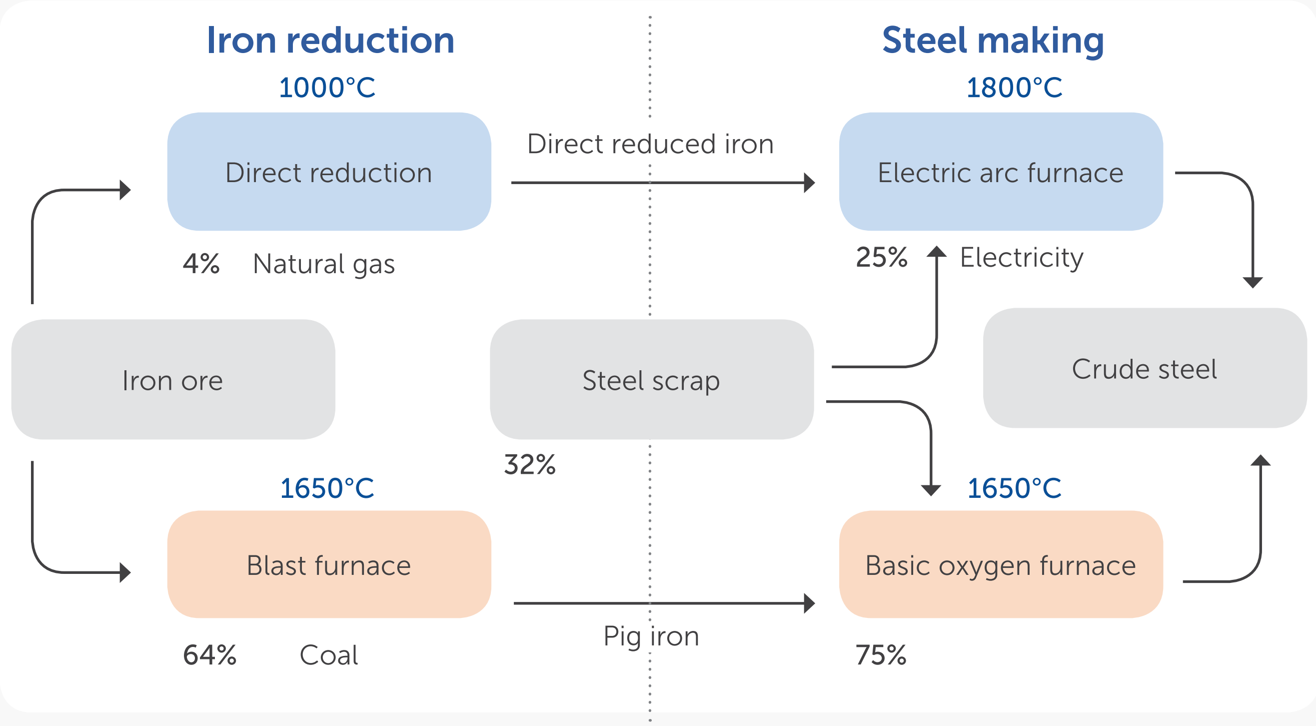
By developing a hydrogen-based steel sector, Australia could have a far more positive impact on global steel-making.

## How steel is made

Iron ore is converted into steel through one of two process routes. The most common route is integrated steel-making where iron (called pig iron) is first produced in a blast furnace, and then refined into crude steel in a basic oxygen furnace. Integrated steel-making is described in more detail below. An alternative process route is called direct reduction. Direct reduced iron is transformed into crude steel in an electric arc furnace.

Steel can be endlessly recycled. About a third of steel is made by recycling waste steel via an electric arc furnace. Figure C9.1 shows how these three process routes contribute to world steel production.

Figure C9.1 The pathways to crude steel – global production




These processes take us to the point of molten steel. Beyond that are activities such as casting, rolling forming and fabrication. These subsequent stages are the same whether the steel emerges from a basic oxygen furnace or an electric arc furnace, and are not part of this analysis.

Energy constitutes about one third of the cost of primary steel-making.[258] The need to reduce (ie remove oxygen from) iron ore makes it an inherently high-energy, high-temperature process. Improvements in efficiency have led to reductions of about 60% in energy required, but any further efficiency gains will be small.[259]

## Conventional steel-making

Seventy-five percent of the world's steel is made via the integrated steel-making route, involving a blast furnace and basic oxygen furnace. The principal energy source in this process is coking coal which must first be converted into coke.[i]

Integrated steel-making requires, on average, 1,400 kg of iron ore, 700 kg of coal, 300 kg of limestone and 120 kg of recycled steel to produce 1,000 kg of crude steel.[260] The average energy use, taking account of the manufacture of raw materials is nearly 20 GJ per tonne of liquid steel, or 5,489 kWh.

