CLIMATE COUNCIL

AUSTRALIA'S CLEAN INDUSTRY FUTURE: MAKING THINGS HERE IN A NET ZERO WORLD

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Cover image: 'Pouring molten metal into mold', photo by DedMityay.

The Climate Council acknowledges the Traditional Owners of the lands on which we live, meet and work. We wish to pay our respects to Elders past and present, and recognise the continuous connection of Aboriginal and Torres Strait Islander peoples to Country.

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Key findings

1 A new Industrial Revolution, triggered by the world's response to climate change, is reshaping the global economy, with major implications and opportunities for Australian industry.

- Most developed nations are trying to at least halve their emissions by 2030. These commitments are redirecting global investment away from fossil fuels and emissions-intensive industries of yesterday, and into the clean industries of tomorrow with places like the United States of America and the European Union already investing heavily.
- Pricing measures against harmful pollution already cover many of the world's largest economies, key nations in our region and markets that Australia competes in, with institutions like the International Monetary Fund now looking to coordinate such financial arrangements. An increasing number of countries are also looking to impose carbon border measures on higher-polluting imports.
- Low-carbon supply chains will shortly become dominant, which requires substantial investment in, and production of, renewable sources of electricity as well as other low-carbon inputs for industry, like renewable hydrogen and green ammonia.
- Australia's huge commercial advantage is our renewable energy resources. Theoretically, we receive enough sunlight to power our nation 100,000 times over, and we boast some of the best onshore and offshore wind resources in the world. This could enable us to become a world-beating exporter of clean energy commodities and critical minerals.
- One collaborative research project between Australia and the United States of America estimates that moving toward net zero could result in Australian jobs within the energy export sector growing by up to one million workers by 2060, compared with only 40,000 workers without significant policy change.

2 Making green metals in Australia using readily available materials under our feet could both secure our nation's economic future, and result in our country playing an outsized role in helping protect us all from harmful climate change.

- If Australia made green steel onshore by refining our own iron ore, rather than exporting more than 90 percent of the raw material overseas, we could avoid 1.5 billion tonnes of greenhouse gas emissions annually (three times the amount Australia emits each year), and generate 10 times the profits that our iron ore industry does today.
- In Sweden, where only 86 million tonnes of iron ore are produced per year, trials to fully decarbonise steel production are underway with plans to shift to full commercial production within five years. In comparison, Australia mined 922 million tonnes of iron ore in 2020-2021.
- An international think tank concluded that Australia could take the lead in the production of zero-emission aluminium globally because it is highly energy intensive to make this popular product, and we have abundant renewable energy. As with green steel, this would onshore more high-value industries, creating new jobs and prosperity for Australians while driving down emissions.
- New South Wales' largest energy user, Tomago Aluminium Company, is already planning to operate solely on renewable energy by 2030. Its smelter uses the same amount of energy as approximately 56,000 households, and this is a major step on the company's pathway to decarbonise.

3 There are readily available opportunities to cut emissions today within every industrial sector examined, as well as many emerging solutions that will be scalable within the next five to 10 years.

- Electrification of mine equipment, and switching to renewables in the grid, represent the greatest opportunities to decarbonise aluminium smelting and non-fossil fuel mining. Increasing renewables in the grid will also be crucial to manufacturing renewable hydrogen in Australia, which will be critical to decarbonise other industries.
- Ramping up renewable hydrogen production would mean Australia could decarbonise many of its industrial processes, such as replacing polluting gas in processes for ammonia and steelmaking.
- With a green ammonia industry we could replace a key, polluting ingredient in modern fertilisers, build a significant export industry, reduce emissions in other industrial processes, and potentially replace the diesel commonly used in shipping.
- Further investment in research and development is required to fully decarbonise industry, but even in the cement industry (considered one of the hardest to abate) there are promising alternatives emerging.

4 Industrial heavyweight states like Queensland are trialling new ways of making things here, as well as exploring major, new export opportunities in renewable hydrogen, green ammonia and critical minerals mining.

- Renewable hydrogen is a major facilitator of many clean industrial processes. As we build up renewable hydrogen capabilities domestically, it can then become a major export opportunity in its own right. Rio Tinto's Yarwun Alumina Refinery in Gladstone, Queensland is trialling the replacement of gas with renewable hydrogen. When fully operational, the facility is expected to produce up to 300 tonnes of renewable hydrogen per year.
- Queensland and Western Australia are home to several facilities that manufacture ammonia or related chemicals. Converting these to green ammonia facilities — with complementary green hydrogen manufacturing capabilities onsite — will create new domestic and export markets for renewable ammonia, and safeguard manufacturing jobs.
- Queensland is among the states that has an abundance of minerals and mineral sands underground, with Australia's reserves of gold, iron ore, lead, nickel, rutile, silver, tantalum, zinc and zircon believed to be the largest in the world. Much of what is found beneath our feet, such as lithium and copper, will be critical in global efforts to decarbonise.

5 Reforming our national laws can incentivise industrial innovation, help key industries thrive in a world where net zero is standard business, and support the development of major, new export opportunities.

- Industry – comprising mining, manufacturing and construction – is directly responsible for around 34 percent of Australia's emissions; or half if their electricity use is counted.
- If our biggest emitters don't pull their weight, Australia can't meet — or improve on — our legislated emissions reduction target and tackle harmful climate change.
- The Safeguard Mechanism, which is under reform, regulates carbon pollution from our 215 biggest industrial emitters. If the Australian Government gets the reform of this policy right, it will help key industries thrive and new ones prosper.
- To avoid our industries from becoming outdated and unwanted in a net zero market, reform of the Safeguard Mechanism should ensure genuine emissions reductions are prioritised, and offsets are used as a last resort in strictly limited situations.
- Critical industries like steel, aluminium, cement and chemicals should not be disadvantaged by allowing new, highly-polluting coal, oil or gas projects entering the Safeguard Mechanism to go ahead.

1. Introduction

The world is undergoing a new Industrial Revolution. Driven by an urgent need to tackle the climate crisis, and grasp the economic advantages of renewable energy, this switch away from fossil fuels is reshaping the global economy with major implications and opportunities for Australian industry.

Australia's economy has repeatedly evolved over the past 50 years. We moved away from a pastoral economy that relied heavily on wool, and we no longer "ride the sheep's back". The service sector has grown rapidly at home, and become an important trade. While manufacturing has declined since its peak in the 1960s, we've maintained strengths in both manufacturing and heavy industry. However, we have been slow to embrace the opportunity to transform emissions-intensive industries so they can thrive in a world that is rapidly decarbonising.

The impetus for acting on climate change is no longer in doubt, but the task is large and the timeline available is short. All parts of our economy must play a role, including the heaviest industrial emitters. This is no easy task, but Australia can't afford to shy away from the challenge. By moving towards a clean energy economy, we can secure Australia's ability to make things at home for decades to come.

In fact, Australia has a comparative advantage in the production of renewable energy, and also has globally significant reserves of metal ores and critical minerals. This means our economy is well-placed to thrive as global demand for low and zero carbon commodities booms with the right policy settings.

Moving to a zero emissions future will result in three major changes to industry in Australia: the phase out of fossil fuel extraction and production, the decarbonisation of many existing industries such as steel and cement, and the rapid scaling up of new industries like critical minerals, renewable hydrogen, green ammonia and metal production.

Figures 1 and 2: For emissions to plummet this decade, we need to rapidly transition away from fossil fuels, towards renewables. Pictured left is our past, the Hazelwood Power Station, a thermal coal power station located in La Trobe Valley, Victoria which was decommissioned in 2017. Pictured below is our future, the 50MW Kidston Solar Project in Kidston, Queensland. A second 270MW solar farm is being built in the Kidston Renewable Energy Hub, and will be fully integrated with the Kidston Pumped Storage Hydro Project, which began construction in 2021.

Today, fossil fuel facilities still account for around half of the emissions regulated under the Safeguard Mechanism – an important national policy for curbing domestic emissions from our biggest industrial polluters. Time is running out for these industries to reform, or be reformed. As our trading partners shift to renewable energy, our fossil fuel exports are expected to decline rapidly. Australia itself is moving rapidly away from coal-fired power. The production of coal, oil and gas is incompatible with a safe climate and these industries will have to be phased out as cheaper and cleaner ways of making things and powering our operations ramp up.

While Australia must switch away from fossil fuel production, other industries can thrive in a lower carbon world. We will continue to need steel, aluminium, cement, fertilisers, chemicals and other industrial products in the decades ahead. Decarbonising production will be key to achieving Australia's emissions reduction targets. It will also ensure the competitiveness of Australian industry in a world where: customers are looking for low-emissions suppliers; trading competitors are pricing carbon for their own industries; and destination markets are imposing carbon tariffs at the border. As the Australian Government prepares to strengthen the Safeguard Mechanism, this report focuses on the key industries regulated by it, and explores the range of mature, pilot and emerging solutions that can help them decarbonise.

The reform of the Safeguard Mechanism is a critical opportunity to decarbonise a range of industries. Getting the new settings right will help future-proof industries and protect Australia's manufacturing and non-fossil fuel mining industries. This, combined with complementary policies that drive large-scale, low-cost renewable energy – especially focused around industrial precincts such as the Pilbara and Gladstone – and innovation in emerging lower-carbon technologies, will deliver jobs and ongoing prosperity for Australians for generations to come.

To set the scene, this report looks first at the seismic shifts underway globally and what this means for Australian industry. We also explore Australia's comparative advantages, and the opportunities we have to cement the nation's future economic prosperity while playing a major role in global efforts to tackle the climate crisis.

We explore five main industries in depth: examining the emissions associated with each; their current status within Australia; and the range of existing and emerging solutions for decarbonisation.

Lastly, we look closely at the proposed reform of the Safeguard Mechanism, and the role it can play in driving the decarbonisation of Australian industry. If we get the Safeguard Mechanism right, it can deliver the biggest reductions to industrial emissions ever seen in Australia. A smartly reformed Safeguard Mechanism, combined with measures that drive opportunities and increase the competitiveness of new clean industries, will lead to further innovation and investment in cleaner products. Getting it wrong will lock in even more carbon pollution, which is fuelling harmful climate change.

We can and should encourage a fast and fair transformation of our economy away from the emissions-intensive activities of yesterday, towards the clean energy economy of tomorrow.

BOX 1: EMISSIONS EXPLAINER

SCOPE 1 EMISSIONS

Scope 1 or direct emissions are those that result from a company's owned or controlled sources. This includes direct emissions from coal mining and gas extraction (fugitive emissions), as well as emissions from chemical reactions in industrial processes (such as cement and steelmaking), emissions from on-site fuel combustion to generate heat and power machinery, and emissions from landfill. These are the emissions included in the Safeguard Mechanism, which covers industrial facilities that emit more than 100,000 tonnes of carbon dioxide equivalent (CO_2e)[1] per year (Clean Energy Regulator 2022a).

SCOPE 2 EMISSIONS

Scope 2 or indirect emissions are produced from the generation of purchased energy. They reflect the emissions produced by the physical burning of fuels at the power station, and are measured as kilograms of CO_2e per unit of electricity purchased by an organisation. These emissions are outside the scope of the Safeguard Mechanism but can also be a significant source of carbon pollution for some industrial sectors.

SCOPE 3 EMISSIONS

Scope 3 emissions are produced within an organisation's value chain, but from sources the facility or business does not own or control – for example, where a company exports a raw material that is then processed into a different product. Emissions from the export coal and gas industry, where coal and gas is extracted then exported from Australia and burned overseas, are considered Scope 3 emissions.

In 2020-21, emissions from the burning of exported coal and gas were more than double Australia's total domestic emissions.

1 CO_2e is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

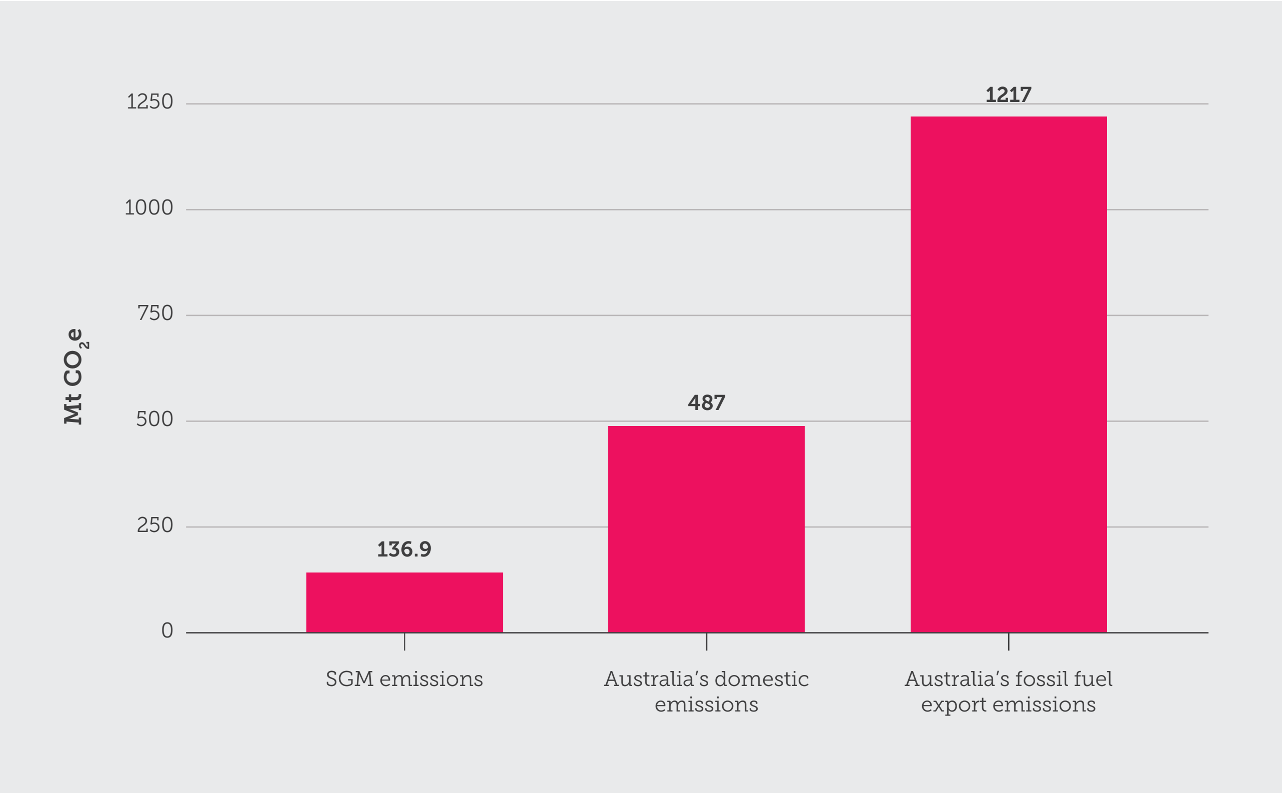


Figure 3: Comparison of the 2021 emissions regulated by the Safeguard Mechanism (SGM), Australia's entire domestic emissions from 2022, and the Scope 3 emissions from Australia's 2021 fossil fuel exports. Climate Council analysis of National Greenhouse Gas Inventory Quarterly Update: June 2022 (DCCEEW 2022b).

2. The future of Australian industry in a net zero world

2.1 No turning back: The global economy is headed to net zero

Under the *Paris Agreement*, countries have agreed to limit global warming to well below 2°C and to pursue efforts to limit the temperature increase to 1.5°C (UN 2015). To achieve this goal and secure a liveable future for us all will require a dramatic acceleration in emissions reductions this decade, and achieving net zero emissions as soon as possible (IPCC 2021).

Since 2015 more than 100 countries, representing around 90 percent of the global economy, have committed to achieving net zero by mid-century (New Climate Institute 2022). More importantly, many of the world's leading economies have made plans for deeper emissions cuts in the near term. Most developed nations now plan to at least halve their emissions by 2030. Taken together, these commitments are already driving a redirection of global investment away from fossil fuels and emissions-intensive industries and into the clean industries of tomorrow (IEA 2020a).

These global trends, including a growing focus on decarbonising heavy industry, have changed the landscape for all Australian businesses. Rapidly decarbonising our industrial sector is critical for securing Australia's future prosperity in a rapidly changing world, and maximising our enormous potential to help drive down global emissions.

Ensuring the swift decarbonisation of our industrial sector is essential to meet Australia's own emission reduction targets.

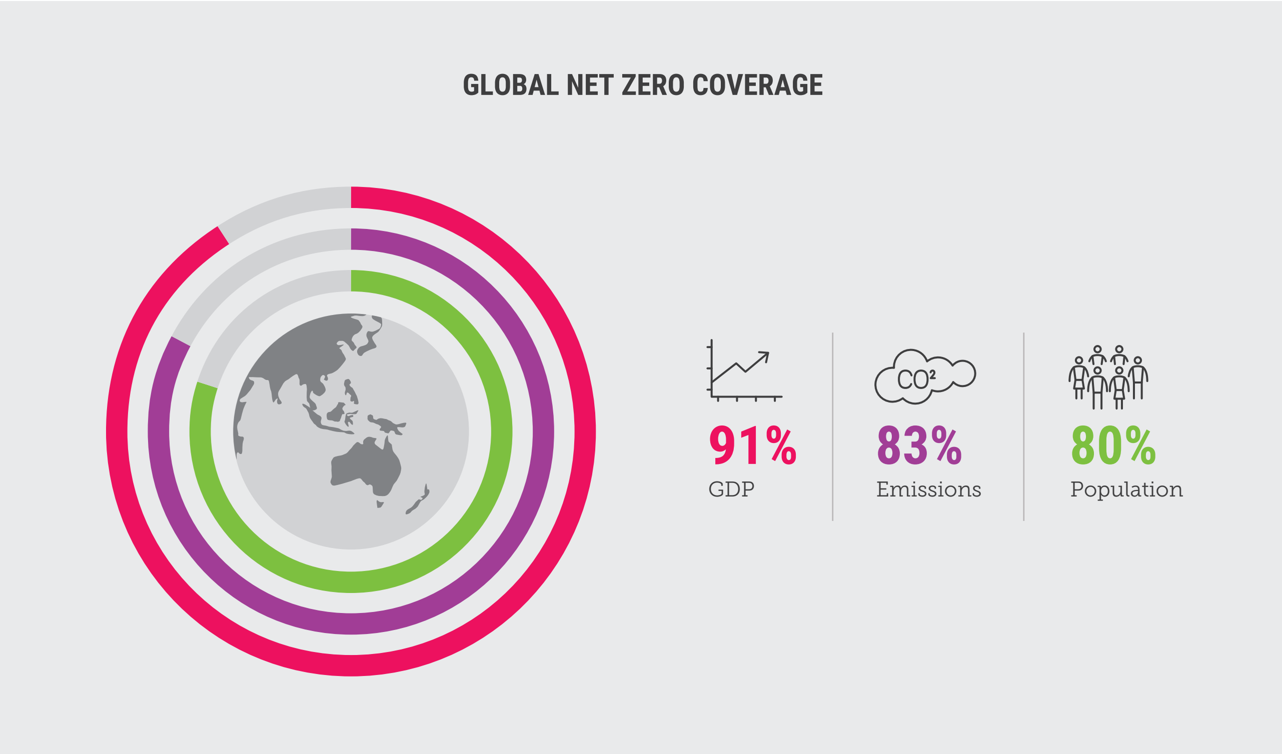


Figure 4: Net zero is now the new global norm. With a legislated target of 43 percent emissions reduction by 2030 (from 2005 levels), Australia is now more closely aligned to its international peers, however most other developed nations have set higher targets (Climate Council 2022c).