The key steps in conventional primary steel-making are:

***Sintering*** **–** iron ore fines (small grained iron ore) are mixed with clay and sometimes a flux (limestone), and heated to 1,300°C to produce a hard pellet. The larger particle size of pellets means they allow better circulation of oxygen or air in the blast furnace and melting is more efficient.

***Coke-making*** **–** high-grade coal, called coking coal, is converted into almost pure carbon by prolonged heating in an oven in the absence of oxygen. In recent years there has been a significant reduction in the coke consumption in the blast furnace, due to increased injection of pulverized coal.

***Lime production*** **–** limestone is converted to lime for use as a flux to remove impurities. About 7.7% of direct emissions arise from the decomposition of limestone for use in blast furnaces.[261]

***Blast furnace*** **–** coke, iron ore pellets and flux are fed into the top of the furnace while coal dust and hot, oxygen-rich air is blown in at the bottom. As the material falls downward the reactions occur that turn iron ore to pig iron.

*i Coke is a high carbon fuel made by heating high-grade bituminous coal in an airless kiln.*

Coke plays three vital roles in a blast furnace:

i. Burning coke provides heat to drive chemical reactions and melt the iron
ii. Upon combustion coke converts to carbon monoxide which reduces iron ore to iron
iii. Coke provides a strong but permeable support to allow a free flow of gases in the furnace.

***Basic oxygen furnace –*** molten pig iron is fed from the blast furnace into the basic oxygen furnace along with steel scrap. At this stage the pig iron contains impurities and too much carbon. Most of this carbon is removed by blowing oxygen through the molten pig iron. Molten steel flows out of the basic oxygen furnace.

**Table C9.1 Energy and emissions to produce 1 tonne of crude steel through blast furnace route[268]**

| Process | | Max temp (°C) | Coke & coal energy (MJ) | Gas energy (MJ) | Electrical energy (kWh) | $CO_2$e (T) |
|---|---|---|---|---|---|---|
| **Pre-processing** | Sintering/pelletising | 1,300 | 2,800 | | 30 | 0.2 |
| | Cokemaking | 1,100 | 1,200 | 200 | 33 | 0.15 |
| | Lime production | 1,000 | 800 | | | 0.12 |
| **Steel-making** | Blast furnace (including air separation units, cold blast blowers and hot blast stoves) | 1,600 | 12,000 | 1477 | 45 | 1.15 |
| | Basic oxygen furnace | 1,700 | | 800 | 26 | 0.2 |
| **Totals** | | | 16,800 | 2,477 | 134 | 1.82 |
| **Total kWh** | | | **5,489** | | | |

## Steel-making with direct reduction

A small but significant percentage of primary steel is made via an alternative process: direct reduction. One advantage of direct reduction is that it does not require the iron to melt, and so the reduction occurs at a lower temperature (≈900°C) than in a blast furnace, and therefore uses less energy. Direct reduction usually uses syngas[ii] as both reductant and fuel, and requires no coke or coal. Worldwide, nearly 60 million tonnes of direct reduced iron are produced every year.[262]

Direct-reduced iron is converted into steel in an electric arc furnace (Section B3). In the furnace an electrical current is passed through the iron and scrap steel, causing them to heat and melt. The process removes impurities from the direct reduced iron and produces liquid steel. Electric arc furnaces can be rapidly stopped and restarted, allowing operators to vary production according to electricity prices.

A tonne of steel produced through the direct reduction route avoids the need for costly manufacture of coke and lime. It is also produces about 40% fewer emissions.[263] One reason this route is not more common is that, overall, it uses far more electricity, which has historically been a more expensive source of energy.

## The all-electric route to primary steel

Most of the greenhouse emissions from direct reduction result from burning natural gas, and the reaction between the carbon monoxide in the syngas and the oxygen in the iron ore. These emissions can be eliminated if methane is replaced with pure hydrogen as fuel and reductant. The by-product of using hydrogen to reduce iron ore is simply water.

ii *Syngas is mainly a mixture of hydrogen and carbon monoxide, and is usually produced by reforming natural gas.*

At least two national projects, in Austria[270] and Sweden[271], are preparing to develop pilot plants for fossil-free steel. The Swedish project, called *HYBRIT*, is focussing on direct reduction using a shaft furnace, a well-established technology.[i] Existing shaft furnaces use syngas containing up to 70% hydrogen, so the aim of *HYBRIT* is to increase this proportion to 100%, eliminating the carbon monoxide content (Box C9.2).