We can help the world decarbonise and grow clean export industries at the same time. Decarbonising industry represents a huge opportunity for Australia to stake our claim as a clean energy superpower; we can't afford to miss this opportunity.

2.2 What changing global markets mean for Australian industry

Global markets for industrial commodities are rapidly changing as many countries – including some of Australia's key trade competitors – adopt policies to reduce emissions from their industrial sectors. The first-mover-advantage is large for those countries that are prepared to invest early in developing lower emissions supply chains and new sources of competitiveness in a globally decarbonising economy (Climateworks and Climate-KIC 2023). If Australian industry does not move quickly to low carbon production, our competitors will secure all-important contracts, relationships and ongoing market share. In short, if we wait until 'everyone else' decarbonises, Australia will miss out on key opportunities in a decarbonising world.

As of 2022, 70 regional, national or subnational carbon prices were in effect – covering many of the world's largest economies, key nations in our region, and markets that compete with Australia (World Bank 2023). Countries are also looking to coordinate their carbon pricing arrangements, with key multilateral institutions including the World Trade Organisation, the International Monetary Fund, and the Organisation for Economic Cooperation and Development (OECD) advocating for a global carbon pricing framework (see WTO 2022; Gaspar and Parry 2021; Fleming and Giles 2021). Put simply, pricing measures on harmful pollution are now a fact of life in the global marketplace in which Australian industries compete.

To prevent these measures from prompting the relocation of production, rather than decarbonisation, an increasing number of countries are imposing or considering imposing carbon border measures. Such measures place an additional cost on goods imported from countries without adequate measures in place to drive down emissions. The European Carbon Border Adjustment Mechanism (CBAM) will begin full operation in October 2023. Similar schemes are under active consideration in the United Kingdom, Canada and Japan (Climate Council 2021a). Modelling commissioned by the Climate Council in 2021 suggested that if China, South Korea and the G7 group of countries adopt similar carbon border measures to the EU, and Australia does not adopt measures to drive down industrial emissions, losses to our national income could reach more than $12 billion, and thousands of jobs would be at risk – especially in Queensland and New South Wales (Climate Council 2021a).

These are not the only ways in which governments are helping heavy industry to remain competitive in a decarbonising world. Some countries, most notably the United States of America (USA), are using significant targeted public investment to accelerate the transformation of their industrial sector. The US Inflation Reduction Act for example – passed by Congress in September 2022 – allocates more than US $369 billion to accelerate the clean energy transition in the US. This includes significant subsidies and tax credits for

Australian industry must decarbonise to remain competitive in a world where net zero is business as usual.

the decarbonisation of heavy industries, such as steel manufacturing, and government procurement rules that require governments to purchase low-carbon materials for public projects (Stashwick et al. 2022). This is expected to substantially reduce the costs of renewable energy and renewable hydrogen that will benefit industrial producers in the US, and enable green exports. Similarly the EU Green Deal includes a range of efforts to drive clean energy and industry development.

Together, these changes mean Australian industry must decarbonise to remain competitive in a rapidly decarbonising world economy, and to thrive in markets that are actively looking for low-emissions suppliers. With an increasingly competitive market for low-carbon products, combined with policy measures such as the USA's Inflation Reduction Act and the European CBAM, economic opportunities abound for both existing industries that have decarbonised, as well as new industries.

Figure 5: The solar farm for Sun Metals Zinc Refinery near Townsville, QLD. To remain competitive in a world shifting to net zero, Australian industries must decarbonise.

2.3 Australia's comparative advantage: a lucrative opportunity

As the world shifts toward net zero emissions, Australia is well-placed to reposition itself as a clean energy and industrial superpower. Leading economist Ross Garnaut says Australia is "better placed than any other country" to prosper from the clean energy transition (Garnaut 2022).

A key advantage is Australia's world-class renewable energy resources. Australia receives the most sunlight per square metre of any continent. Theoretically, we receive enough sunlight to power our nation approximately 100,000 times over (Geoscience Australia 2021). Australia also has some of the best onshore and offshore wind resources in the world. This means Australia can produce low-cost renewable electricity, which when backed by storage or grid firming, provides the crucial commercial advantage needed to develop new clean industries. Australia can transform its existing industrial precincts into renewable energy industrial precincts, such as in Queensland, Western Australia, and the Hunter Valley in New South Wales, to capitalise on this abundance (Beyond Zero Emissions 2020).

The rest of the world is heavily investing in green industrial production. For example, the USA's Inflation Reduction Act is expected to substantially lower the costs of renewable energy and hydrogen that benefit industrial producers and enable green exports. Similarly, the European Union's Green Deal contains a range of efforts to incentivise clean energy and industry development. For its part, China is subsidising the production of solar and wind energy, electric vehicles and batteries to the tune of US $564 billion in 2022 (Schonhardt 2023). While Australia has great potential, we have been slow to capitalise on our competitive advantages, and now must act quickly to grasp the economic opportunities still available.

Perhaps Australia's biggest opportunity for new industries is in green metals, especially green iron/steel and green aluminium (Garnaut 2022; Climateworks Centre and Climate KIC-Australia 2023). As outlined in the next section, this could also result in Australia making a significant, positive contribution to global emissions reduction efforts.

Overall, the potential benefits for embracing clean energy export industries are huge – and will be measured in jobs, investment and economic growth. By conservative estimates, Australia's clean energy exports have the potential to generate 395,000 jobs by 2040 – with many of these jobs in the same regions and communities that currently house fossil fuel industries (Business Council of Australia 2021).

An interim report from the *Net Zero Australia* project – comprising researchers from The University of Melbourne, The University of Queensland and USA's Princeton University – estimates that moving toward net zero will see total jobs in the energy export sector grow to between 600,000 and one million by 2060, compared with 40,000 workers in the sector without significant policy change (McCoy et al 2022). In coming decades, Australia could grow a clean export mix worth $333 billion annually; almost triple the value of existing fossil fuel exports (Beyond Zero Emissions 2021).

Figure 6: Bungala Solar Farms in South Australia (pictured) is the largest of three operational solar farms in South Australia, the others being Tailem Bend Solar and the Adelaide Desalination Plant (Government of South Australia 2023).

2.4 How building clean industries in Australia can help drive emissions reductions globally

Australian firms can use our competitive advantage in renewable energy to onshore and decarbonise key industrial processes. For example, rather than exporting iron ore or bauxite to China for refining, raw inputs can be processed here to make steel and aluminium using renewable energy resources.

Over the past decade Australia's top-earning export has been iron ore, with 82.4 percent of it going to China's steel smelters (Griffith 2022). The downstream (Scope 3) emissions of these exports are around 1.5 billion tonnes of greenhouse gas emissions per year, which equates to more than three times Australia's annual greenhouse gas emissions (DCCEEW 2022b; Department of Industry, Science and Resources 2022a). This highlights the opportunity that Australia has to reduce global greenhouse gas emissions by unlocking 'green steel' technologies and onshoring steel production, as well as the significant potential this presents for Australian jobs and economic prosperity. If Australia starts refining iron ore into green steel domestically, before export, it would generate roughly ten times current earnings for iron exports (Griffith 2022).

Overall, shifts in the global economy towards net zero as the world undergoes decarbonisation will favour Australia. Our abundant renewable energy resources, such as solar and wind, and our ability to manufacture green products such as steel and ammonia will give us the competitive edge in a low carbon economy (CSIRO 2019). Low-carbon supply chains will become dominant, and will require substantial investment in, and production of, renewable sources of electricity, and other low-carbon industry inputs such as renewable hydrogen and green ammonia. This will present even more new green export opportunities for Australia, and will allow Australia to capitalise on this comparative advantage (Bruce et al, 2018; Garnaut, 2019; Climateworks 2020).

As the world shifts toward a decarbonised economy, Australia is well-placed to reposition as a clean energy superpower. Australia has huge commercial advantages that could enable it to become a world-beating exporter of clean energy commodities and critical minerals that are key to the global energy transition.

Tackling the climate crisis means a rapid shift from fossil fuels to clean energy. It is crucial that Australian industry seizes the opportunities of decarbonisation.

3. Driving Australian industry towards net zero

Industry – comprising mining, manufacturing and construction – is directly responsible for around 34 percent of Australia's Scope 1 emissions (DCCEEW 2020). Mining accounts for around 20 percent of Australia's emissions, manufacturing for around 12 percent and construction for around two percent of emissions. If electricity use by these sectors is included (Scope 2), industry is responsible for close to half of Australia's emissions (Climateworks 2020). Clearly, tackling industrial emissions is crucial.

The Safeguard Mechanism applies to facilities that emit more than 100,000 tonnes of (Scope 1) carbon dioxide equivalent (CO_2e) in a financial year. As such, facilities that are covered extend across a broader range of sectors than are traditionally referred to as 'industry', including electricity generation, mining, oil and gas extraction, manufacturing, transport and waste. Collectively, these facilities accounted for 140 Mt CO_2e in 2020-21, or around 28 percent of Australia's emissions (RepuTex 2021).

This report focuses on heavy industry so it excludes sectors like waste and transport, which are included in the Safeguard Mechanism. The sectors we focus on are steel, aluminium (refining and smelting), concrete and cement, chemicals and fertilisers, and non-fossil fuel mining. The Scope 1 emissions from these industries are around 49 Mt CO_2e. This equates to almost 10 percent of Australia's total emissions in 2022 (see Figure 8).

Figure 7: Waterloo Wind Farm, South Australia. Combining our world-leading renewable resources such as wind and solar with our mining and manufacturing strengths, Australia has enormous advantage in a decarbonising world.

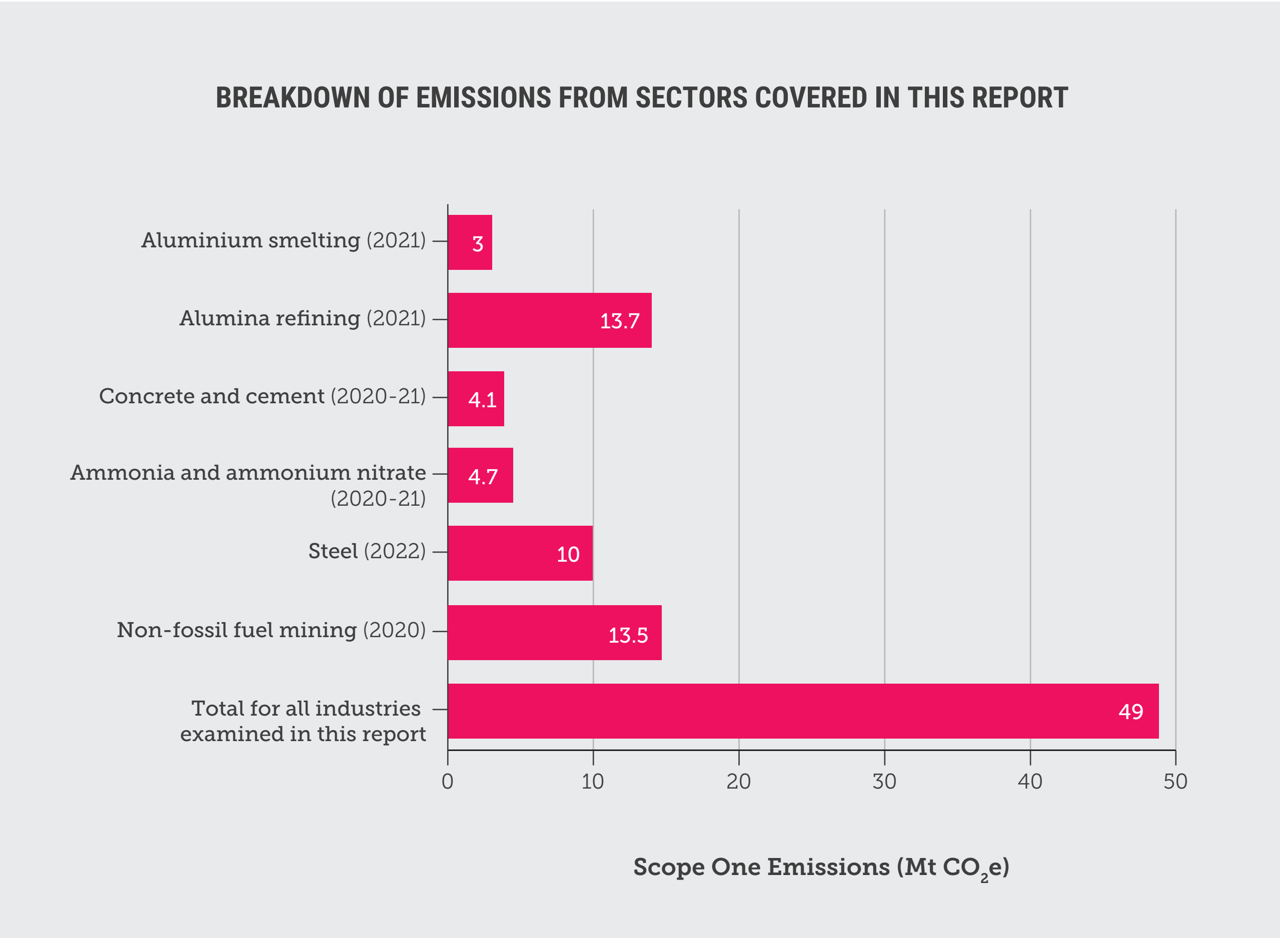


Figure 8: Breakdown of emissions from sectors covered in this report.

Note: Different years are used to count emissions from different sectors as emissions data comes from a range of different sources. The most up-to-date source available has been used for each industry. See Appendix 1 for emissions from covered facilities under the Safeguard Mechanism for these sectors for 2020-21.

Sources: Steel: DCCEEW 2022a; Alumina and aluminium: Australian Aluminium Council 2022b; Concrete and cement: CIF 2022; Non-fossil fuel mining: DCCEEW 2023; Ammonia and ammonium nitrate: Clean Energy Regulator 2022b.

The industrial sector — including its electricity use — accounts for close to half of Australia's emissions. Tackling industrial emissions is urgent and crucial.

3.1 Steel

3.1.1 STEELMAKING IN AUSTRALIA TODAY

Economic value — contribution to Gross Domestic Product of the steel value chain	\$11 billion (with annual turnover of \$29 billion)
Number of Australians employed across the supply chain	110,000. 22,000 in primary steel production, almost 39,000 in heavy fabrication, and almost 49,000 in medium fabrication and general manufacturing
Total annual production volumes	6 million tonnes (2022)
Total annual emissions (CO_2e, 2022)	11 million tonnes (Scope 1: 10 million tonnes)

Sources: ASI 2022b; Steel Fabrication Services 2019; DCCEEW 2022a.

The majority of Australia's crude steel comes from two integrated steelworks: BlueScope Port Kembla in the Illawarra (New South Wales) and Liberty One Whyalla in South Australia. With a combined production capacity of around 4.2 million tonnes per annum (Mtpa), these two steelworks make up around 70 percent of Australia's crude steel production (Venkataraman et al. 2022). Both of these plants currently use the emissions-intensive Blast Furnace-Basic Oxygen Furnace method described below. The rest of Australia's crude steel production comes from scrap metal via Electric Arc Furnace (Venkataraman et al. 2022). In 2022, Australia produced around 6 Mt of steel (DCCEEW 2022), with the majority of this used domestically. The total value of steel exports was a relatively modest \$800 million (Office of the Chief Economist 2022).

Figure 9: The Port Kembla Steelworks, in Wollongong, New South Wales has been operational since 1928. Now operated by BlueScope Steel, the company was once a part of BHP before it became a completely stand-alone steel company in 2002.

3.1.2 CONVENTIONAL PRODUCTION PROCESS

Primary steel production consists of several stages. The first step is reducing the iron from which steel is made. In this process, carbon and other impurities are removed, then secondary refining occurs and various alloys are added, converting iron into molten steel. Continuous casting in cooling moulds sets the molten steel into basic shapes, which are further processed and manufactured into final shapes, depending on the intended use.

The vast majority of the world's primary steel production uses one of two methods (see Figure 10). In the most conventional method, the blast furnace produces molten pig iron (also known as crude iron) from iron ore by the reducing action of carbon, supplied using a form of processed coal known as coke. In blast furnaces, the carbon in the coal reacts with the oxygen in iron ore, which produces iron (as a metal) with carbon dioxide as the by-product. Oxygen is then blown through molten pig iron in a Basic Oxygen Furnace, removing further impurities, lowering the carbon content and converting the pig iron into steel. This method is emissions-intensive because it relies on fossil fuels to generate the huge amounts of heat required as well as a reduction agent (in the form of coking coal). Globally, approximately 70 percent of steel is produced using this method (World Steel Association 2022).

In the second method – called Direct Reduction, or Direct Reduction Iron (DRI) – solid-state reduction of iron ore is performed using reducing gases produced from either coal or gas. A combination of hydrogen and carbon monoxide – called synthesis gas, or syngas for short – is the main reducing gas used in the 'direct reduction' technology. Syngas is used as the reducing agent to remove the oxygen from the iron ore and convert the ore to metallic iron. The resultant iron is then converted into steel in an electric arc furnace. Both of these methods are used to produce new or 'virgin' steel (termed primary steel production), using iron ore as the main source of metallic input. Only a small percentage of the world's steel is produced with the conventional DRI method (119.2 Mt in 2021) (MIDREX 2022). This method is relatively less emissions-intensive because it uses gas as a feedstock instead of coal.

Electric arc furnaces are also commonly used by themselves to recycle steel scrap – this is called 'secondary' steelmaking. In many cases, the distinction between primary and secondary steelmaking becomes blurry, as scrap is often used to supplement iron ore in primary steel production, and iron ore can also be used in electric arc furnaces.

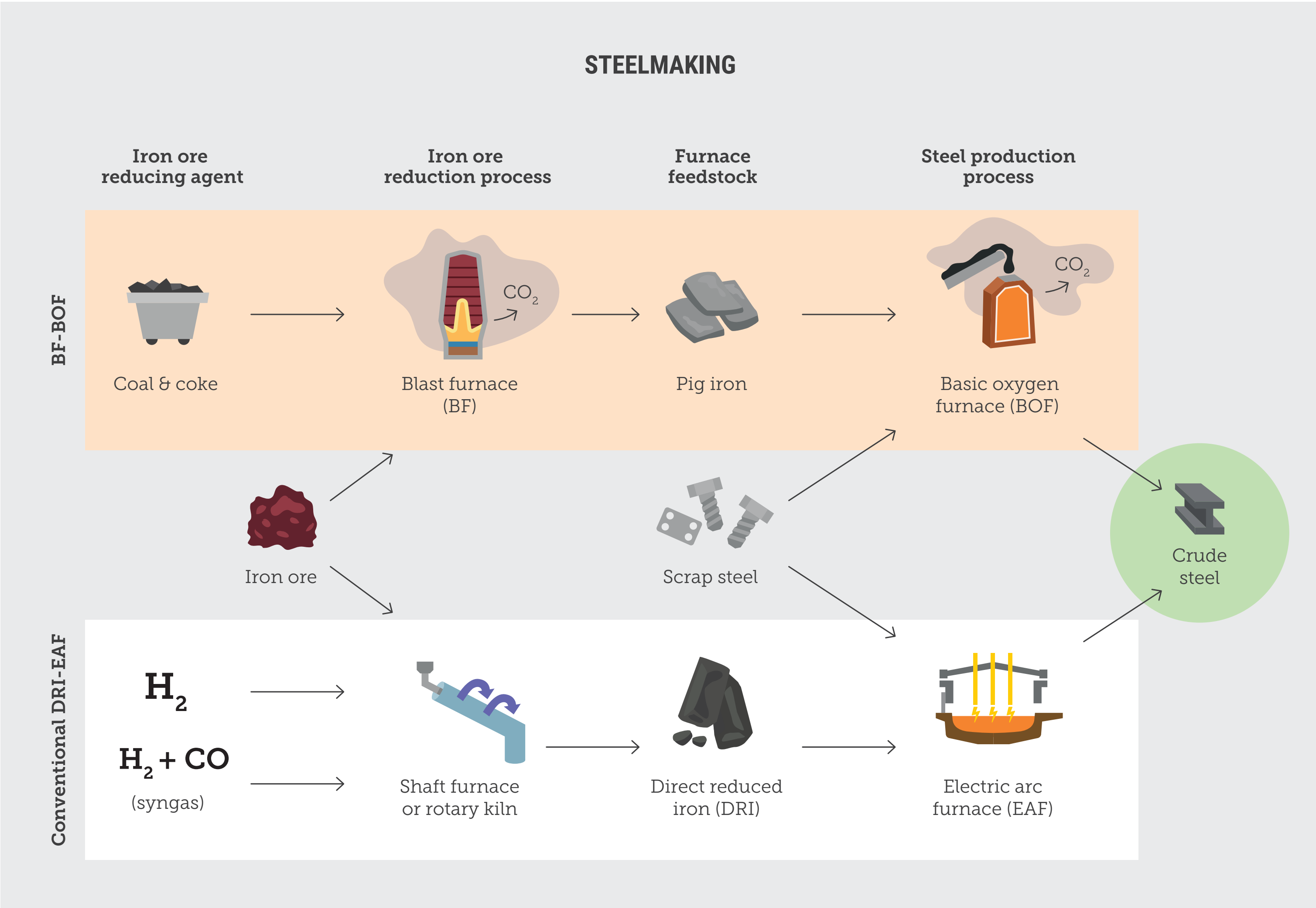


Figure 10: The two main processes for steelmaking today: Blast Furnace followed by Basic Oxygen Furnace and Direct Reduced Iron followed by Electric Arc Furnace. **Source:** Adapted from US Energy Information Administration 2022.

3.1.3 EMISSIONS

The process of turning iron ore into steel is emissions-intensive. Of all the energy used in the world, the global steel industry accounts for 5.9 percent of usage. It is also responsible for approximately six to nine percent of global emissions (Pooler 2019). In 2021, every tonne of steel produced generated an average of 1.9 tonnes of carbon dioxide (see Table 1) (World Steel Association 2022).

The different methods of steel production have different levels of energy and emissions intensity (see Table 1). The Blast Furnace-Basic Oxygen Furnace (BF-BOF) method is the most emissions-intensive form of primary steel production, generating around 2.3 tonnes of CO_2 per tonne of steel produced. The combined Direct Reduction Iron (DRI) – Electric Arc Furnace (EAF) method generates lower CO_2 emissions because it generally uses gas as a feedstock instead of coking coal – it generated 1.65 tonnes of CO_2 per tonne of steel produced in 2021. Secondary steel production – using scrap to recycle steel in an electric arc furnace – is the least emissions-intensive.

Table 1: Emissions and energy intensity of different methods of steel production.

CO_2 emissions intensity by production route		Energy intensity by production route
Tonnes CO_2 per tonne of crude steel cast		GJ per tonne of crude steel cast
Global average	1.9	21.3
BF-BOF	2.3	24.4
Scrap-EAF	0.7	10.0
Conventional DRI-EAF*	1.7	25.3

*Data concerning global crude steel production using DRI is not currently collected, the denominator in this calculation is therefore calculated by the worldsteel data management team based on information contained in worldsteel's collective databases. **Source:** World Steel Association (2023).

Green iron and green steel both offer new clean industry opportunities for Australia, and can help secure our economic future while tackling the climate crisis.

In Australia, steel production accounted for 11 Mt of CO_2e in 2022, or around 2 Mt CO_2e per Mt of steel. This is equivalent to 2.2 percent of Australia's total emissions (DCCEEW 2023b). The majority of these emissions come from chemical reactions in the process of making steel (8 Mt CO_2e) (i.e. using coke and pulverised black coal as a reducing agent in the blast furnace). The remainder are emissions from burning fossil fuels to create heat (2 Mt CO_2e), and from electricity usage (1 Mt CO_2e) (see Figure 11) (DCCEEW 2022).

With Australia needing around six million tonnes of steel annually to provide the backbone for our buildings, infrastructure and heavy equipment, it is highly beneficial that we have the capacity to manufacture it competitively here. That is why it's so important Australia's handful of domestic crude steel producers transform to keep thriving as we move towards net zero.

Further, as the world's largest producer and exporter of iron ore, the production of green iron or steel in Australia offers one of the greatest opportunities for new clean industries – a chance to both secure Australia's economic future and play an outsized role in global efforts to tackle the climate crisis.

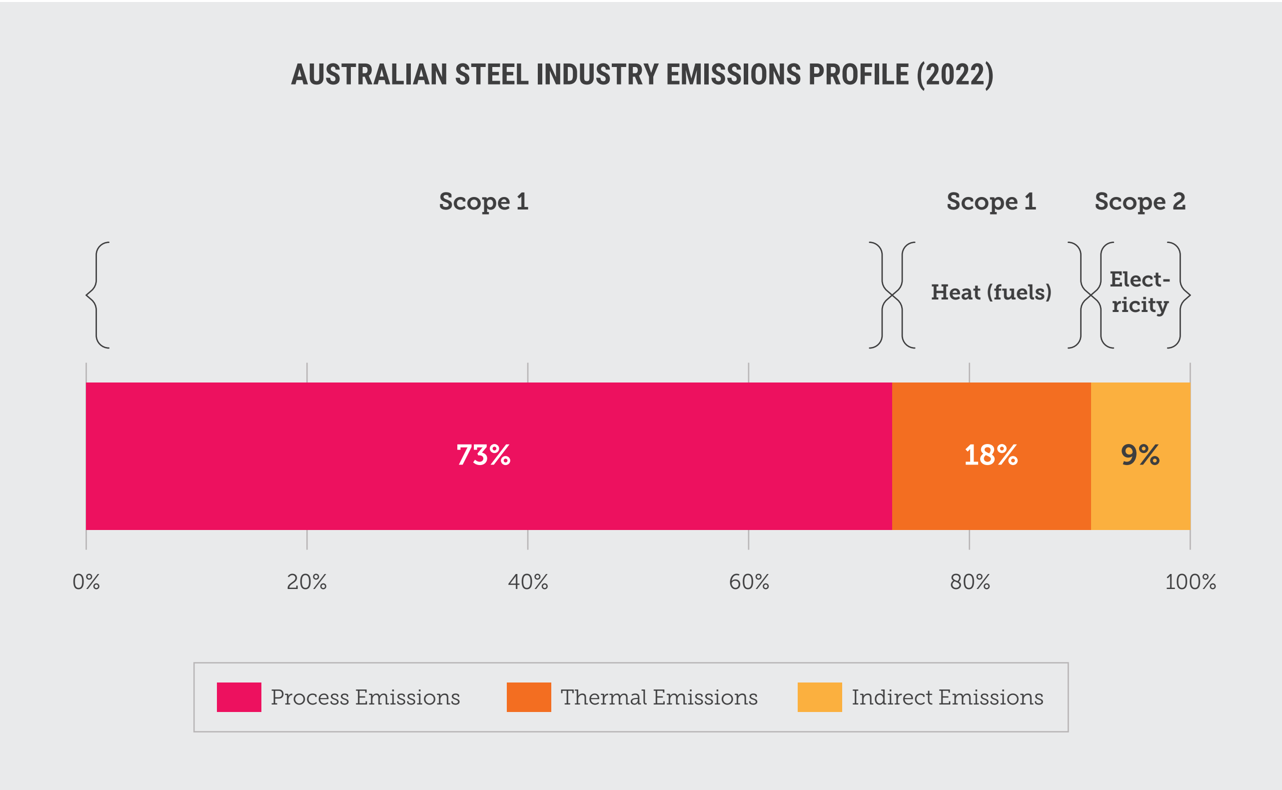


Figure 11: Australian steel production emissions profile (2022). **Source:** DCCEEW 2022a.

3.1.4 STEEL SOLUTIONS

The International Energy Agency (IEA) has said that direct emissions from steelmaking need to be reduced by 50 percent by 2050 to meet the world's climate targets under the *Paris Agreement* (IEA 2020b). This can be achieved by embracing emerging technologies and process changes to produce 'green steel', and negates the need for harmful fossil fuels in the production of steel.

Currently, Australia exports more than 90 percent of its iron ore to China, Japan and South Korea for steel production in those countries (Department of Industry, Science and Resources 2022a).[2] The downstream (Scope 3) emissions of these exports are around 1.5 billion tonnes of carbon pollution a year, or approximately three times Australia's annual domestic emissions (DCCEEW 2022b; Department of Industry, Science and Resources 2022a). Australia can boost jobs here at home and help cut emissions globally by onshoring and then ramping up the production of green steel or green iron, instead of simply exporting the raw iron ore.

Australia has an opportunity to unlock technologies that will help with emissions reduction in various stages of the steel production chain. One important technology shift which is already under trial is a modified form of the DRI/EAF method. This new production process uses hydrogen-based direct reduction combined with an electric arc furnace, offering a genuine pathway to zero-carbon steel (see Figure 12).

Other pathways to reduce emissions from steelmaking include hydrogen direct reduction combined with a melter and followed by a blast oxygen furnace (or H-DRI Melter BOF, discussed in the example of Thyssenkrupp below, see Box 4) and electrolytic steelmaking (discussed in the case study of Boston Metal below, see Box 5). Increased recycling of steel is another method of reducing emissions from steelmaking. However, this opportunity is not discussed in this report, as there is not enough high-quality scrap available to meet demand for steel through this pathway alone.

Hydrogen Direct Reduction

Hydrogen Direct Reduction (H-DRI for short) uses renewable hydrogen instead of gas or coal to strip oxygen out of the iron ore to create iron. The by-product of this process is water rather than carbon dioxide. Using hydrogen direct reduced iron as the feedstock for an electric arc furnace powered by renewables allows steel production to be fully decarbonised.

What is renewable hydrogen?

Renewable hydrogen is made when clean, renewable electricity — like wind and solar — is used to split water into oxygen and hydrogen. Renewable hydrogen can replace fossil fuels for some industrial processes, and has an important role in the manufacture of green steel.

2 In 2020-2021, Australia exported 871 million tonnes of iron ore. This is forecast to increase to 920 million tonnes exported in 2022-2023. Data obtained from Department of Industry, Science and Resources (2022)

For electric arc furnaces, there is no need for a reductant as in blast furnaces, where coal is used as a reductant. Electric arc furnaces use electricity to melt steel. This means that the main source of emissions is from electricity production. When electricity comes from renewable sources, the emissions intensity drops dramatically. These furnaces can use either scrap steel or direct reduced iron (DRI) as the raw material (or a combination) (see Figure 12).

H-DRI that is transported hot can be directly added into an electric arc furnace, which also reduces the amount of energy required. The H-DRI/EAF process allows for emissions-free steel production whenever renewable hydrogen and electricity are used together. There are already pilot facilities using this method to make green steel internationally, with the next step being to rapidly scale it up. There are also opportunities to export hydrogen direct reduced iron – as a bulk commodity, it is lower cost to transport and appropriate for large-scale export to a range of markets (Climateworks Centre and Climate-KIC-Australia 2023). With Australia's world-beating capacity to generate clean renewable electricity and hydrogen through our plentiful wind and sun, our local industries should be in the box seat to benefit from this shift in technology. One limitation of this technology route is that it requires high quality, low impurity iron ore. Most of the iron ore that Australia currently produces is lower grade.

Exporting green iron provides a large-scale opportunity for Australian iron ore; combined with Australia's abundant renewable energy resources, the benefits are significant.

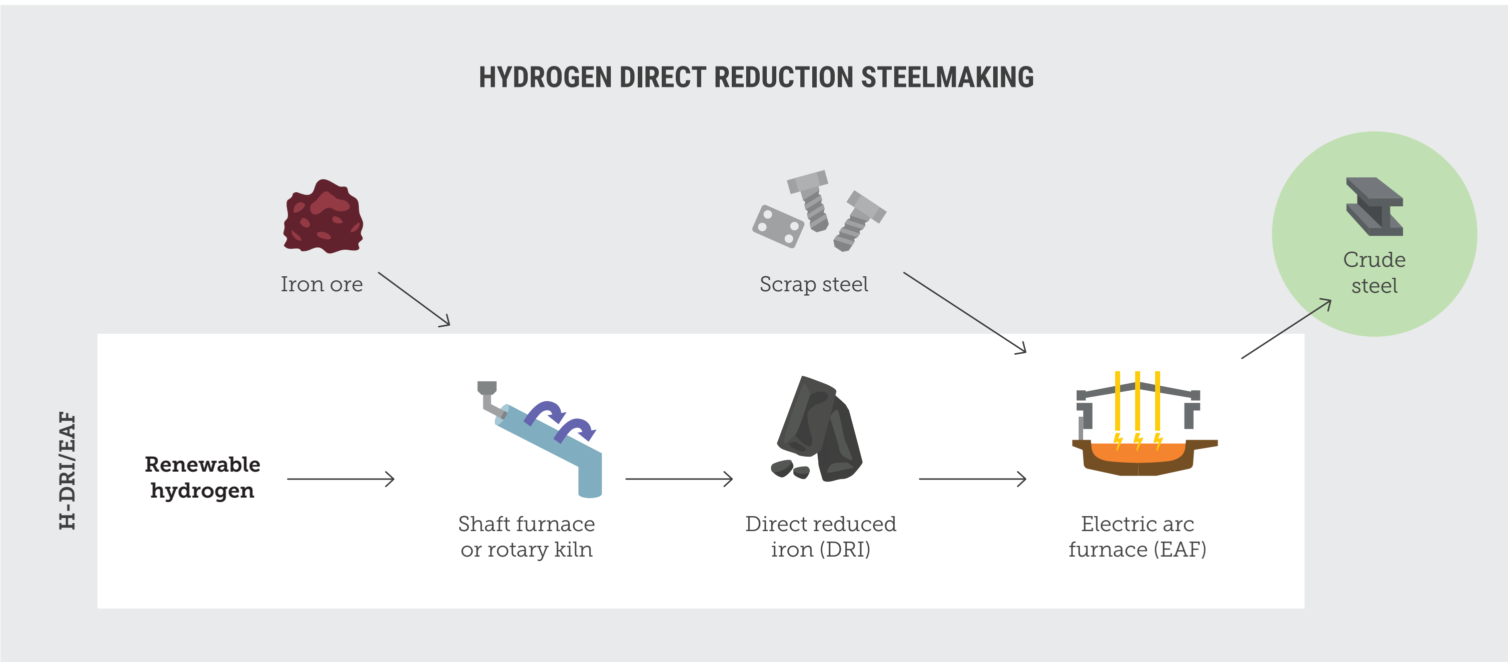


Figure 12: Hydrogen Direct Reduction Steelmaking. **Source:** Adapted from US Energy Information Administration 2022

BOX 2: WHYALLA STEELWORKS (LIBERTY ONE/GFG ALLIANCE) – MOVING TOWARDS HYDROGEN DIRECT REDUCTION WITH ELECTRIC ARC FURNACE (H-DRI/EAF)

Whyalla Steelworks – part of the Liberty Group of the global GFG Alliance – is an integrated steelworks in South Australia and Australia's sole manufacturer of steel rail and sleeper systems. Currently, Whyalla Steelworks uses the BF-BOF method. However, the GFG Alliance plans to replace its blast furnace at Whyalla with a direct reduced iron plant and an electric arc furnace. This is part of a major upgrade of the facility which is already underway, and is set to be completed by 2024. The new plants will initially be powered by gas before being converted to hydrogen produced by a large solar plant that GFG is building at Whyalla. GFG Alliance aims to produce carbon-neutral steel by 2030 through this process. As the direct reduction process requires high-grade, low-impurity iron ore feedstock, the mining arm of GFG Alliance – SIMEC Mining – has also been working to expand production of magnetite ore, which is a high-quality iron ore product. In 2022, the company announced it had produced its first high-quality magnetite pellets. This will be a critical enabler in the transition to green steel production at the Whyalla steelworks.

Figure 13: Whyalla Steelworks was opened in 1941, when the South-Australian "Steel City" had a population of 5,000. In 2021 Whyalla had a population of 21,242 people (ABS 2021).

BOX 3: HYBRIT DEVELOPMENT – HYDROGEN DIRECT REDUCTION WITH ELECTRIC ARC FURNACE: DECARBONISING THE STEEL SUPPLY CHAIN

In Sweden, HYBRIT (Hydrogen Breakthrough Ironmaking Technology) Development has delivered fossil fuel-free steel to customers in a trial (Reuters 2021). HYBRIT is a partnership between a mining company (LKAB), a steelmaker (SSAB), and an energy company (Vattenfall). Together, they are working to decarbonise each step of the steel production process, including electrifying the mine site where ore is mined. The proposed process replaces coking coal and other fossil fuels with renewable hydrogen, and produces carbon-free sponge iron. This is then fed into a renewables-powered electric arc furnace. HYBRIT Development plans to shift to full commercial production within five years, with the overall goal of a fossil fuel-free process by 2035.