This 'How to' guide uses another type of hydrogen-based direct reduction called Circored. The advantage of Circored is this it has already been proven – a commercial plant with an annual capacity of 500,000 tonnes operated in Trinidad from 1999 until 2006 (Box C9.3).

A key motivation for developing Circored was its ability to work with fine grains of iron ore (< 2mm diameter). Iron ore fines tend to stick when heated above 680°C,[272] hindering their reduction. Therefore before standard direct reduction processes, they must first be formed into pellets or sinter. Pelletising/sintering is costly and energy-intensive, and for this reason fines are a cheaper form of iron ore.[ii] With Circored the reduction with hydrogen occurs at a lower temperature (650°C) than other reduction processes, meaning the fine particles do not stick and the costly pelletising process is avoided.

### Box C9.2 HYBRIT – zero carbon hydrogen in Sweden

Like Australia, Sweden has both iron ore reserves and significant resources of renewable energy. This has inspired a joint venture, called HYBRIT, to explore making steel with renewable hydrogen. HYBRIT aims to develop an existing method of natural gas-based direct reduction to run on pure hydrogen.

HYBRIT is already designing a pilot plant near the country's iron ore fields, and plan to build a commercial-scale plant by the late 2020s. The Swedish Energy Agency is funding half the costs of the pilot plant.

HYBRIT estimates that steel made using hydrogen would cost 20-30% more than conventional steel.  However, they expect this difference to disappear as renewable electricity prices fall and the cost-penalty for carbon emissions rises.

***"We are contributing to the long-term competitiveness of the Swedish steel industry and ... helping to drive the transition to a fossil-free industry and a sustainable society."*** [269]

***Erik Brandsma, Director General of the Swedish Energy Agency.***

### Box C9.3 Circored

Circored is a technology to produce direct-reduced iron from iron ore fines using pure hydrogen as the sole reducing agent. A commercial Circored plant owned by Lurgi Metallurgie (now Outotec) began operation in Trinidad in 1999, closing down in 2006 due to the low market price of direct reduced iron. At maximum output the plant could produce 65 tonnes per hour – more than 500,000 tonnes per year. The hydrogen was sourced from steam reforming natural gas. The process could be scaled up to a much larger plant making 2.5 million tonnes per year.

*i Shaft furnaces, such as the natural gas-based Midrex® and HYL/Energiron.*

*ii Direct reduction can use both main types of iron ore - haematite and magnetite.*

### The Circored process: energy and other inputs

The Circored process requires 1.6 tonnes of iron ore fines and 58 kilograms of hydrogen to make 1.03 tonnes of direct reduced iron. This iron is converted into 1 tonne of liquid steel in an electric arc furnace. Figure C9.3 quantifies the energy inputs to produce a tonne of steel using an electrically-driven Circored system followed by an electric arc furnace. Two alternative Circored-based systems are presented:

- 90% electric, with natural gas for the heating requirements
- 100% electric, with additional hydrogen for the heating requirements.

In both systems most of the electricity (2,769 kWh) is required for electrolysis to produce the hydrogen. In the all-electric system an additional 1,511 kWh is required to produce 1,058 kWh of hydrogen to be used as fuel in the Circored process and the electric arc furnace.

An additional 400 kWh of electricity is used to supply 70% of the energy in the electric arc furnace. Electric arc furnaces derive some of their energy from burning carbon, which is added to reduce impurities. Normally coal provides this carbon source, but to reduce emissions biochar can be used instead.[264] Circored direct reduced iron contains no carbon so we must add extra carbon to produce steel – 150 kW of biochar in total.

The 90% electric system would use 4,505 kWh per tonne – an 18% reduction in energy compared to the blast furnace route. This would lead to emissions of 197 kg emissions per tonne of steel - a 90% reduction.

For truly zero carbon steel we need the 100% electric route, requiring 4,958 kWh per tonne – a 10% reduction in energy compared to the blast furnace route. An alternative all-electric system could supply the required heat through electrical resistance.

## Conclusion

The most common steel-making process relies on large quantities of coal and emits 1.8 tonnes of carbon dioxide per tonne of product. An alternative process, direct reduction, requires no coal and can work with pure hydrogen.

The Circored process has demonstrated the viability of direct reduction using hydrogen. If we used renewable hydrogen as the chemical reductant and natural gas as the fuel source we can reduce steel-related emissions by 90%, and energy use by 18%. For zero carbon steel we could either generate more renewable hydrogen as the fuel source or electrify Circored's heat processes.