Sweden only produces approximately 86 million tonnes of iron ore per year, whereas Australia mined 922 million tonnes in 2020-2021. This highlights the massive opportunity for Australia to develop a home-grown green steel industry using the raw inputs which are right under our feet (Department of Industry, Science and Resources 2022).

Figure 14: Hydrogen Breakthrough Ironmaking Technology steelmaking process (HYBRIT) produced the world's first ever fossil-fuel-free steel back in 2020, and delivered a first shipment of "green steel" to Volvo in August 2021 (Recharge 2022).

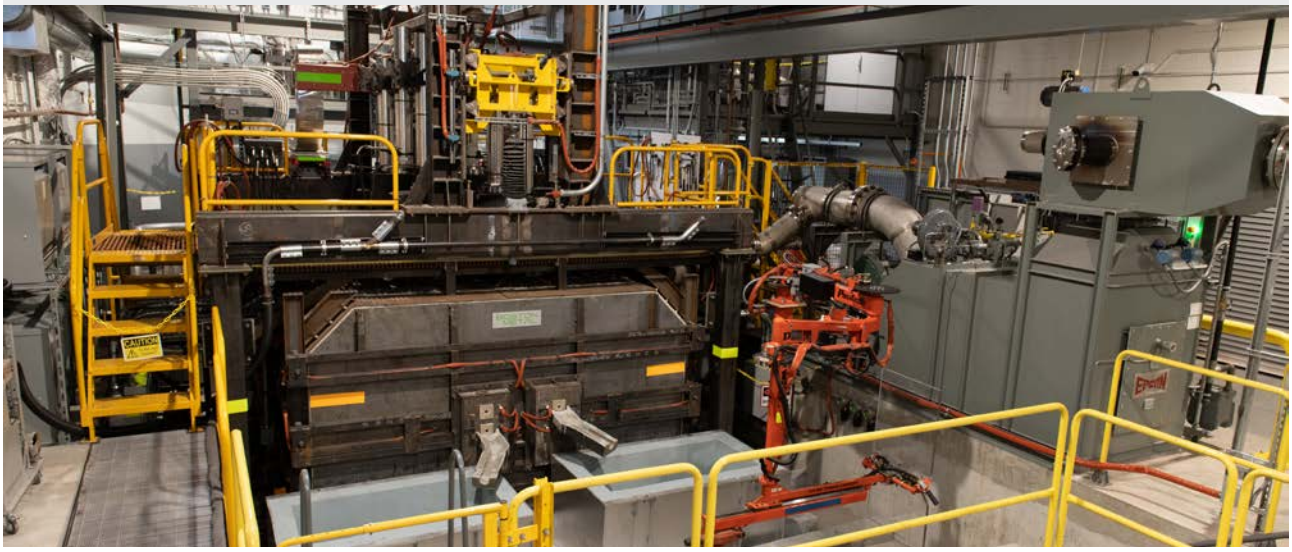
BOX 4: THYSSENKRUPP – DIRECT REDUCED IRON WITH MELTER FOLLOWED BY BLAST OXYGEN FURNACE

German steelmaker Thyssenkrupp is proposing a middle ground option that allows for lower-emissions steel using the existing plant structure, and using a lower grade iron ore. It has announced its plans to replace the coal-fired blast furnaces with hydrogen-powered direct reduced iron plants. Located in Duisburg, Germany, the proposed integrated melting unit, known as a submerged arc furnace (SAF), will be completed in 2025 with an estimated capacity of 1.2 Mt per year. A direct reduction plant will be integrated with a melting unit to melt the iron into a hot liquid. This liquid iron can then be directly added to the existing blast oxygen furnace. While this does not represent zero-carbon steelmaking, it is still significant progress, as it produces a high-quality steel using a lower-grade of (blast furnace) iron than is needed for the H-DRI/EAF option, whilst using less emissions than a coal-fired route (Nicholas 2022). The first plant is planned to be operational by 2026, with a further three planned.

BOX 5: BOSTON METAL – ELECTROLYTIC STEELMAKING

In the United States, Boston Metal is trialling an alternative carbon-free steel production process, which alters the process to turn iron ore into high purity molten iron. Their patented Molten Oxide Electrolysis process aims to produce green steel in one step, as well as other metals such as tin. The produced molten metal can be added directly into downstream steelmaking, with no reheating required as it is already liquid. It uses renewable electricity to convert the iron ore into steel, and is a zero-carbon process. While trials are still underway, this represents an alternative to the H-DRI/EAF route of green steel production.

Figure 15: Boston Metal's Molten Oxide Electrolysis cell. Currently still undergoing testing, the company is on track to reach commercialisation by 2026 to meet the growing demand for green steel.



There are advantages for first movers in this space, but there is also a risk for decarbonisation laggards to be left behind. BlueScope Steel's Port Kembla steelworks was the third largest emitting facility covered by the Safeguard Mechanism in 2020-2021 (Clean Energy Regulator 2022). In 2022, BlueScope announced it would forge ahead with relining a mothballed blast furnace. If it proceeds, this major investment in old steelmaking technology will likely mean the company continues to make steel using the traditional emissions-intensive process for at least another two decades. This could risk Australia's largest steelmaker losing market share to international competitors as our trading partners increasingly seek out lower carbon supply chains. In parallel, BlueScope has also signed a memorandum of understanding with both Rio Tinto and Shell to trial a range of decarbonisation projects (BlueScope 2021). These will focus on industrial-scale hydrogen production, as well as piloting a H-DRI furnace and iron smelter powered by renewable energy. This example highlights why Australia needs strong policy incentives driving major industrial emitters towards rapidly scaling up and commercialising newer technologies. Any emissions benefits from pilot projects can quickly be dwarfed by investment decisions which go against the global trend towards cleaner solutions.

Australia will always need steel, which means there are strong economic gains from being able to produce it locally, competitively and much more cleanly. Through promising new production processes and switching out dirty fossil fuels for clean, renewable electricity, it is already possible to make zero emissions steel. The challenge now is to quickly improve pilot technologies and scale up their use so that we can rapidly cut emissions this decade. This will not only ensure Australia maintains our existing sovereign steelmaking capability, but grows a bigger domestic industry to create more new jobs while driving down global emissions.

3.2 Aluminium

3.2.1 ALUMINIUM PRODUCTION IN AUSTRALIA TODAY

	Alumina refining	Aluminium smelting
Economic value (export revenue, 2021, AUD)	$7.5 billion	$4.8 billion
Number of Australians employed (2021)	5,509 direct, plus 2,977 contractors	2,987 direct, plus 499 contractors
Total annual production (million tonnes) (2021)	21 million tonnes	1.6 million tonnes
Total annual emissions (2021) (CO_2e)	Total: 14.6 million tonnes (Scope 1: 13.7 million tonnes)	Total: 19.7 million tonnes (Scope 1: 3 million tonnes)

Source: Australian Aluminium Council 2022b.

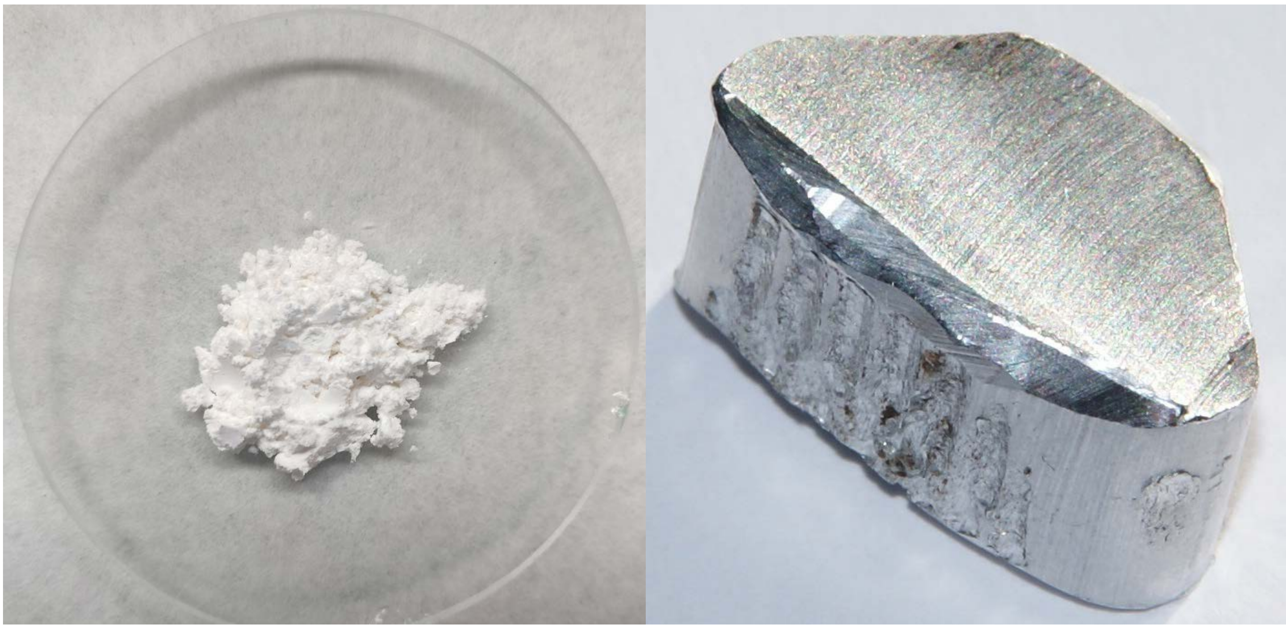
Aluminium is another essential metal, used in a wide range of contexts where light and flexible but highly durable materials are needed. Everything from building materials and aircraft parts to household appliances and packaging rely on aluminium.

The primary aluminium value chain (sometimes called supply chain) refers to the process of making aluminium – from mining bauxite through to refining alumina and then smelting aluminium. Australia is a leading producer of both aluminium ore (bauxite) and aluminium oxide (alumina), which is smelted to make aluminium. Much of the bauxite and alumina produced in Australia is exported, while some is refined and smelted here in Australia. There are five main bauxite mines in Australia (producing more than 10 Mt of bauxite per year), six alumina refineries and four aluminium smelters, primarily located across regional Australia (see Figure 16).

Figure 16: The primary aluminium value chain. Bauxite mines in orange (>10 Mt), alumina refineries in grey and aluminium smelters in blue. **Source:** Adapted from Strengthening our Aluminium Industry (Australian Aluminium Council 2022d).

3.2.2 CONVENTIONAL PRODUCTION PROCESS

Bauxite contains aluminium oxide. This is separated from the ore through a process of refining. The refining process consists of several steps, but can be broken down into two main stages. First, bauxite is milled and combined with steam and a caustic soda solution, under high pressure, to extract alumina hydrates. Then, temperatures of around 1,000°C are applied to remove chemically bound water from the alumina hydrates and produce the final product: a white powder called aluminium oxide, or alumina. The vast majority of emissions (95 percent) from the refining process are released to the atmosphere as a direct result of fossil fuel combustion during this process.

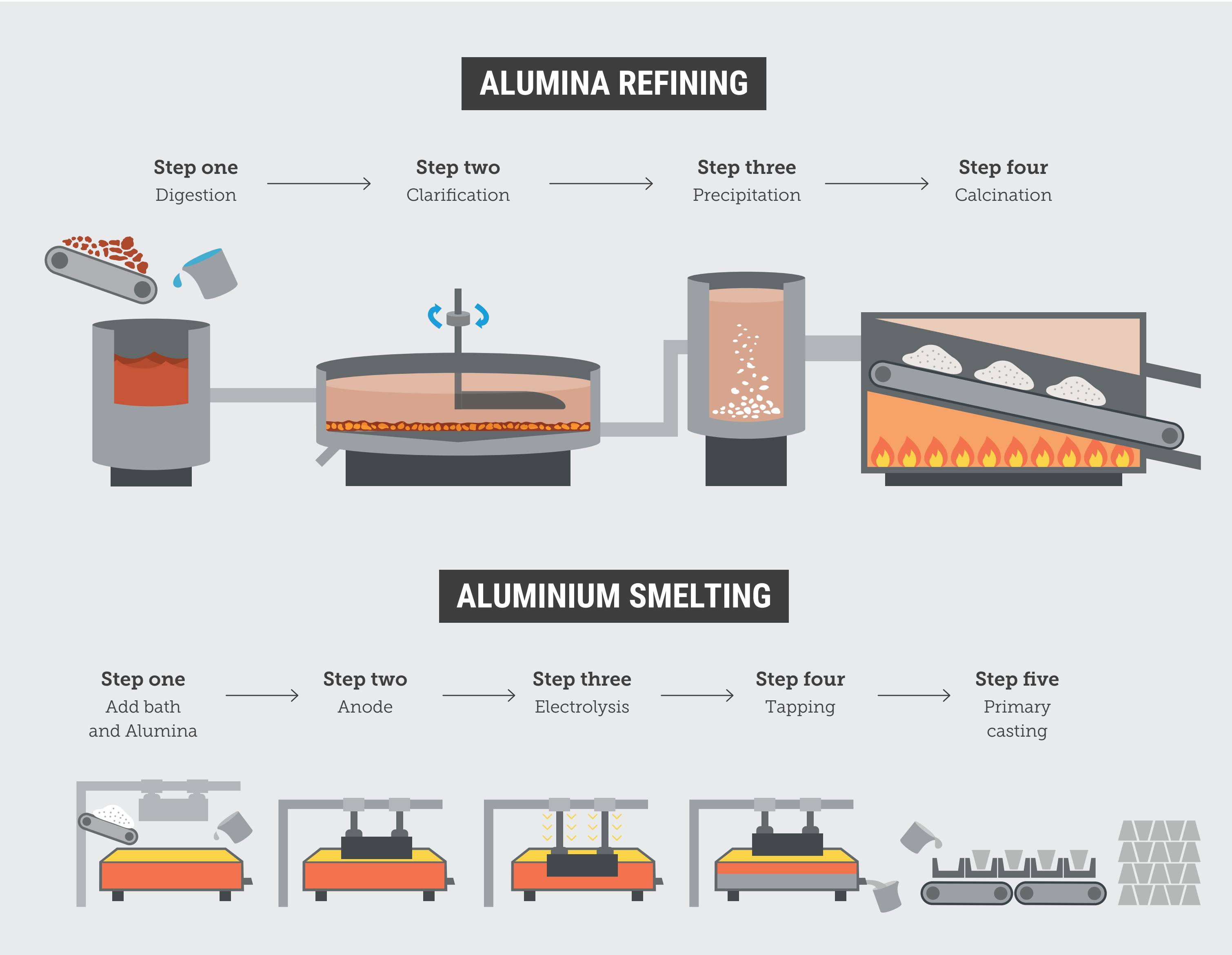


Figures 17 and 18: Aluminium oxide or alumina is a white powder (pictured left), while aluminium is a solid silvery metal (pictured right).

In the next stage, alumina is turned into the finished aluminium via a smelting process.

Aluminium smelting is the most energy and emissions-intensive stage of the production process. To produce aluminium, electricity and carbon are combined with alumina in potlines. An electrical current is made to flow through one pot to the next, reacting with carbon anodes that line each pot. There are two main sources of direct (Scope 1) emissions in aluminium smelting: the consumption of these carbon anodes, and the generation of thermal energy for high temperature processes. However, the vast majority of emissions from aluminium smelting are indirect – from purchased electricity. The process of aluminium smelting requires electricity continuously throughout the day and night, to keep the electrolysis process running. The majority of this is delivered through the grid, which means the greatest decarbonisation opportunity for aluminium smelting is shifting to renewable energy (Australian Aluminium Council 2022d; Deloitte 2022b).

Figure 19: Alumina refining and aluminium smelting process. **Source:** Adapted from Australian Aluminium Council (2023).



3.2.3 EMISSIONS

Existing aluminium production processes produce a very large quantity of emissions, particularly from the electricity used in the smelting process.

Alumina refining is an energy-intensive activity, with the Australian alumina industry consuming around 220 petajoules of energy (PJ) in 2021 (or 10.5 gigajoules (GJ) per tonne of alumina produced). This is greater than the annual energy consumption of Tasmania or the Northern Territory (Australian Aluminium Council 2022b; Deloitte 2022).

In 2021, the alumina refining industry was responsible for the release of around 14.6 Mt of CO_2e in total, around 42 percent of emissions from Australia's primary aluminium value chain or around three percent of Australia's total emissions (Australian Aluminium Council 2022b; DCCEEW 2022a). The Scope 1 emissions from alumina refining (13.7 Mt CO_2e) are 24 percent of Australia's Scope 1 emissions from manufacturing (Australian Aluminium Council 2022b; DCCEEW 2022a). These emissions are considered relatively difficult to reduce because the typical refining process relies on the direct combustion of fossil fuels at the facility level to generate the high temperatures needed.

The aluminium smelting industry produced 19.7 million tonnes of CO_2e in 2021 (Deloitte 2022b). This represents around 57 percent of the total emissions

Currently, all six refineries in Australia rely on fossil fuels to produce on-site heat and electricity, representing a significant opportunity to switch to renewable energy and cut emissions.

Figure 20: Located in Gladstone, Queensland Alumina Limited is one of the world's largest alumina refineries.