**Table C9.2 Hydrogen-based steel-making reduces energy and emissions.**

| | Energy (kWh) | Emissions (T CO2e / T) |
|---|---|---|
| Conventional steel-making (blast furnace) | 5,489 | 1.82 |
| **Renewable hydrogen routes** | | |
| Circored with natural gas | 4,505 | 0.197 |
| Circored – 100% hydrogen | 4,958 | 0 |

Figure C9.3 Energy requirements to produce 1 tonne of crude steel through direct reduction with hydrogen[273]

| Process Stage | Circored with natural gas: Electrical energy (kWh) | Circored with natural gas: Fuel energy (kWh) | All-electric Circored: Energy (kWh) |
|---|---|---|---|
| **Hydrogen production** (58 kg) in an alkaline or PEM electrolyser. | 2,769 | - | 2,769 |
| **Pre-heating of iron ore fines to 850°C - to dry and calcine the ore and to provide heat for the reduction.**<br>**Pre-reduction - preheated ore is fed to a circulating fluidised, achieving 70% reduction.**<br>**Direct reduction – second stage reduction in a fluidised bed operating at 650°C, achieving 95% reduction.** | 128 | 858 (natural gas) | 1,354 (production of hydrogen for fuel) |
| **Flash heating at 700-750°C.**<br>**Smelting** – hot DRI is fed continuously to an electric arc furnace. Molten steel heated to 1800°C. Carbon is injected to reduce impurities. | 400 | 200 (natural gas)<br>150 (biochar) | 686<br>+ 150 (biochar) |
| **Total Energy** | 4,505 kWh | | 4,958 kWh |

# C10 How to electrify ammonia

- About 1% of global emissions are from ammonia production.
- Australia has an exciting opportunity to become a major manufacturer and exporter of zero-emissions ammonia.
- Renewable ammonia can be cost-competitive with conventional ammonia within a few years.

Ammonia is one of the world's most important industrial chemicals, playing a vital role as the principal building block in nitrogen fertilisers.[i] It is also used in the manufacture of plastics, dyes, explosives and synthetic fibres.

Australia makes 2 million tonnes of ammonia per year – 1% of world output – at four plants in New South Wales, Queensland and Western Australia.[274] The global average emissions per tonne of ammonia is 2.9 tonnes of $CO_2$, causing about 1% of world emissions. The Australian average is 2.0 tonnes CO2, and even the best available technology can only reduce this by only 10-20%.

### Ammonia as an energy carrier in the low carbon economy

Ammonia, a colourless gas, is a compound of hydrogen and nitrogen ($NH_3$). It is set to play an important part in the low carbon economy as it offers a practical way of handling renewable hydrogen. Liquid ammonia contains more hydrogen by volume than compressed or liquified hydrogen and is easier to store and transport than pure hydrogen[ii]

Ammonia could become an important source of seasonal storage of variable renewable energy, complementing batteries and pumped hydro. It is especially relevant to places that can't generate enough renewable energy. CSIRO and others have also described the potential for ammonia to be used as a zero-carbon fuel to power fuel cells, internal combustion engines and gas turbines.[275]

If ammonia were to account for just 1.5% of the world's fuel, world production would double. Australia has an exciting opportunity to become a major manufacturer and exporter of zero emissions ammonia. We could even repurpose our LNG export infrastructure to export ammonia.

## Standard ammonia production process

The conventional manufacture of ammonia involves extracting nitrogen from air, and hydrogen from a fossil fuel. Most ammonia plants are steam methane reformers, in which natural gas provides both feedstock and fuel.

Each tonne of ammonia made in Australia requires 10 kWh (36 GJ) of natural gas. Globally the most efficient plants require 7.8 kWh (28 GJ) of natural gas.[276] Ammonia is also made from coal and oil, though this leads to even higher greenhouse emissions.

**Table C10.1 Ammonia production and greenhouse gas emissions[290]**

| | Energy (GJ/tonne) | Energy (kWh/tonne) | Emissions (tonnes CO2e / per tonne) | Total emissions (million tonnes CO2e) |
|---|---|---|---|---|
| **Best practice** | 28 | 7.8 | 1.5 | n/a |
| **Australia** | 36 | 10 | 1.9 | 4 |
| **World** | 41 | 11.4 | 2.5 | 420 |

*i Nitrogen fertilisers decompose to produce nitrous oxide, a potent and long-lived greenhouse gas. We can reduce these emissions by various measures, such as efficient application of fertiliser, but there is as yet no full solution.*

*ii Ammonia is liquid at -33°C or under pressure of less than 1 MPa.*

**Table C10.2 Processes and energy requirements to produce 1 tonne of ammonia using standard steam reforming process with natural gas[291]**

| Process stage | | Temperature (°C) | Energy input (kWh) |
|---|---|---|---|
| 1. | Primary reformer feedstock – the largest portion of natural gas is used not as a fuel, but as a feedstock providing the source of hydrogen. | | 5,694.4 |
| 2. | Primary reformer fuel – natural gas and steam are reacted at 1,000°C to produce carbon monoxide and hydrogen (syngas). | 600 | 4,083.3 |
| 3. | Secondary reforming – carbon monoxide and hydrogen are mixed with air to produce more carbon monoxide and hydrogen gas. The air also provides nitrogen for the subsequent synthesis of ammonia. | 1,000 | 0.0 |
| 4. | $CO_2$ removal – carbon monoxide is converted to carbon dioxide and vented (Often some carbon dioxide is captured and used to manufacture urea.) | | 333.3 |
| 5. | Methanation – remaining carbon oxides are converted to methane. | 500 | 83.3 |
| 6. | Ammonia synthesis – hydrogen and nitrogen are reacted at 450oC and 200 bar pressure over a catalyst to form ammonia. | 450 | -555.6 |
| 7. | Boilers – Primary and secondary reforming and ammonia synthesis all produce waste heat which is reused in the boilers. | | -1,388.9 |
| 8. | Turbines, compressors, other | | 1,694.5 |
| | | **Total 9,944** | |

Figure C10.1 Energy requirements to produce 1 tonne of ammonia using all-electric process[294]

| Process Stage | All-electric ammonia: Electrical Energy (kWh) |
|---|---|
| **1. Desalination**<br>1 tonne of ammonia requires 1.5 tonnes of pure water. This can be produced efficiently from sea water using mechanical vapour recompression | 30 |
| **2. Electrolysis**<br>A large alkaline electrolyser requiring 50 kWh to produce 1 kg of hydrogen.[292] This electrolyser is 70% efficient and uses more than 90% of the energy in an electrified ammonia plant.<br>(By 2030 the cheapest and most efficient electrolysers are likely to be Polymer electrolyte membrane (PEM) and solid oxide electrolysis cells).[293] | 8,824 |
| **3. Air separation to acquire nitrogren**<br>A cryogenic air separation unit extracts nitrogen from air. Such air separation units are a well-developed technology currently used in coal-based ammonia production. | 90 |
| **4. Hydrogen and nitrogen reaction**<br>The Haber-Bosch process - a centrifugal compressor synthesises hydrogen and ammonia to form ammonia | 550 |
| **Total Energy** | 9,494 kWh |

## Electrified ammonia production

Ammonia can also be made using hydrogen created by electrolysing water (Section B4). Until the 1960s, most fertilisers in Europe came from hydropower-based electrolysis and ammonia production in Norway.[277] The only inputs required by an all-electric ammonia plant are energy, air and water.

The falling cost of renewable electricity has led to renewed interest in making ammonia via electrolysing water. For example, an ammonia plant running on wind energy is already operating near Oxford, UK[278], and in the Netherlands a global consortium is building an ammonia plant with a 25 MW electrolyser using tidal energy.[279]

Now at least two renewable ammonia plants are coming to Australia. Yara, the world's biggest ammonia producer, plans to build a demonstration plant producing renewable ammonia in the Pilbara, WA. The plant will use desalinated seawater and is expected to be operating by 2019.

In February 2018 the South Australian Government announced that Hydrogen Utility (H2U) would build a 5 MW electrolyser system at Port Lincoln. The hydrogen will be used to generate electricity for the grid, with a portion reserved to produce renewable ammonia.[280]

### An opportunity for Australia

> ***"Thanks to the recent cost reductions of solar and wind technologies, ammonia production in large-scale plants based on electrolysis of water can compete with ammonia production based on natural gas, in areas with world-best combined solar and wind resources."[281]***
>
> ***Cédric Philibert, International Energy Agency.***

Today a 25 MW electrolyser is considered large, but there are no major technical challenges to scaling up to much larger systems. As long ago as the 1920s, Norsk Hydro built a 135 MW electrolyser in Norway. Larger systems would enable cheaper production. The successor company to Norsk Hydro, Nel Hydrogen, plans to build a 400 MW electrolyser for $US175 million. This represents a two-thirds reduction in cost per kilowatt compared to much smaller installations.

### Process steps and energy inputs

Figure C10.1 illustrates the steps and energy inputs involved in renewable ammonia production. Overall our electrified process uses 9,494 kWh per tonne of ammonia[iii] – marginally less than a typical Australian plant using natural gas. More than 90% of this electricity is required to run the electrolyser.

The electrified system is far simpler than the conventional steam reforming process, replacing the first five processes with a single step – electrolysis.[282] We have assumed the desalination of seawater, though with access to freshwater this step would be unnecessary. Once the electrolyser has produced the hydrogen, production proceeds in a similar way to conventional ammonia plants.