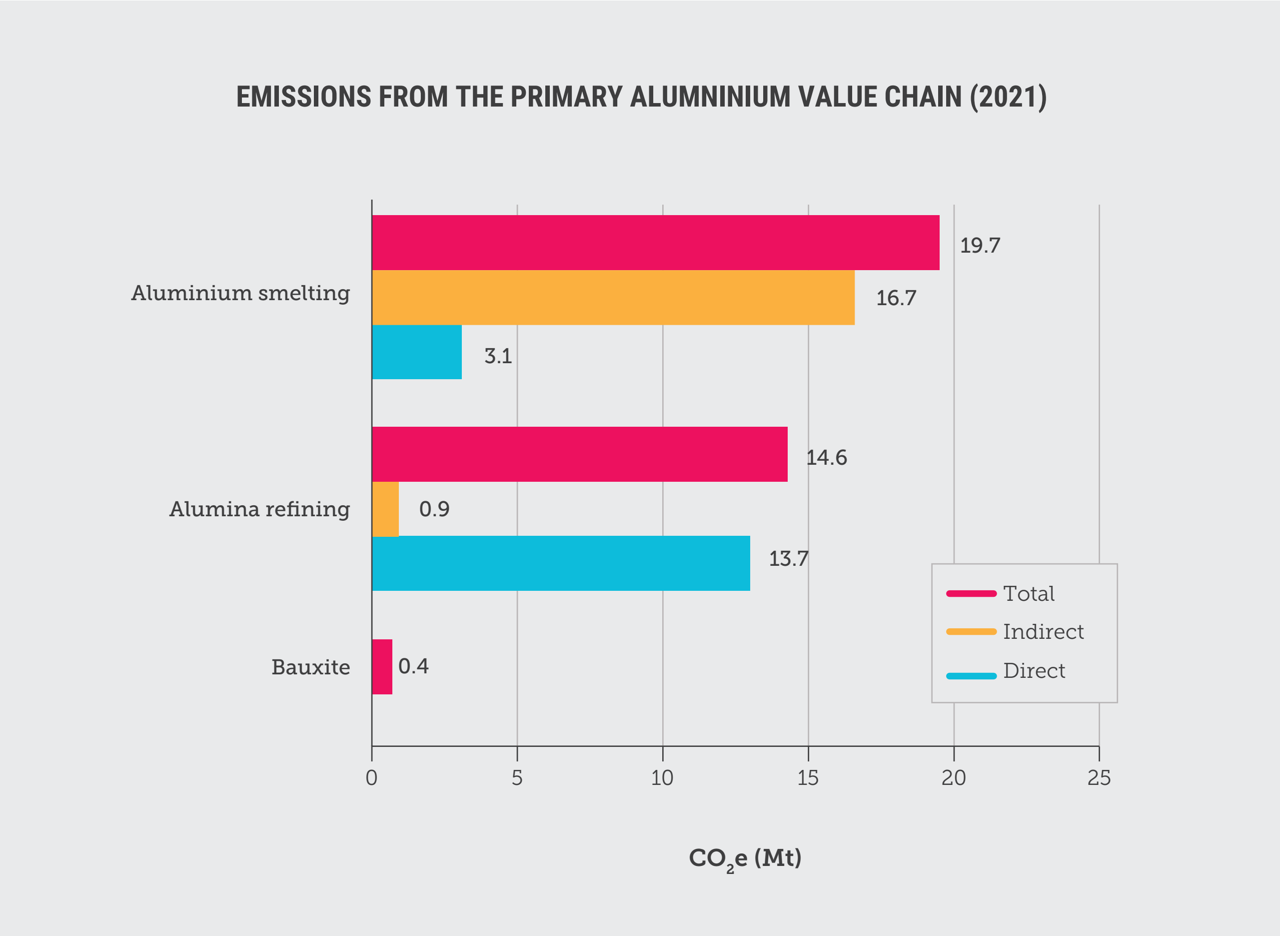


Figure 21: Direct (Scope 1) and indirect (Scope 2) emissions from the primary aluminium value chain (in 2021). **Source:** Adapted using data from Australian Aluminium Council (2022b).

from the primary aluminium value chain and around four percent of Australia's total emissions (Australian Aluminium Council 2020; DCCEEW 2022a; Deloitte 2022). The direct emissions from aluminium smelting were 3 Mt CO_2e (2021), equating to around five percent of direct emissions from the manufacturing sector (Australian Aluminium Council 2022b; DCCEEW 2022a). Unlike with alumina refining, the vast majority of emissions from aluminium smelting are from the use of electricity. These emissions will be relatively easier to address as the grid transitions to renewable energy backed by storage.

Decarbonising aluminium production – in particular, through cleaner sources of electricity – will be an essential part of achieving deep cuts in Australia's emissions. In fact, with Australia's abundance of renewable energy we have a strong opportunity to take the lead in the production of zero emissions aluminium globally (Institute for Energy Economics and Financial Analysis 2020). As with green steel, this would mean bringing more high-value industry onshore, creating new jobs and prosperity for Australians while helping drive down global emissions.

3.2.4 ALUMINIUM SOLUTIONS

Decarbonising the electricity grid is the first, and greatest, opportunity for lowering emissions from aluminium production. Technology and process changes, together with increased recycling and operational efficiency, will further decarbonise the production of this essential material. The following section examines each of these opportunities.

Cleaner sources of electricity

Approximately 50 percent of total emissions from the production of aluminium come from electricity production for smelting. Considering smelting is already an electrified process, using renewable energy provides a straightforward solution to reducing emissions intensity in this process (Climateworks and Climate-KIC 2022a: 19). Aluminium smelters in Australia have started to convert their facilities to renewable energy sources. As smelters renew their contracts for energy supply, they have the opportunity to source renewable energy from on or off grid sources, drastically reducing their emissions. Renewables backed by storage (such as batteries or pumped hydro) or grid firming (where renewable sources are diversified to ensure stability in supply) will be critical to balance capacity and demand moving forward.

Further, in the alumina refining process, fossil fuel-fired boilers provide the steam required. There is the potential for the coal or gas-fired boilers currently used today to be replaced with electric boilers in the future (Deloitte 2022b). Electric steam generation has been demonstrated through pilot projects at Alcoa's Wagerup facility in Western Australia, for example; the next step is to demonstrate it can provide the pressure and heat required for the refining process at a commercial scale.

Process emissions

Smelting: inert anodes

The second pathway for emissions-free production of aluminium is addressing direct emissions released during the smelting process, which make up approximately 15 percent of total emissions in the manufacturing process for this metal (ETC 2018). These are emitted through the consumption of carbon anodes during the smelting process, and are referred to as 'direct' or 'process' emissions. Another form of direct emission is thermal energy; energy used to create industrial heat and steam. Inert anodes are an alternative to the carbon anodes used in the smelter to create aluminium, and produce little to no carbon emissions when renewable energy is used, with oxygen as the by-product. While this technology is not yet commercially available, major aluminium companies — including in Australia — are undertaking research and development into these emerging technologies with a view to further reducing process emissions (Australian Aluminium Council 2022).

Refining: Mechanism Vapour Recompression (MVR) process and calcination

Process heating is required during the multi-stage process of refining bauxite to make alumina. This typically uses fossil fuel-powered boilers to create the steam necessary for the digestion phase of the process, which dissolves the alumina from the bauxite in a caustic soda solution. This process can be switched to one based on Mechanical Vapour Recompression (MVR) which can be powered by renewable electricity. The MVR process takes waste water vapour and recompresses it to achieve the heat and pressure required for alumina refining — eliminating the steam demand by traditional fossil fuel boilers. This circular process creates no greenhouse gas emissions if renewable electricity is used in electric boilers, and saves a significant amount of water (Deloitte 2022b).

The final step of the refining process is calcination, where the material is washed and dried at temperatures above 1,000°C. This results in the dry powdered form of aluminium oxide, or alumina. Currently this process produces significant emissions because gas is used to reach the high temperatures necessary for drying. Approximately 24 percent of alumina refining emissions come from calcination and this has been identified as an important process to decarbonise (ARENA 2022a). Both electric calcination and renewable hydrogen calcination have been identified as technologies that could be commercially available by 2035 (Deloitte 2022b). Emissions produced during the calcination process could be reduced to zero if this was fuelled entirely by renewable energy.

Sustainability

The final avenue for lowering emissions in aluminium manufacturing is recycling materials and increasing resource efficiency. While this won't remove all aluminium emissions, it does mean aluminium can be recycled infinitely without losing its valuable properties of lightweight strength and flexibility. Recycling aluminium scrap requires only 5 percent of the energy required to produce primary aluminium, and the use of post-consumer scrap can decrease the need for emissions-intensive primary aluminium by up to 15 percent (World Economic Forum 2020). Increased collection and recycling of aluminium is worth pursuing in parallel with efforts to reduce emissions from primary aluminium production.

Renewables are now the cheapest form of electricity generation and the transition to a grid powered by renewables is well underway.

BOX 6: ELYSIS

In 2018, Rio Tinto and Alcoa formed a partnership to commercialise a new technology that they have named ELYSIS. The ELYSIS™ technology, using inert anodes instead of carbon anodes, eliminates all direct greenhouse gas emissions from the aluminium smelting process and emits oxygen as its by-product.

Apple is a partner in the joint venture, and has used the first batch of aluminium with zero emissions from smelting for MacBook Pros, and has committed to use the next batch in iPhones. ELYSIS – a Canadian company with headquarters in Montreal – also has investment backing from the Canadian government and the Quebec government.

The team at ELYSIS aim to commercially demonstrate their technology this year (2023) (ELYSIS 2023a).

Figure 22: The ELYSIS™ technology was successfully demonstrated and has been producing metal at the Alcoa Technical Center, near Pittsburgh in the United States, since 2009 (ELYSIS 2023b).

BOX 7: EMISSIONS REDUCTION OPPORTUNITIES – CASE STUDIES

Decarbonising electricity:

At the time of writing, Tomago Aluminium Company was seeking investment proposals to implement its plan to achieve 100 percent renewables by 2030.

Tomago is the largest energy user in New South Wales, with the smelter alone drawing a continuous 850MW of demand when operational (Regan 2022) — equivalent to approximately 56,000 households. Switching to renewable energy for electricity will significantly reduce the emissions of these operations, and is an important step on the pathway to decarbonisation.

Another example is Rio Tinto's BC Works operation in British Columbia, Canada, which is one of the world's largest aluminium smelters. BC Works is powered by the Kemano Powerhouse, a renewable hydropower facility. Rio Tinto has modernised its on-site operations, and as a result is one of the lowest carbon aluminium smelters in the world. Rio Tinto have said this move has made its operations not only cleaner, but also more efficient and commercially competitive: the company now produces double the aluminium with only half the greenhouse gas emissions (Rio Tinto 2021a). This illustrates the opportunities for combining renewable energy with existing operations to decarbonise aluminium smelting.

Process emissions:

The Australian Renewable Energy Agency (ARENA) has granted $8.6 million to Alcoa to undergo electric calcination trials (ARENA 2022b), and Rio Tinto and Sumitomo are partnering up at Rio Tinto's Yarwun Alumina Refinery in Gladstone, Queensland, to explore the use of hydrogen to replace natural gas at the refinery (Rio Tinto 2021). The pilot trial will involve developing a renewable hydrogen production facility on-site, and explore options to replace gas in the alumina refining process. Half the hydrogen produced will be used for the alumina refinery trials, with the other 50% used for other projects in Gladstone. When fully operational, the facility is expected to produce up to 300 tonnes of renewable hydrogen per year.

Other trials are underway to decarbonise the remaining process emissions in aluminium manufacturing. One area undergoing investigation is replacing the carbon anode with an inert anode, with companies such as Rio Tinto and Alcoa exploring the correct anode material, with ceramics, metal alloys, or a composite (Aluminium for Climate 2021).

Alcoa has secured an ARENA grant to explore the integration of a Mechanism Vapour Recompression into its Wagerup alumina refinery in Western Australia (ARENA 2021). Alumina refining is a significant contributor to greenhouse gas emissions, and uses substantial amounts of fossil fuels in the existing process.

This project seeks to create a pathway to low-emissions alumina refining, by swapping the fossil fuel-generated thermal energy with renewables-powered mechanical vapour recompressors. Using this process in a hard-to-abate process such as alumina refining illustrates the steps that are already underway to make fossil fuel use in manufacturing obsolete.

Australian aluminium is an essential input for so many goods and activities; we only have a handful of facilities making it here, so it's essential they transform to thrive. Aluminium is one of the easier manufacturing processes to decarbonise because switching to renewable energy can cut out around half of the emissions. Increasing sustainability and circularity through aluminium recovery and recycling will help achieve incremental emissions reduction in the meantime while the necessary technology and process changes continue to emerge and scale up. These changes will be required to complete the path to zero emissions aluminium, with more research and development required to focus on promising new techniques.

Figure 23: Alcoa's Wagerup alumina refinery, the site for their Mechanical Vapour Recompression trial for low carbon alumina refining.

3.3 Chemicals and fertilisers

3.3.1 CHEMICALS AND FERTILISER PRODUCTION IN AUSTRALIA TODAY

Economic value (export revenue, 2021, AUD)	\$281.4 million*
Number of Australians employed	3,400
Total annual production volumes	1.8 million tonnes of ammonia, 1.9 million tonnes of ammonium nitrate, and 0.5 million tonnes of fertilisers
Total annual emissions (2020-21)	4.7 Mt CO_2e**

* \$194.2 million USD, converted 20 February 2023.

** This figure is based on the reported emissions from the facilities that produce ammonia, ammonium nitrate and ammonium phosphate that are covered by the Safeguard Mechanism. Gibson Island is excluded, as it is no longer operational.

Sources: United Nations 2022; Climateworks Centre and Climate KIC-Australia 2023.

Ammonia is one of the key ingredients in modern fertilisers. Ammonia binds air-borne nitrogen, making it available in fertiliser production. Ammonia can be applied directly to the soil as a liquid fertiliser, but is more commonly used as the base material for fertilisers such as urea, ammonium phosphate, ammonium nitrate and ammonium sulphate. In Australia, many facilities produce ammonia in order to manufacture ammonium nitrate for use as an explosive in the mining and quarrying industries.

Ammonia is a toxic, colourless gas with a pungent odour. It can be condensed easily under pressure -10°C (or at -34°C), and is soluble in water. Ammonia is transported and stored as a pressurised, liquified gas. Aside from its uses in fertilisers and explosives, ammonia is used widely in other applications. Chemicals produced from ammonia include cyanides, nitric acid, hydrazine, and amino acids. Ammonia (and chemical compounds derived from it) are used in the manufacture of many products including synthetic fibres, dyes, pesticides, industrial and household cleaners and disinfectants, plastics, resins, medicines, fuel cells, rocket fuel and in metal treating operations. Ammonia was once widely used as a refrigerant, and can be used to purify water supplies.

In Australia, ammonia is produced in Western Australia, New South Wales and Queensland. In Western Australia the main producers of ammonia and its derivatives are CSBP and Yara Pilbara Fertilisers. The Yara Pilbara Fertilisers plant, located on the Burrup Peninsula in Western Australia, is one of the largest ammonia production sites in the world, producing an average 840,000 tonnes of ammonia annually. This equates to around five percent of the global market and half of Australia's production (Climateworks and Climate-KIC 2022b). Some of this ammonia is exported to domestic and global

markets from the Port of Dampier – mainly for use in fertilisers – and some is converted into ammonium nitrate. Also in Western Australia, CSBP operates an ammonia plant in Kwinana, with capacity to produce up to 255,000 tonnes of ammonia per annum. Much of the ammonia is used internally in CSBP's ammonium nitrate, sodium cyanide and fertiliser businesses.

In NSW, approximately 360,000 tonnes of ammonia and 400,000 tonnes of ammonium nitrate are produced each year on Kooragang Island in Newcastle. This represents around 20 percent of domestic production of ammonia. In Queensland, Orica produces ammonium nitrate at its Yarwun Nitrates facility in Gladstone, using imported ammonia and nitric acid produced on-site. Queensland Nitrates operate a fully integrated ammonium nitrate facility near

Figures 24 and 25: Yara Pilbara Fertilisers Plant, located on the Burrup Peninsula in Western Australia, is one of the largest ammonia production sites in the world.

Moura in Central Queensland, and Incitec Pivot produce ammonia at two facilities: Moranbah and Phosphate Hill. Phosphate Hill manufactures around 975,000 tonnes of ammonium phosphate per year, using its own ammonia, phosphoric acid and granulation plants, and its own phosphate mine. Incitec Pivot's ammonia facility at Gibson Island was recently shut down (at the end of 2022) due to an inability to source affordable gas for production. Fortescue Future Industries and Incitec Pivot are investigating the development of a large-scale renewable hydrogen facility to support the conversion of the Gibson Island ammonia facility to run on renewable hydrogen instead of gas.

3.3.2 CONVENTIONAL PRODUCTION PROCESS

Ammonia is produced through a chemical reaction between hydrogen and nitrogen. The most common method uses gas, water and air to produce ammonia. To obtain the hydrogen, gas (methane CH_4) is used as a feedstock in a process called methane steam reforming. In this process, methane and steam are heated to around 1,000°C and pressurised inside a reformer containing a nickel catalyst, causing the methane to separate into hydrogen and carbon monoxide (the carbon monoxide is later converted into carbon dioxide). The Haber-Bosch process is then used to react hydrogen with nitrogen to produce ammonia (NH_3) (see Figure 26).

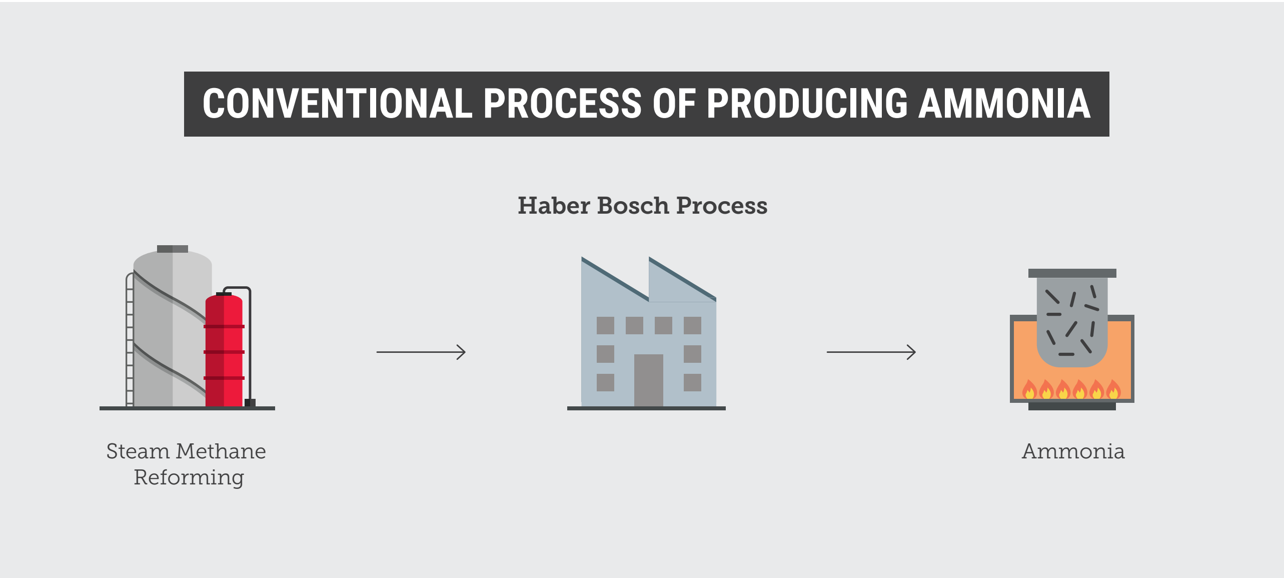


Figure 26: Conventional process of producing ammonia[3] **Source:** Adapted from Climateworks and Climate-KIC 2023.

3.3.3 EMISSIONS

For every tonne of ammonia produced, around 35 GJ of energy is consumed and around 1.87 tonnes of CO_2e is produced (Climateworks and Climate-KIC 2022b). Approximately 90 percent of the CO_2 produced in ammonia production is from the methane steam reforming process. In 2020-21, facilities covered by the Safeguard Mechanism that produced ammonia reported 4.7 Mt CO_2e (Clean Energy Regulator 2022b). This is equivalent to around one percent of Australia's total emissions in 2022. Whilst this may seem small, it is roughly equivalent to the emissions from domestic aviation (DCCEEW 2023a). The production of ammonia and ammonium nitrate in the Pilbara alone generated around 1.5 Mt CO_2e in 2020-21 (Clean Energy Regulator 2022). Globally, ammonia production accounts for around 1.8 percent of emissions (The Royal Society 2020). Ammonium nitrate is made by reacting ammonia with nitric acid. In this reaction, nitrous oxides are released, accounting for an additional 0.25 tonnes of CO_2e per tonne of ammonium nitrate that is produced (Climateworks and Climate-KIC 2022b).