*iii The theoretical minimum energy input is 7,000 MWh per tonne.*

## Operating and capital costs

Most of the energy and a large part of the cost of producing ammonia is related to the cost of hydrogen. Section B4 shows that, at current natural gas prices, it is now possible to make hydrogen at a competitive cost in a location with very good renewable energy resources. In 10 years' time, with a renewables price of 4 c/kWh, electrolysis may be the cheapest way to make hydrogen in Australia – below A$2.5 per kilogram.

The large upfront capital cost of an ammonia plant also has a strong influence on production costs. The cost per tonne of ammonia can be significantly less for larger plants. This is true for both conventional steam methane reformers and all-electric systems.

The operating costs estimates above assume large-scale production. Small-scale electrolysers built in Australia today cost around A$1,500 per kilowatt. By scaling up we can reduce this cost dramatically. NEL Hydrogen is planning to build a 400 MW electrolyser for just A$584 per kilowatt.[283]

We have used this price in the estimates in Table C10.3 which shows costs for a renewable hydrogen plant with a capacity of 300,000 tonnes per year – a similar capacity to Incitec Pivot's steam methane reformation plant at Gibson Island, Queensland. The capital cost of $538 million is similar to the cost of a new steam methane reformation plant of the same size.

**Table C10.3 The capital cost of a renewable hydrogen plant with a capacity of 300,000 tonnes per year would be similar to a conventional ammonia plant with the same capacity.**[284]

| Equipment | Cost (million A$) |
|---|---|
| Electrolyser 440 MW | 257 |
| Air separation unit | 47 |
| Mechanical vapour recompressor | 34 |
| Haber-Bosch synthesis loop | 200 |
| **Total** | **538** |

## Cost of renewable ammonia

In the last five years the price of conventional ammonia in Australia has fluctuated between A$510 and A$740 per tonne,[285] and is expected to vary within the upper half of this range for the next 30 years.[286] The price is largely driven by volatile prices for natural gas, which typically represents 55% of cost of conventional ammonia production.[287]

If renewable electricity is priced at 4 c/kWh ammonia can be made for A$600-625 per tonne.[288] This means that in Australia renewable ammonia can be cost-competitive with conventional ammonia within a few years. The long-term price of renewable ammonia will also remain stable, creating greater certainty for buyers and sellers.

## Conclusion

About 1% of global emissions are from ammonia production. These emissions can be eliminated by making ammonia with renewable hydrogen. Renewable ammonia may have an important role to play in the zero-carbon economy as a carrier of hydrogen. It will soon be cost-competitive in places with excellent renewable energy resources, like much of Australia.

*What is the potential that we see? We believe that it could grow to a full replacement of our current natural gas consumption by producing hydrogen with a solar field...There is tremendous potential to produce renewable ammonia which could replace conventional fuel production in the future.*[289]

*Chris Rijksen, Yara (world's largest ammonia producer).*

# Appendix 1

## Estimating future renewable electricity prices to 2028

The energy cost comparisons in this report use our estimates of current and future prices for renewable electricity and gas (Table D1). We are not attempting to forecast future energy costs but presenting one plausible scenario.

Electricity costs for industrial consumers are comprised of two main components: wholesale and network costs.

### Wholesale renewable energy costs

All around the world the wholesale price for solar PV and wind energy has fallen steeply over the last five years. By 2028 in Australia the cost of wind power could fall by a further 23% and the cost of solar PV by a further 53% (Table D1). This would make wind power available at 4.7 c/kWh and solar at 3.6 c/kWh. The average for wind and solar PV would be 4 c/kWh, assuming a 40%/60% split for wind and solar PV.

### Notes to Table D1:

#### Solar PV

*Learning curve: For more than 40 years solar PV has tracked a consistent learning curve. Since the late 1970s cumulative production volume has doubled many times (400GW by 2017* [295]*), with an average price reduction of 18-22.5 % each time.*[296,297] *We have assumed the most commonly cited learning curve of 21% continues for the next 10 years.*

*Growth rates: In the last decade panel production has grown by an average of more than 40% per year, leading to four doublings of cumulative production from 2008 to 2016.* [298] *(Nearly all mainstream forecasts have repeatedly under-estimated this growth.) We have conservatively estimated a growth rate of 25% until 2028. This would lead to further doublings of cumulative production in 2021, 2024 and 2028.*

#### Onshore wind

*Learning curve: the historic learning curve for wind is about 12%.*[299] *There is good reason to think this rate will continue as average turbine size and capacity factors increase.*

*Growth rates: In the last decade wind turbine production has grown by an average of more than 20% per year.* [300] *We have conservatively estimated a growth rate of 13% until 2028. This would lead to further doublings of cumulative production in 2023 and 2028.*

These projections are based on historical growth rates and learning curves. A learning curve is the rate at which the price of a manufactured products falls relative to industry maturity, typically represented as the percentage reduction in cost for every doubling of cumulative production. Our application of past growth rates and learning curves to price projections is explained in the notes to Table D1.