Decarbonising ammonia and ammonium nitrate is a key step toward decarbonising chemical production in Australia. Green ammonia also offers significant export opportunities in conjunction with renewable hydrogen. Green ammonia could reduce emissions in other industrial processes, is a way for hydrogen to be transported as it doesn't need to be stored at low temperatures and pressures, and has potential for large-scale use in the shipping industry. All of these are opportunities that a scaled-up green ammonia industry in Australia could capitalise on.

Creating green ammonia with renewable hydrogen demonstrates that it is possible to maintain and grow our chemicals industry, while simultaneously ending its reliance on fossil fuels.

3.3.4 AMMONIA SOLUTIONS

Conventional ammonia production uses fossil fuels at various stages, and most ammonia plants use gas as both a feedstock and a fuel. So there are multiple opportunities to lower emissions for ammonia production by using renewable energy instead throughout the production process.

The conventional process to create ammonia requires two gas streams to react together at high temperatures — one hydrogen and one nitrogen. These then become 'fixed' to produce ammonia. This process of converting hydrogen and nitrogen into ammonia can be decarbonised if both the feedstock and fuel are switched to renewable hydrogen.

BOX 8: TWO-STEP GREEN AMMONIA PRODUCTION

HYDROGEN PRODUCTION

Renewable hydrogen can be created using an electrolyser, which requires only water and a renewable energy source — such as wind or solar power — to create the hydrogen (Suryanto et al. 2021; Du et al. 2022). This technique for producing zero emissions hydrogen to use as a feedstock is already being tested at the Yara ammonia plant in Karratha, Western Australia (Yara 2022).

Using renewable hydrogen as the feedstock can cut emissions within the manufacturing process, by eliminating one fossil fuel input. It is important to note that not all hydrogen is zero emissions. Hydrogen produced using gas — so-called 'blue' hydrogen — still causes significant emissions. If this type of hydrogen is used in the production process for ammonia, it won't sufficiently lower emissions.

NITROGEN PRODUCTION

For the nitrogen side of the reaction, researchers from Monash University/Jupiter Ionics are investigating how the nitrogen reaction process can be decarbonised. Using specially designed catalytic electrodes powered by renewable energy, ammonia can be made electrochemically — an electrical current that catalyses a chemical reaction — rather than relying on fossil fuels to create the reaction.

Using their patented 'Macfarlane Simonov Ammonia Cell', nitrogen and water are fed into each side of the cell respectively. Hydrogen is stripped off the water, then transported across the cell where they are combined with the nitrogen atoms to form ammonia. When the energy required to drive the reaction is sourced from renewable energy, the resultant ammonia is carbon-free.

This process is similar to the electrolysis used for renewable hydrogen production (Suryanto et al. 2021), and represents a significant technology shift that vastly reduces the amount of electrical energy required to create ammonia. The researchers estimate that this technology could be commercially available as soon as 2025 (MacFarlane 2021).

Replacing methane with the two combined strategies above can enable carbon-free ammonia synthesis. The result would be lower emissions, improved operational efficiency, and substantial cost reduction in ammonia manufacturing. There has been a significant break-through in this research, and this new process of producing 'green' ammonia has the potential to make fossil fuel use in the existing process — and in ammonia production more generally — obsolete. Using the example of Monash University researchers, this process could be commercially scalable within five years.

Ammonia also assists with the transport of hydrogen. To transport hydrogen, it needs to be liquified (achieved at temperatures below -253°C), whereas ammonia can be liquified at -34°C, or at -10°C with a small amount of pressure. The ammonia can be shipped then converted back to hydrogen when needed. These transport requirements for hydrogen are significant roadblocks for exporting hydrogen, however, ammonia solves this problem in its capacity as an 'energy carrier'. Ammonia can act as the intermediary in the energy supply chain, by being transported as a liquid then converted into hydrogen for end-use applications. Using green ammonia in this context has added downstream benefits of lower carbon operations for other industries. Global demand for Australian hydrogen could be over three million tonnes annually by 2040, worth up to $10 billion each year, and Australia has already signed an agreement with Japan to begin these dual renewable exports (ACIL Allen Consulting 2018; ARENA 2022c). Using ammonia as a source of on-demand hydrogen has significant benefits, and represents a new green energy export (MacFarlane 2021).

Green ammonia also has potential as a fuel source. Ammonia can replace fossil fuels such as diesel in combustion engines in vehicles with only minor adjustments, and has potential for use on a larger scale for the shipping industry. Ammonia can be transported in a liquid state, and can be converted back into hydrogen. Ammonia is a key enabler for exporting renewable energy, it can be transported to power plants to generate emissions-free electricity, and it can be split or 'cracked' into hydrogen gas to be used in fuel cell vehicles. In Gladstone, Queensland, for example, plans are underway to create an ammonia export terminal (see Box 9).

BOX 9: THE HYDROGEN UTILITY (H2U) AND ORICA – RENEWABLE HYDROGEN AND GREEN AMMONIA PRODUCTION, GLADSTONE

The Hydrogen Utility (H2U), an Australian-based developer of hydrogen infrastructure, is proposing a large-scale chemical complex at Yarwun in Gladstone, Queensland, for the production of renewable hydrogen and ammonia. In April 2022, Orica and H2U announced a strategic partnership to support initiation of the first phase of the proposed project (Orica 2022).

The proposed development will be constructed in stages to integrate up to 3 gigawatts (GW) in electrolyser capacity for hydrogen production and up to 5,000 tonnes per day in ammonia production capacity. It is expected that the proposed facility would be supplied solely by renewable energy from new-build solar and wind resources in Queensland.

The master plan is expected to take approximately six months, with construction scheduled to commence in 2023. The facility will be co-located with existing ammonia storage and export/import facilities at the Port of Gladstone. The project is awaiting state government approval; pending the environmental impact statement process.

Figure 27: The H2-Hub™ Gladstone Project (planned for the Port of Gladstone, pictured) is one of two near-term developments by H2U. The Eyre Peninsula Gateway project in South Australia is also in the pipeline.

Green ammonia has significant potential, not only for fertilisers but also for a wide variety of uses in other industrial settings. In particular, chemicals and fertilisers are important for Australia's agricultural sector.

Green ammonia production highlights one of the important opportunities for renewable hydrogen, and underlines the importance of scaling up our overall renewable energy generation capacity. This allows Australia to continue producing the clean energy needed to make renewable hydrogen at scale, and opens up new export opportunities.

We know how to make renewable hydrogen — it is a tried and tested solution, and we now need to rapidly scale up its production. Transforming the other half of ammonia's process is also needed and efforts to work out how should continue, but companies can get on with cutting emissions today by switching to renewable hydrogen as quickly as possible.

Australia needs to rapidly scale up its renewable energy production, including renewable hydrogen. We know how to make it, and it is the key to unlocking decarbonised industrial processes.

3.4 Non-fossil fuel mining

3.4.1 NON-FOSSIL FUEL MINING IN AUSTRALIA TODAY

Economic value (export revenue) (2021-22, AUD)	Iron ore: $153 billion Bauxite: $1.2 billion Copper, nickel, lithium and zinc: $19.6 billion
Number of Australians employed	Metal ore mining: 124,900 Construction material mining: 8,500 Non-metallic mineral mining and quarrying: 4,300 Mining support services: 47,500* Exploration: 23,300*
Total annual production volumes	Iron ore: 913 million tonnes Bauxite: 10 million tonnes Copper, nickel, lithium and zinc: 2.6 million tonnes
Total annual emissions (Mt CO_2e)	13.5 million tonnes

*Figures include exploration and support services for coal and gas extraction

Sources: ABS 2022; Department of Industry, Science and Resources 2022b; Climateworks Centre and Climate KIC-Australia 2023.

Australia has an abundance of minerals and mineral sands underground. The reserves beneath our feet of minerals like gold, iron ore, lead, nickel, rutile, silver, tantalum, zinc and zircon are believed to be the largest in the world. We are also ranked in the top five for a wide range of other commodities including: antimony, bauxite, cobalt, copper, diamond, ilmenite, lithium, magnesite, manganese ore, niobium, tin, tungsten and vanadium (Geoscience Australia 2023a).

Iron ore is one of the most important commodities that Australia produces, both in terms of volume mined, and export revenue. Iron ore is Australia's largest source of export revenue, worth $133 billion in 2021-22 (Minerals Council of Australia 2023). There are 29 iron ore mines in Australia, with 97 percent of Australia's iron ore mined in Western Australia.

Another significant mineral commodity is bauxite, which is the primary raw ingredient for aluminium (see section 3.2 above). Australia is the world's largest producer of bauxite, mining more than 100 Mt per year, which is roughly a quarter of global production (Australian Aluminium Council 2022a). Bauxite is mostly mined in Queensland, Western Australia and the Northern Territory, with six main mines around the country supplying feedstock for local alumina refineries, as well as for export. Around 40 percent of the bauxite we produce is exported (Australian Aluminium 2022a).

3.4.2 CONVENTIONAL PRODUCTION PROCESS

All of the major Australian iron ore mines and bauxite mines are surface (open cut) mines. The process of open cut mining involves a number of steps including removing overburden, drilling and/or blasting to break rock, excavation, loading and hauling ore to a processing area and removing overburden and waste rocks from the mine site.

Conveyors are used to transport ores, concentrates and tailings across different stages of the mining cycle and to transport ore to processing plants and materials to stockpiles. Crushing and grinding raw materials into smaller sizes are part of the processing stage of mining, as is beneficiation (treatment of ore to further concentrate minerals).

Australia is rich in minerals. We provide over a third of the world's iron ore, and over a quarter of the world's bauxite, as well as many other minerals critical for the clean energy transition.

3.4.3 EMISSIONS

For a typical iron ore mine, around 56 percent of emissions come from diesel use in haulage trucks (31 percent), loading (14 percent), drilling (four percent), other equipment (5 percent) and blasting (two percent). Another 37 percent of total emissions is from electricity use at mine sites for conveying, crushing and grinding and beneficiation – processes that separate and remove low-value materials from the valuable mineral ore (McKinsey and Company 2021) (see Figure 28).

The Scope 1 emissions from metal ore mining and quarrying (e.g. gravel and sand) are around 13.5 Mt CO_2e, accounting for 2.7 percent of Australia's total emissions, or around 13.3 percent of mining-related emissions. The rest of mining-related emissions are from coal mining and gas extraction (DCCEEW 2023). Globally, around 40-50 percent of emissions in metal ore mining are 'Scope 1', and around 30-35 percent of emissions are 'Scope 2 – from use of non-renewable electricity on mine sites (McKinsey and Company 2021). The emissions intensity of mines varies widely depending on the type of mine, and its location (McKinsey and Company 2021).

ADDRESSING EMISSIONS FROM MULTIPLE SOURCES IS KEY TO THE DECARBONISATION OF MINING

Example, %: Iron ore; open pit; Australia; Run of mine: 25 Mt per annum

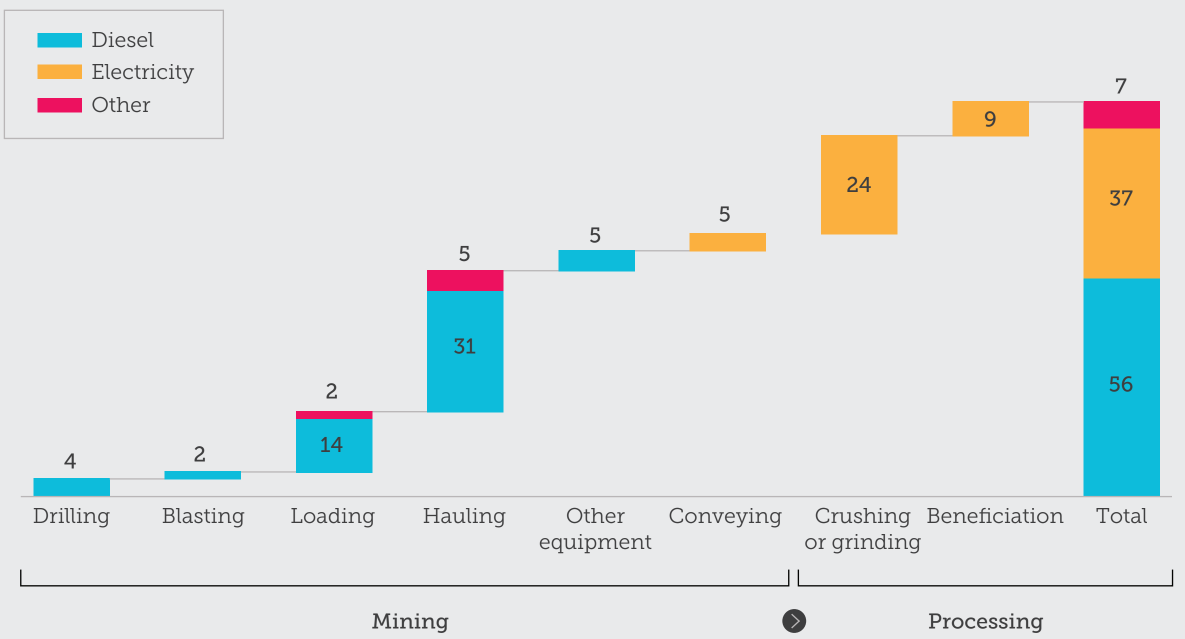


Figure 28: Emissions breakdown from a typical iron ore mine. **Source:** McKinsey and Company (2021).

As new mining facilities start up to unlock Australia's vast reserves of critical minerals — such as lithium and copper — these should be set up with a far lower carbon footprint than yesterday's.

Many of the minerals that Australia mines will be critical in efforts to decarbonise the world, because of their importance in manufacturing everything from solar panels to batteries to wind turbines. Furthermore, as Australia's trading partners and other major economies decarbonise their own industries, there will be increasing demand around the world for low- and zero-emission raw inputs in order to fully decarbonise value chains (see discussion below). This means that to protect our traditional export strengths and keep growing new markets in critical minerals, we must embrace opportunities to cut emissions in the mining sector.

3.4.4 NON-FOSSIL FUEL MINING SOLUTIONS

Mining operators have strong – and growing – opportunities to cut emissions from their mines by using cleaner power sources and switching to zero emission vehicles. Mining requires a mixture of solutions to reduce emissions, and many opportunities exist for incremental decarbonisation on the way to low emissions operations. Electrification, increasing uptake of renewable energy, and using zero-emission transport collectively provides significant emissions reduction opportunities in this sector. When combined with more sustainable practices and efficient operations, as well as circular economy approaches — such as using secondary raw materials — there are many opportunities for mine sites to be less emissions-intensive, with facilities in Australia and abroad already taking many of these steps.

Fuel-switching and zero-emissions transport

Electrifying transportation and equipment can significantly lower mining emissions. Phasing out diesel in favour of hydrogen or electric battery trucks, using electric, battery or renewable ammonia-powered trains, and electrifying equipment such as drill rigs and excavators will significantly lower direct emissions. Further research and development into long-term solutions for other equipment, such as drivetrains, is needed.

There are multiple opportunities for mining facilities to reduce greenhouse gas emissions, as well as advantages. Australia has significant exports relating to raw materials and metals, such as iron ore, gold, and lead. As the demand for lower-carbon products continues to increase, opportunities will exist for low to no carbon raw materials as well as final end products. Decarbonising the production of raw materials such as iron ore, which can then be processed into a 'green' end product such as steel, illustrates the potential of decarbonising the value chain of this product, and many others. In doing so, there are advantages for 'first movers', and Australia can maintain its dominance in exporting minerals in a decarbonising world.

Electrification and renewables uptake

Switching to renewable sources of electricity could substantially reduce emissions in non-fossil fuel mining. There are multiple options, depending on grid connectivity. Mining sites connected to the grid can buy renewable energy as their source of electricity. Facilities that are not connected to the grid can and are installing on-site renewable electricity generation and storage, such as solar panels and batteries.

Some mines are moving towards 100 percent electrification, allowing for significant uptake in renewable energy, such as the Newmont Goldcorp Borden gold mine in Canada. The mine has been electrified and their entire underground fleet uses electricity and batteries, with 70% of demand met with on-site renewable energy. Others have been connecting on-site solar farms to provide their own on-demand renewable electricity. For example, Pilbara Minerals have built and connected a Contract Power six megawatt solar farm to their lithium extraction operations in Western Australia (Ballard 2021), and Rio Tinto's Gudai-Darri iron ore mine is building an 83,000 solar panel farm which has the capacity to provide a third of the mine site's energy needs (Rio Tinto 2022). Establishing renewable generation at, or dedicated to, mine sites provides zero-emissions electricity, which is an important step on the path to decarbonising the mining industry.

BOX 10: FORTESCUE METALS GROUP

Fortescue Metals Group (Fortescue) has announced its heavy industry decarbonisation plan, which seeks to eliminate fossil fuel use and eliminate Scope 1 and 2 emissions (excluding Scope 1 shipping emissions) for its iron ore operations by 2030. Fortescue has said that by implementing this strategy, at maturity, the company will avoid three million tonnes of CO_2e emissions annually, by eliminating diesel, natural gas, and the purchase of carbon offsets in the form of Australian Carbon Credit Units (ACCUs) in its iron ore supply chain (Fortescue Metals Group 2022).

Figure 29: A subsidiary of Fortescue Metals, Fortescue Future industries is a global green energy company committed to producing green hydrogen.

BOX 11: FUEL-SWITCHING CASE STUDIES

Partnering with First Mode, Anglo American has released a prototype of a zero-emissions hydrogen-powered mine haul truck, the largest in the world. It features an integrated system, and all fuelling and haulage, as well as renewable hydrogen production. It will be initially used at the mine site in South Africa (Anglo American 2022), before being rolled out to approximately 400 ultra-class haul trucks. This is significant as traditional diesel-run haul trucks represent approximately 31 percent of emissions for mining; switching to a zero-emissions model powered by renewable hydrogen will allow for substantial emissions reduction for this site.

Figure 30: Partnering with First Mode, Anglo American's nuGen™ Zero Emission Haulage Solution was first launched in South Africa in May 2022 and $200 million has been invested to accelerate the vehicle's development and commercialisation.

3.5 Concrete and cement

3.5.1 CEMENT MANUFACTURING IN AUSTRALIA TODAY

Economic value (2021-22, AUD)	$2.3 billion. The broader cement, concrete and aggregate sector generates annual revenue of $15 billion.
Number of Australians employed	1,288 directly (in five integrated clinker and cement manufacturing plants). The broader cement, concrete and aggregate sector employs 30,000 people directly, and a further 80,000 indirect jobs.
Total annual production volumes (2020-21)	5.26 million tonnes of clinker and 9.6 million tonnes of cement in 2020-21.
Total annual emissions (CO_2e)	4.7 million tonnes.