This projection is similar to forecasts by various experts such as the International Renewable Energy Agency[301] and Germany's Mercator Research Institute[302].

**Table D1 Projected future costs of renewable electricity in Australia based on industry learning curves and global growth rates. (See notes to Table D1)**

| | Solar PV – rooftop | Solar PV – utility | Wind |
|---|---|---|---|
| Estimated learning rate to 2028 | 21% | 21% | 12% |
| Estimated global growth rate to 2028 | 25% | 25% | 13% |
| 10-year cost reduction | 53% | 53% | 23% |
| Cost of generation in 2018 (c/kWh) | 7.0 | 7.0 | 6.0 |
| Cost of generation in 2028 (c/kWh) | 3.6 | 3.6 | 4.7 |
| **Cost range of renewable energy in 2028* (c/kWh)** | | **4** | |

**Assumes a renewable energy mix for industrial use of 45% utility solar; 15% rooftop solar; 40% wind.*

It is also consistent with the US National Renewable Energy Laboratory's 2030 price goal of US3c/kWh for utility-scale.[303] (Their 2020 price goal was achieved three years early.) The projection is actually less optimistic than some, such as those of leading Australian solar researcher Professor Martin Green, who expects a PV price of about 1.5c/kWh by 2020.

Another indication of the credibility of our projection is world record low prices. In 2013 the world record low price for solar PV (set in the US) was about Aus 10 c/kWh.[304] Five years later even the *average* Australian price for solar is well below this – around 6.5c/kWh. Today the lowest solar prices are already lower than our forecast for 2028, with contracts signed in Mexico, Saudi Arabia and Dubai for around Aus 2c/kWh.[i]

By 2028 we estimate the price of onshore wind to reduce by 23%, due to a learning curve of 12% and a growth rate of 13%. This would make onshore wind available at 4.6c/kWh compared to today's price of about 6 c/kWh. Again this is consistent with international estimates. The International Renewable Energy Agency's central estimate for the price of onshore wind in 2025 is US 4.2 c/kWh.[305] Other analysts believe the cost of wind will fall more quickly, halving by 2030[306] or 2040.[307]

## Network costs

The other major component of electricity bills is fees for network services (poles and wires). These fees vary widely among industrial electricity users. In general the higher the electricity demand, the lower their network fee per kilowatt hour. For some very large users low network costs account for less than 10% of electricity bills. But for many manufacturers, especially small and medium-sized enterprises, network costs account for a third to one half of their electricity costs. Electricity network costs in Australia are high by international standards[308] and are unlikely to decline significantly in the short-term.[ii] For our modelling we assume network costs will stay at their current levels until 2028. This approach is consistent with forecasts produced by the Australian Energy Market Operator.[309]

For our analysis of energy costs we have used a network charge of 5 c/kWh. This is based on billing information shared with us by manufacturers connected to the distribution (not transmission) system.

Some manufacturers are able to access a lower rate. For example, we calculated that a "large" customer of United Energy might pay a network charge of 3.5 c/kWh, based on this provider's usage and peak demand tariffs for 2018.[310] United Energy is the network supplying south-east Melbourne where 40% of Victoria's industry is situated. For United Energy a large customer must use at least 400 MWh per year and draw power of more than 150 kW.[311] Many manufacturers profiled in this report will meet these criteria, especially once they electrify.

The network charges of large electricity users are strongly influenced by peak demand as well as overall consumption. Manufacturers can significantly reduce their network charges by smart demand management, especially at times of peak demand. Electrical heating technologies assist demand management.