Sources: CCAA 2022, CIF 2022.

Concrete is one of the most used materials on earth – second only to water – and cement is the 'glue' that binds it, making up around 12 percent of the concrete mixture, alongside aggregates such as sand and gravel (CIF 2022; VDZ 2022). There are many different types of cement, which are used for different construction purposes. The most common type of cement is called 'Portland cement'.

There are five integrated cement plants in Australia (see Figure 31), which make clinker and cement as a continuous process. Together, these produce around 60 percent of the cement manufactured domestically. The remaining 40 percent is manufactured with the use of imported clinker that is made into cement at grinding facilities located around Australia (VDZ 2022). In 2020-21 5.6 million tonnes of clinker were produced in Australia, and 9.6 million tonnes of cement (CIF 2022).

The cement and concrete industry in Australia is domestically focused, with the majority of cement used locally for building, infrastructure and other construction uses. Some cement (equivalent to around 5-10 percent of domestic production) is also imported directly into Australia.

Figure 31: Location of integrated cement manufacturing plants in Australia. **Source:** CIF 2022.

3.5.2 CONVENTIONAL PRODUCTION PROCESS

Portland cement is made by heating limestone and other minerals to temperatures of around 1,450°C in a rotating kiln to make a substance called clinker. Clinker is then sent to a grinding mill, where it is blended with gypsum and other materials – depending on the type of cement required (see Figure 32).

3.5.3 EMISSIONS

The chemical process of heating limestone to very high temperatures releases large amounts of CO_2 as a byproduct. Like coal, limestone is a material that was formed over millions of years from organic matter, and exposing it to high temperatures causes the carbon that was trapped in it to be released. This chemical process accounted for 60 percent of the sector's emissions in 2020-21, or around 2.8 Mt CO_2 (CIF 2022), while those from burning fossil fuels to generate the required heat (around 1,400°C-1,500°C) accounted for around 28 percent. In addition, emissions are generated from the use of electricity, which is needed to grind the clinker to make cement. These amounted to around 12 percent of the

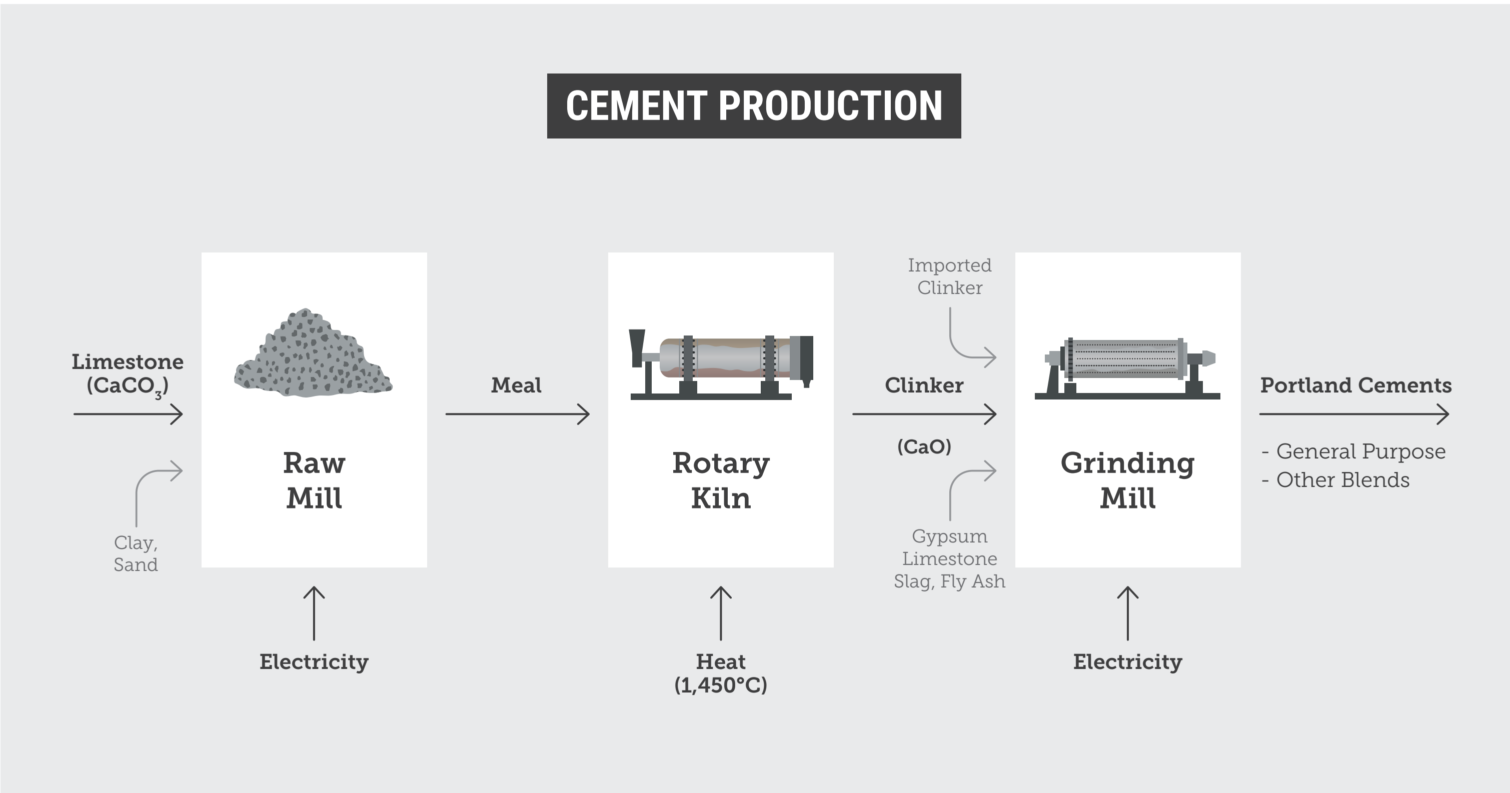


Figure 32: Process diagram for cement production. **Source:** CIF 2022.

sector's emissions in 2020-21 (see Figure 33) (CIF 2022). Overall, the emissions from integrated clinker and cement production in Australia were 4.7 Mt of CO_2-e in 2020-21 (CIF 2022), which is approximately one percent of Australia's total emissions.

As with other construction materials like steel, there is a growing recognition of the 'embedded carbon' contained within our homes, commercial buildings and infrastructure projects because of the construction industry's reliance on emissions-intensive concrete. This is sparking interest both in alternative building methods – which reduce the use of concrete overall – and new production processes that reduce the emissions from cement and concrete production.

While Australian operations only account for a relatively small proportion of global cement and concrete production, working to decarbonise cement production – through innovation and pioneering new technologies and processes – can play a significant part in driving down not only Australia's emissions but also global efforts to decarbonise this highly emissions-intensive industry. There are already promising signs that this critical industry can end its reliance on fossil fuels, and the industry should continue to capitalise on the opportunities presented by green concrete.

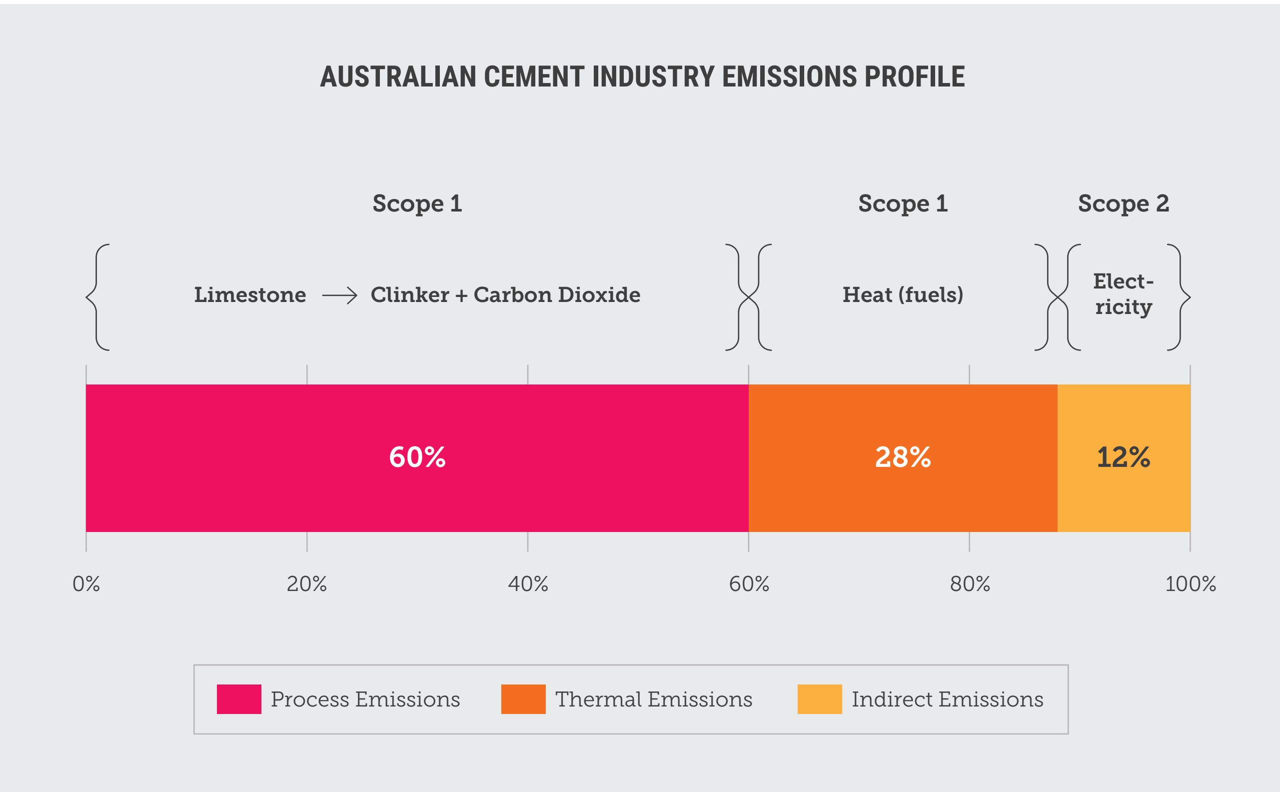


Figure 33: Australian cement industry emissions profile. **Source:** CIF (2022).

3.5.4 CEMENT SOLUTIONS

The cement industry is considered one of the hardest-to-abate sectors (ETC 2018; Watari et al. 2022), with pathways towards its full decarbonisation still requiring further research and development. Limestone, a key ingredient in Portland cement, has been compared with coal for its global warming potential (Beyond Zero Emissions 2017). However, there are promising signs of the technology shifts needed to reduce emissions. There are also opportunities to make the production process less emissions-intensive, including less concrete generally, while progress continues towards full decarbonisation.

Supplementing clinker

Cementitious materials are materials that behave like cement, and can supplement a portion of clinker (Cement Industry Federation 2022). Clay and waste materials such as furnace slag — a waste product from steelmaking — and fly ash — a waste product of coal-fired power — can supplement clinker, known as mineral addition. Australia currently limits the amount of mineral addition in Portland cement to 7.5 percent of the total content. However, the latest research suggests this limit could be increased to 12 percent, which would reduce cement industry carbon emissions by approximately 250,000 tonnes annually, or 5 percent (Cement Industry Federation n.d.). Whilst fly ash can be added as a beneficial supplement in Portland cement as an intermediate step to reduce emissions, there is a limit to this as an additive. This is why geopolymer concrete (discussed below) offers a greater decarbonisation opportunity, as it replaces the emissions-intensive components of traditional cement.

Geopolymer concrete

As noted, the most emissions-intensive aspect of cement production is when limestone ($CaCO_3$) is heated in the kiln. This process, known as 'calcination', creates quicklime (CaO), which produces CO_2 as a by-product and accounts for more than half of the emissions in cement making. New alternatives to limestone are emerging, offering an opportunity to reduce process emissions.

For example, geopolymer concrete is an emerging and promising alternative. Geopolymer concrete does not use Portland cement based on emissions-intensive limestone. Instead, it uses waste material to create a replacement binder. By avoiding the calcination of limestone, geopolymer concrete can be produced with far fewer emissions. Additionally, geopolymer concrete is more sustainable than Portland cement, as waste products from other manufacturing processes can be used in this process (Farooq et al. 2021). Waste products such as fly ash or furnace slag are mixed with sand and construction aggregate, then activated with an akali, such as sodium hydroxide (see Figure 34). These types of concrete are already being used in Australia for major infrastructure projects such as the Wellcamp Airport (see below) in southeast Queensland (CIES UNSW 2015; Glasby et al. 2015).

As Australia transitions away from the use of fossil fuels such as coal, fly ash will become less readily available. Therefore, more research and development is needed to move towards clay-based concrete. Research and trials into clay-based concrete will need to be scaled up as Australia reduces its fossil fuel use.

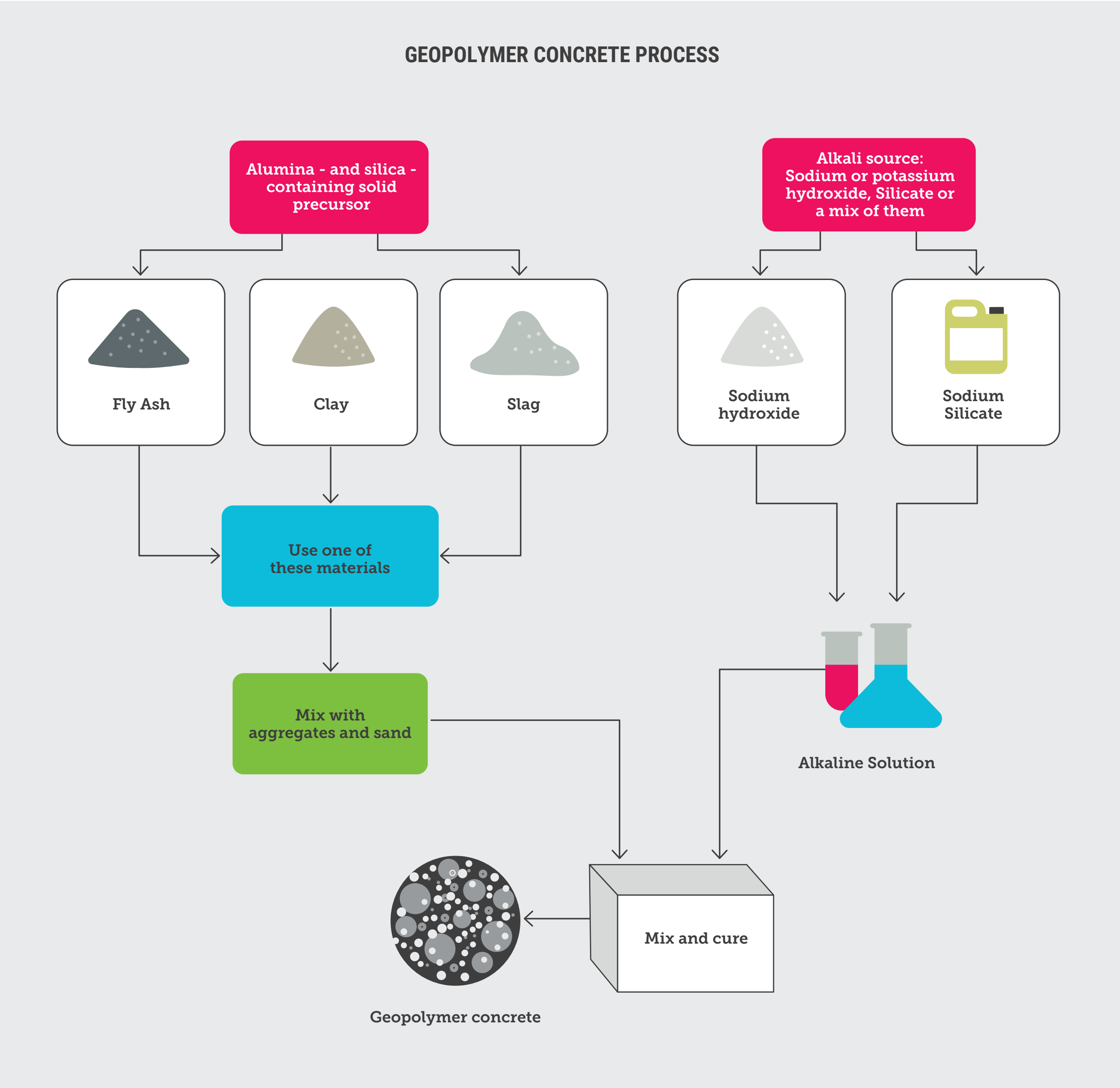


Figure 34: Australian cement industry emissions profile. **Source:** CIF (2022).

Decarbonising electricity and transport

Decarbonisation of the electricity grid and transport can contribute to lower emissions across many sectors. While electrification and fuel-switching alone is insufficient to reduce all industrial emissions, this will lead to incremental drops in emissions and is an important piece of the decarbonisation puzzle.

There have been numerous trials to electrify and use renewable energy as a fuel source to fire cement kilns. One successful trial has been the result of a partnership between CEMEX and Synhelion, where they created clinker using only solar energy (CEMEX 2022). With cement kilns operating at approximately 1,500°C, the heat needed to create clinker was previously thought to be too high for renewable energy. Excitingly, the Synhelion technology has produced clinker by concentrating solar power to generate industrial heat exceeding 1,500°C. Breakthroughs such as these, once commercially scalable, have the potential to deliver a step-change for multiple industrial processes that require very high heat — including producing clinker.

Concrete is the foundation upon which much of our modern world is built, and it will continue to be an important construction material for years to come. While we can alter and reduce the amount of concrete we use, this will only cut emissions so far. It is essential to avoid emissions in the first instance. These trials show that concrete can be produced without fossil fuels, and it is essential to keep driving progress in research, and technical trials in order to produce zero emissions concrete.

BOX 12: WELLCAMP AIRPORT

Wellcamp Airport, located outside of Toowoomba in southeast Queensland, has been touted as the world's greenest airport (Geopolymer Institute 2014). This is due to significant uptake in geopolymer concrete in the construction process created by the company Wagners.

The project used more than 40,000 cubic metres (100,000 tonnes) of their low carbon concrete; avoiding approximately 6,600 tonnes of emissions (Geopolymer Institute 2014; Glasby et al. 2015). Wagners' 'Earth Friendly Concrete' contains no cement, and saves approximately 250kg of CO_2 per cubic metre poured (Wagners 2023).

This is another great example of Queensland's zero emissions transformation – not just in heavy industry, but in the built environment as well.

Figure 35: The Toowoomba Wellcamp Airport provides interstate, intrastate and international connectivity for the Darling Downs, Granite Belt, Surat Basin and Southern Downs regions. Construction on the airport began in 2012 and has been operational since 2014.