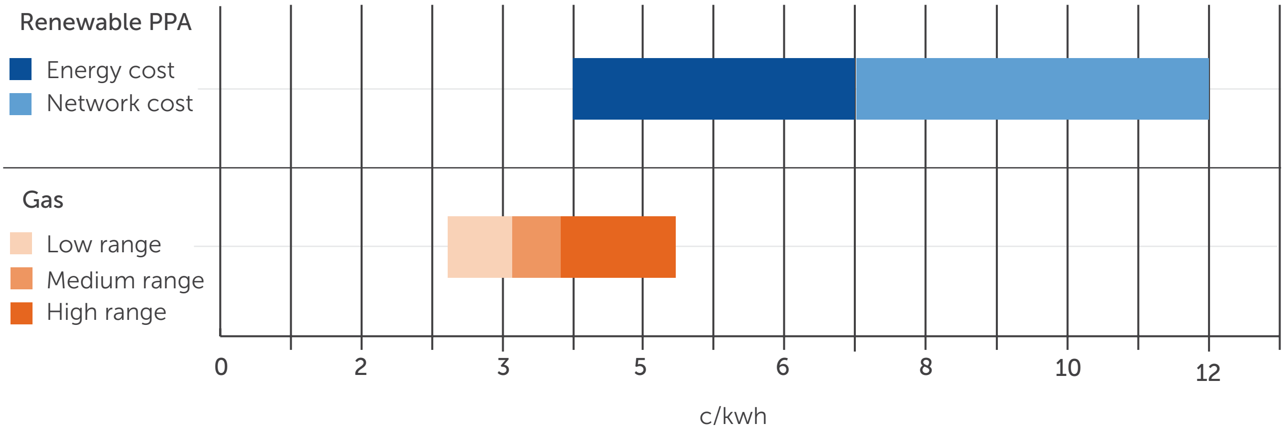
For the 'How to' guides on steel and ammonia we have assumed generation of renewable electricity takes place on-site. In this case the manufacturer will, of course, pay no third-party network costs.

Retail costs for industrial users are minimal and we have excluded them from our price projections.

*i Overseas prices cannot be directly translated into Australian prices as countries have different incentives and cost structures which can be hard to quantify.*

*ii Although lower costs could be achieved either by writing down the monetary value of networks, or by raising their productivity – i.e. increasing the amount of electricity they distribute by electrifying industry.*

Figure D1 Cost ranges of different energy sources 2018 to 2028



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# The Zero Carbon Australia project

## Our vision is for a zero carbon Australia.

Our Zero Carbon Australia series outlines and costs a national transition to a zero emissions economy within ten years. Our research demonstrates that this vision is achievable and affordable.

## Stationary Energy Plan

Launched in 2010, this plan details how a program of renewable energy construction and energy efficiency can meet the future energy needs of the Australian economy.

## Building Plan

This 2013 plan outlines a practical approach to fixing Australia's buildings in a decade, showing how we can halve the energy use of our buildings, deliver energy freedom to people, and transform our homes and workplaces to provide greater comfort.

## Transport Plan

Commenced in 2014, when complete this plan will show how Australia can maintain and enhance mobility without fossil fuels. The 2014 High Speed Rail study proposes a high speed rail network connecting capital cities and major regional centres along the east coast by 2030. The 2016 Electric Vehicle report shows how replacing all urban cars with electric vehicles in 10 years could be cost neutral and would have many social benefits.

## Land Use: Agriculture & Forestry

The 2013 discussion paper shows how greenhouse gas emissions from land use – agriculture and forestry – can be reduced to zero net emissions within 10 years.

## Renewable Energy Superpower

Launched in 2015, this plan highlights the enormous opportunities Australia has to leverage its natural advantages in solar and wind resources.

## Zero Carbon Industry Plan

A plan for producing industrial materials such as cement, metals, plastics and chemicals without the emissions. Rethinking Cement (2017) was the first part of this plan. Electrifying Industry is the second instalment, focusing on industrial heat.

### About Beyond Zero Emissions

Beyond Zero Emissions is one of Australia's most respected climate change think tanks. We produce independent research demonstrating that zero emissions is technically feasible now.

Our work is carried out by a small staff of experts, with the help of academic institutions and a large network of volunteer scientists, engineers and economists. We are funded by private foundations and concerned individuals.

You can be a part of our audacious vision for a Zero Carbon Australia by making a donation to fund our research. Eighty-five percent of our researchers are volunteers, making your donation go a long way.

**To find out how, visit** http://bze.org.au

## Is Australian manufacturing ready for the next wave of industrial revolution: the zero-carbon economy?

*Electrifying Industry,* by the award-winning team at Beyond Zero Emissions, shows how Australian manufacturers can stop burning fossil fuels by switching to renewable electricity.

This transition can be powered by Australia's unparalleled potential to generate renewable energy. The cost of solar and wind energy has fallen to a level where any manufacturer can reduce their bills by switching to renewables.

Electricity is a remarkably versatile form of energy that can be used to power *any* industrial heat process. This report shows the potential of electrical heat technologies to save energy, reduce costs and increase productivity.

It includes 10 'How to electrify' guides for making many common industrial products without fossil fuels, including milk powder, paper, aluminium casting, brick, glass, plastic, steel, ammonia and beer.

Zero-emissions manufacturing is the next frontier for industry worldwide. *Electrifying Industry* shows why renewable electricity is an unmissable opportunity for Australian manufacturing today.

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