4. Driving industrial decarbonisation: the Safeguard Mechanism

Australia cannot meet — or improve on — our legislated emissions reduction target and tackle harmful climate change if our biggest emitters do not pull their weight.

The Safeguard Mechanism regulates carbon pollution from Australia's 215 biggest industrial emitters, which together produce around 28 percent of our country's total emissions. This includes industrial facilities in the sectors profiled in this report, as well as large coal, oil and gas facilities.[3]

Strengthening the Safeguard Mechanism is a key part of the Federal Labor Government's plans to cut harmful greenhouse gas emissions this decade. If we get this reform right, it can incentivise the transformation of key Australian industries to thrive in a world where net zero is standard business. However, if we get it wrong it will result in Australia's biggest emitters operating on a pollution as usual basis, putting Australian businesses at an economic disadvantage globally, and putting a safer climate out of reach.

Figure 36: The Safeguard Mechanism came into effect on 1 July 2016. The Federal Government is currently undergoing a process of reforming the policy and how we regulate the country's top polluters.

3 For more information on the major fossil fuel emitters regulated by the Safeguard Mechanism see *Introducing the Dirty Dozen: Australia's filthiest fossil fuel polluters* — Climate Council, 2023. Available at: https://www.climatecouncil.org.au/wp-content/uploads/2023/02/Climate-Council-Report-Introducing-the-Dirty-Dozen-Feb-2023-1.pdf

4.1 How does the Safeguard Mechanism work?

The Safeguard Mechanism regulates carbon pollution from Australia's 215 biggest industrial emitters, which together produce around 28 percent of our country's total emissions. This includes industrial facilities in the sectors profiled in this report, as well as large coal, oil and gas facilities.

Each facility within the Safeguard Mechanism is set a baseline for their emissions. A 'Safeguard facility' must keep its net emissions at or below its baseline. These baselines on Scope 1 CO_2e emissions are designed to 'safeguard' any emissions offsets made through the Emissions Reductions Fund. When the framework was established under the former government, these baselines were caps above which emissions were not supposed to rise. In reality, companies often breached these caps and the former government simply let them adjust these baselines higher without any penalty for breaching them (Climate Council 2023b).

Now, the Australian Government is proposing to set new emission baselines for all companies covered by the Safeguard Mechanism, and then reduce these baselines each year by approximately five percent until Australia reaches net zero. Companies that breach their baseline in any year are proposed to be allowed to buy offsets – that is, pay for emission cuts that have been delivered elsewhere – to make up the difference. Companies that reduce emissions below their baseline will receive credits, which they can sell to those other companies. The Australian Government is proposing to provide $600 million in dedicated funding to support industrial facilities to transform their operations to cut emissions in line with their declining baselines.

Government regulations, like the Safeguard Mechanism, are in place in a range of other countries and trading markets. Such an approach has been successful in driving down industrial emissions by incentivising companies to invest in technologies or cleaner production processes. In order to provide this incentive for Australia's biggest industrial emitters, the new rules need to be well designed.

4.2 Getting the Safeguard Mechanism right

There are several key settings that should be prioritised to ensure the Safeguard Mechanism delivers genuine emissions reductions we need now to transform Australian industry while tackling harmful climate change.

Recommendation 1:

Prioritise genuine emissions reductions

The Safeguard Mechanism must send a strong signal to our biggest emitters that their operations should be transformed to deliver genuine emissions reductions. If corporations are allowed to buy unlimited carbon offsets while continuing to pollute as usual, this will not incentivise real improvements in technology, fuel sources and processes. The products our industries create will soon become outdated and unwanted as our major trading partners move towards net zero.

BOX 13: WHAT ARE CARBON OFFSETS?

Carbon offsets are used by a company or organisation to compensate for what they are emitting, and are claimed as a decrease against their "net emissions". Offsetting involves purchasing carbon credits. Typically, one credit permits the emission of one tonne of 'carbon dioxide equivalent' (a combined measure of the warming potential of various greenhouse gases).

Right now, many big emitters are buying offsets so that they can continue to pollute as usual. Offsetting has become the first and too often the only thing businesses are doing when it comes to climate action. These reductions might look good on paper or in advertising, but do not result in the genuine emissions reduction we need to protect the people and places we love from harmful climate change.

Carbon offsets should only be used as a last resort, for the minor amount of emissions that cannot be immediately avoided by making changes in the way we use energy, transport goods or decarbonise production (Climate Council 2023a). Offsets are no substitute for genuine emissions reductions, and unfettered use of offsets in the Safeguard Mechanism would very likely fail to reduce emissions (Climate Analytics 2023).

As explored in this report, Australia's key industries have different decarbonisation pathways and different opportunities to update technology or fuel switching today. Carbon offsets will only be needed in limited circumstances and industries in which it is not yet possible for facilities to fully avoid or reduce their emissions. Paying for carbon offsets is not a long-term or genuine solution to tackling climate change, and businesses should focus on every other option available first. If designed well, the Safeguard Mechanism can put the right incentives in place by limiting the use of offsets and ensuring facilities demonstrate genuine efforts to permanently cut their emissions.

Recommendation 2:

Don't disadvantage key domestic industries

There are more than 100 new coal and gas projects in the development pipeline in Australia. Those likely to proceed this decade could generate enough emissions in 2030 for the coal and gas sector to exceed the Safeguard Mechanism's entire emissions budget (Energy Resource Insights 2022). If built, many of these projects are expected to emit more than 100,000 tonnes of CO_2 each year, and the Australian Government is assuming they will be regulated by the Safeguard Mechanism as they begin operating.

Every new, highly-polluting entrant to the Safeguard Mechanism will add to the scheme's overall emissions profile and make achieving Australia's national emissions reduction targets more difficult — or even impossible.

This is particularly true for fossil fuel projects. Global expert consensus is clear that any new coal or gas projects are incompatible with having any chance of avoiding the worst climate impacts (Climate Council 2021b; IEA 2021a). Any new coal or gas project puts a safe climate at risk, and Australia's proposed pipeline of new coal and gas facilities threatens to add a gigantic amount of additional emissions into the Safeguard Mechanism. This will force existing facilities — including those in the key industry sectors profiled in this report — to work even harder to ensure emissions captured under the scheme continue to reduce each year as intended.

The Safeguard Mechanism should prioritise the transformation of industries which have a long-term future in a net zero world, and support them to keep thriving. Burdening them with the emissions of new fossil fuel entrants would make this difficult.

Recommendation 3:

Direct industry support where it is needed most

Transforming Australia's heavy industries will require significant new investment — from financial markets, private capital and government co-investment. The Australian Government has established a dedicated funding pool to support businesses in the Safeguard Mechanism to undertake technology trials, buy new equipment and update their facilities to cut emissions. Companies will also be able to apply for other support — like slower baseline decline rates — if they can demonstrate that they will be significantly affected by the new Safeguard Mechanism settings.

These industry supports should only be provided to sectors which can continue to thrive as the world decarbonises. This means prioritising key sectors like steel, aluminium, cement and chemicals rather than subsidising harmful fossil fuels or propping up industries that have no long-term future in a decarbonised world.

Emerging industries that will support the world's clean energy transformation – like critical minerals mining – should also be prioritised for support over polluting fossil fuels. Australians made it clear at the last federal election that they want to see much stronger climate action at a national level. They expect our national policies to back, and public money to be invested in, industries that will protect our ongoing prosperity, over polluting fossil fuels that are fuelling the climate crisis.

If we get the Safeguard Mechanism right, it can drive the transformation of our key domestic industries. In conjunction with other initiatives to reduce decarbonisation barriers and support investment towards the clean energy and industry transition, the Safeguard Mechanism can result in major cuts to industrial emissions. This will be essential in our shared national effort to tackle harmful climate change, while continuing to grow Australian jobs and prosperity.

The science is clear: new coal and gas is incompatible with a safe future, and Australia should be aiming high and going fast on emissions reductions this decade.

5. Conclusion

Industrial decarbonisation is fundamental to achieving Australia's emissions reduction target and securing our future prosperity in a world rapidly heading to net zero emissions.

In many cases, where solutions already exist, and the focus must be on ensuring these are rapidly scaled to ensure Australian companies don't get left behind in the race to produce green commodities. Where new technologies and processes are required, further investment into research and development will be necessary.

Key opportunities to decarbonise our industries are already available, and many solutions are emerging that will be scalable within the next five to 10 years across all industries. The key opportunities for emissions reduction right now are:

- Replacing polluting coal and gas with clean renewable energy. The biggest opportunities exist in aluminium and mining, but switching to renewable energy can account for significant emissions savings across all sectors considered in this report. More investment is needed to ensure the energy system is decarbonised at the scale needed to fuel industry's transition;
- Process changes and emerging technologies, such as the use of renewable hydrogen to replace polluting gas in chemical processes. This is promising in industries such as ammonia and steelmaking. Capitalising on site-based renewable hydrogen generation to feed into ammonia plants, for example, offers economic and emissions reduction benefits. Other process changes such as creating concrete without the use of limestone reduces harmful emissions in this production process, and has shown potential for a range of uses;
- Switching out diesel trucks and heavy machinery for zero-emission alternatives offer opportunities in the mining sector, and decarbonising mining processes allows for downstream benefits including lower carbon inputs — such as iron ore — for other sectors;
- Ramping up renewable hydrogen production allows for many industrial processes to be decarbonised, but also represents an opportunity in its own right. Australia has abundant resources that allow for the large-scale production and export of renewable hydrogen; and
- Recycling, circularity and efficiency measures play a role in all industries as a way to increase sustainability and reduce emissions incrementally. The biggest opportunities for this relate to steel, aluminium, and concrete, where recycling and efficiency are key.

Figure 37: Alpha HPA (High Purity Aluminium) in Gladstone, is a 10-hectare facility that will be capable of producing 10,000 tonnes of HPA per year.

Australia has to move fast or risk being left behind in the race to a decarbonised global economy. Global demand for green products such as iron, steel, and ammonia is only increasing, and we risk losing out if we delay the transition to lower-emission modes of production. Supporting and protecting the longevity of our industries requires change. We cannot afford to stand still as the rest of the world decarbonises. Heavy industry is a major employer in Australia, especially in our regional communities. We want everyone in Australia, including those living in Queensland, Western Australia and other major industrial hubs to have a bright future. In adapting, and embracing the opportunities that decarbonisation creates they can.

The right government policies — including strong reform of the Safeguard Mechanism — will incentivise Australian companies to accelerate the necessary changes; through deployment of existing technologies and, where necessary, innovating and investing in the development of new solutions.

Given how essential these industries are to Australia's ongoing need for raw and production materials, we must retain our sovereign manufacturing capability and keep making essential things here.

We can help the world decarbonise and grow clean export industries at the same time. Decarbonising industry represents a huge opportunity for Australia to stake our place in global markets for many decades to come as net zero becomes business as usual. We can't afford to miss this opportunity.

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Appendix 1: Safeguard facilities in sectors covered by this report (2020-21)

Facility name	State	Responsible emitter	Reported emissions (Mt)[4]
ALUMINIUM			
Kwinana Alumina Refinery	WA	ALCOA OF AUSTRALIA LIMITED	1.3
Pinjarra Alumina Refinery	WA	ALCOA OF AUSTRALIA LIMITED	1.6
Wagerup Alumina Refinery	WA	ALCOA OF AUSTRALIA LIMITED	1.4
Portland Aluminium Smelter	VIC	ALCOA PORTLAND ALUMINIUM PTY LTD	0.6
Queensland Alumina Limited Refinery	QLD	QUEENSLAND ALUMINA LIMITED	3.3
Bell Bay Smelter	TAS	RIO TINTO ALUMINIUM (BELL BAY) LIMITED	0.4
Boyne Smelters Limited	QLD	RIO TINTO ALUMINIUM LIMITED	0.9
Rio Tinto Yarwun	QLD	RTA YARWUN PTY LTD	2.1
WOR01 Worsley Alumina Refinery/ Mine	WA	SOUTH32 WORSLEY ALUMINA PTY LTD	3.7
Tomago Aluminium Smelter	NSW	TOMAGO ALUMINIUM COMPANY PTY LTD	1.2
SUB-TOTAL			**16.4**

4 These are Scope 1 emissions reported for facilities covered by the Safeguard Mechanism in the 2020-2021 reporting period (Clean Energy Regulator 2022b).

Facility name	State	Responsible emitter	Reported emissions (Mt)
AMMONIA			
CSBP Kwinana Facility	WA	CSBP LIMITED	0.7
Moranbah	QLD	INCITEC PIVOT LIMITED	0.5
Kooragang Island	NSW	ORICA AUSTRALIA PTY LTD	1.0
Yarwun Nitrates	QLD	ORICA AUSTRALIA PTY LTD	0.3
Queensland Nitrates Ammonium Nitrate Plant	QLD	QUEENSLAND NITRATES PTY LTD	0.2
YPF Ammonia Plant	WA	YARA PILBARA FERTILISERS PTY LTD	1.5
Gibson Island	QLD	INCITEC PIVOT LIMITED	0.4
Phosphate Hill	QLD	INCITEC PIVOT LIMITED	0.5
SUB-TOTAL			**5.1**

CEMENT			
Birkenhead Operations	SA	ADBRI LIMITED	0.8
Cockburn Operations	WA	ADBRI LIMITED	1.0
CEM NSW Berrima	NSW	BORAL LIMITED	1.0
Railton	TAS	CEMENT AUSTRALIA (GOLIATH) PTY LTD	1.0
Fisherman's Landing	QLD	CEMENT AUSTRALIA (QUEENSLAND) PTY LTD	1.6
SUB-TOTAL			**5.5**

MINING			
GEM01	NT	GROOTE EYLANDT MINING COMPANY PTY LTD	0.2
Huntly Mine	WA	ALCOA OF AUSTRALIA LIMITED	0.1
Gove Operations	NT	RTA GOVE PTY LIMITED	0.1
Rio Tinto Weipa	QLD	RTA WEIPA PTY LTD	0.2
Mount Isa Mines Copper and Zinc Operations	QLD	MOUNT ISA MINES LIMITED	0.3
Sunrise Dam	WA	ANGLOGOLD ASHANTI AUSTRALIA LIMITED	0.2
Tropicana Gold Mine	WA	ANGLOGOLD ASHANTI AUSTRALIA LIMITED	0.3
Gruyere Mine Site	WA	GRUYERE MINING COMPANY PTY LTD	0.2
Granny Smith Mine Site	WA	GSM MINING COMPANY PTY LTD	0.1

Facility name	State	Responsible emitter	Reported emissions (Mt)
Fimiston	WA	KALGOORLIE CONSOLIDATED GOLD MINES PTY LTD	0.2
Telfer Gold Mine	WA	NEWCREST MINING LIMITED	0.5
Newmont Boddington Gold Operation	WA	NEWMONT BODDINGTON PTY LTD	0.2
Newmont Tanami Operation	NT	NEWMONT TANAMI PTY LTD	0.2
Carosue Dam	WA	NORTHERN STAR (CAROSUE DAM) PTY LTD	0.1
Jundee Gold Mine	WA	NORTHERN STAR RESOURCES LTD	0.1
Duketon South Operations	WA	REGIS RESOURCES LIMITED	0.2
ARC01 Mining Area C — MNG Facility	WA	BHP IRON ORE PTY LTD	0.4
Jimblebar Mine	WA	BHP IRON ORE PTY LTD	0.3
Newman Operations	WA	BHP IRON ORE PTY LTD	0.3
YAN01 Yandi/Marillana Creek Mine — MNG Facility	WA	BHP IRON ORE PTY LTD	0.2
Christmas Creek Mine	WA	CHICHESTER METALS PTY LTD	0.6
Cloudbreak Mine	WA	CHICHESTER METALS PTY LTD	0.4
Sino Iron Project — Cape Preston	WA	CITIC PACIFIC MINING MANAGEMENT PTY LTD	1.2
Solomon Mine	WA	FMG SOLOMON PTY LTD	0.4
Hope Downs 1 Mine	WA	HAMERSLEY HMS PTY LTD	0.2
Hope Downs 4 Mine	WA	HAMERSLEY HMS PTY LTD	0.1
Yandicoogina Mine	WA	HAMERSLEY IRON — YANDI PTY LIMITED	0.2
Brockman 2 / Nammuldi Mines	WA	HAMERSLEY IRON PTY. LIMITED	0.3
Brockman 4 Mine	WA	HAMERSLEY IRON PTY. LIMITED	0.2
Marandoo Mine	WA	HAMERSLEY IRON PTY. LIMITED	0.2
Paraburdoo Mine	WA	HAMERSLEY IRON PTY. LIMITED	0.1
Tom Price Mine / WTS	WA	HAMERSLEY IRON PTY. LIMITED	0.2
Mesa A Mine	WA	ROBE RIVER MINING CO. PTY. LTD.	0.1
West Angelas Mine	WA	ROBE RIVER MINING CO. PTY. LTD.	0.3
Roy Hill Mine	WA	ROY HILL HOLDINGS PTY LTD	0.4
Koolyanobbing Iron Ore Operations	WA	YILGARN IRON PTY LTD	0.1
Savage River Mine	TAS	GRANGE RESOURCES (TASMANIA) PTY LTD	0.1
SIMEC Mining — Middleback Range Iron Ore Mine (Whyalla)	SA	ONESTEEL MANUFACTURING PTY LIMITED	0.1

Facility name	State	Responsible emitter	Reported emissions (Mt)
CAN01	QLD	SOUTH32 CANNINGTON PROPRIETARY LIMITED	0.1
McArthur River Mine Operations	NT	MCARTHUR RIVER MINING PTY. LTD.	0.1
NMK01 Nickel West Mt Keith Facility	WA	BHP BILLITON NICKEL WEST PTY LTD	0.1
Murrin Murrin Operations	WA	MURRIN MURRIN OPERATIONS PTY LTD	0.5
Ravensthorpe Nickel Operation	WA	FQM AUSTRALIA NICKEL PTY LTD	0.2
SUB-TOTAL			**10.7**

STEEL MANUFACTURING			
Port Kembla Steelworks	NSW	BLUESCOPE STEEL (AIS) PTY. LTD.	6.3
Liberty Primary Steel Whyalla Steelworks	SA	ONESTEEL MANUFACTURING PTY LIMITED	2.3
Liberty OneSteel Laverton Steel Mill	VIC	THE AUSTRALIAN STEEL COMPANY (OPERATIONS) PTY LTD	0.1
Western Port Works	VIC	BLUESCOPE STEEL LIMITED	0.1
SUB-TOTAL			**5.5**
TOTAL			**46.6**

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The Climate Council acknowledges the Traditional Owners of the lands on which we live, meet and work. We wish to pay our respects to Elders past and present, and recognise the continuous connection of Aboriginal and Torres Strait Islander peoples to Country.

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