Industry and waste

INDUSTRY AND WASTE

Sector summary

Australia's industries can prosper in a low emissions world. Rapid decarbonisation, primarily through electrification, fuel switching and process changes, can contribute materially to meeting Australia's emissions reduction targets. There are opportunities for the sector to supply zero and low emissions materials (such as steel and ammonia) to the domestic economy and deliver low emissions exports (such as alumina and aluminium) to Australia's trading partners.

Emissions from the industry and waste sector were 64 Mt CO_2-e in 2022 (CCA, 2024a). The sector's emissions are concentrated at a small number of large facilities (over 50% of emissions emanate from just 20 major facilities). Reducing emissions at many major facilities hinges on replacing or retrofitting large industrial assets at a suitable time. Further significant emissions reductions in the sector could occur from the 2030s as new and emerging technologies become available. There may be residual emissions after all available technologies have been taken up.

For the industry and waste sector to decarbonise, a portfolio of solutions will be required:

- widespread deployment of energy efficiency and adoption of a circular economy approach
- electrification and fuel switching (including to hydrogen and biofuels) to decarbonise high temperature process heat to produce iron and steel, alumina, ammonia and cement
- substitution of feedstock materials, including using electrolytic hydrogen, to produce iron and ammonia, alternative materials for cement, and captured CO_2 for chemicals, plastics and building materials
- carbon capture use and storage (CCUS) to capture emissions not abatable through other measures.

Decarbonisation of the industry sector and unlocking associated opportunities is highly dependent on the availability of a reliable supply of sufficiently firmed decarbonised electricity, and new fuels where they are required.

Other barriers to decarbonisation include technological readiness of solutions for key processes and issues associated with access to sufficient raw, recycled or recovered material, as well as to infrastructure. Substantial new private investment will be required to replace or retrofit large assets, including in major facilities in trade exposed industries.

Addressing these issues will require improved planning and coordination within industries and government, and between them. Development of low emissions industrial precincts and improving materials circularity is likely to aid decarbonisation efforts.

IW.1 Sector state of play

The industry and waste sector processes, manufactures and produces goods, and disposes of materials that have reached their end of life. Australia's industry and waste sector's Gross Value Added contributed around 5% of Australia's total Gross Domestic Product in 2022-23 (Appendix B). In 2023, the export of manufactured goods from the sector generated over $140 billion, approximately 25% of Australia's exports for that year (ABS, 2024). The sector consumed 18% of Australia's energy in 2021-22, including from electricity, gas, liquid and solid fuels (DCCEEW, 2023).

The sector accounts for approximately 7% of total employment, employing more than 900,000 people, including more than 250,000 women (Appendix B).

As industry decarbonises, competition with other sectors for electricians and engineers could cause shortages, delays and increased costs. Further, ongoing and projected labour and skills shortages in manufacturing may hinder Australian ambitions for growth of low emissions industries (MISA 2023; Climate Council 2023).

Within the industry and waste sector, the authority considered the following sources of emissions (scope 1):

- production of alumina and aluminium, iron and steel, lime and cement and ammonia
- emissions from waste
- manufacturing (including chemicals and plastics other than ammonia, food and beverages, building materials, pulp and paper)
- some synthetic greenhouse gases.

Emissions from the five highest emitting subsectors (alumina and aluminium, iron and steel, lime and cement, ammonia, and waste) are responsible for over 80% of the industry and waste sector's total scope 1 emissions (Table IW.1). The authority focused its analysis on decarbonisation technologies for these five subsectors but has also considered decarbonisation opportunities in the sector more generally, especially in relation to process heat.

Table IW.1: Industry and waste emissions breakdown by subsector, 2021-22

Subsector	Mt CO_2-e	Subsector share (%)
Alumina and aluminium	15	24
Waste	12	19
Iron and steel	11	17
Lime and cement	9	13
Ammonia*	5	8
Other industry	13	19
Total	64	100

Note: (DCCEEW & DISR 2024; CER 2024; CCA 2024a)*includes the production of ammonia derivatives

Emissions in the industry and waste sector originate from combustion of fossil fuels for heat and on-site electricity generation, industrial process and product use (IPPU),[1] and methane produced in landfills. Emissions in the sector have decreased from 79 Mt CO_2-e in 2005 to 64 Mt CO_2-e in 2022 (CCA, 2024a), which reflects decreased emissions from:

- energy use for manufacturing, with metals manufacturing having the largest decrease.
- IPPU, due to decreased emissions across manufacturing. The largest decrease was from metals manufacturing due to lower emission rates of perflurocarbons (PFCs) in aluminium smelting. Small improvements in emissions intensity of cement production have also played a role.
- the waste sector, largely due to landfill gas capture, but this decline has slowed in the last decade.

1 Industrial Processes and Product Use (IPPU), covers greenhouse gas emissions occurring from industrial processes, from the use of greenhouse gases in products, and from non-energy uses of fossil fuel carbon.

IW.2 Existing and prospective technologies

Emissions reduction opportunities currently available for deployment in the industry and waste sector include:

- **energy efficiency** to provide incremental emissions reduction by reducing energy consumption (AIETI, 2021).
- **electrification** of low temperature process heat, which is likely to occur at the end of asset life, eliminating emissions from fuel combustion (AIETI 2021; RACE for 2030 2021; ARENA 2019; McKinsey 2020).
- **fuel substitution** for some industrial processes, including biofuels used in existing assets to decarbonise high temperature heat processes (AIETI 2021; MPP 2023).
- **scrap metal recycling** to reduce the amount of primary metal production (AIETI, 2021).
- **landfill diversion** to redirect organic waste.

Thermal storage may be deployed as part of electrification or energy efficiency upgrades, to reduce energy demands and support decarbonisation by easing use of variable renewable energy in steady industrial processes. These technologies are expected to become more widely available for higher temperature processes and may be particularly relevant for medium to high temperature heat processes.

While many emissions reduction opportunities are available to decarbonise the sector, technologies are not yet commercially available at industrial scale to fully decarbonise several key industrial processes, particularly alumina, iron and steel and cement production, which comprise approximately 50% of the sector's emissions footprint.

Major changes expected in the industry and waste sectors over time include:

- increasing demand for decarbonised electricity and alternative fuels, including hydrogen and biofuels
- changing consumer preferences, and policy preferences in major markets, for goods produced using low emissions processes
- increasing opportunities for exports of low emissions metals, materials, and manufactured goods
- increasing circularity in the economy.

IW.2.1 Decarbonising process heat

Process heat is the thermal energy used in the production of manufactured goods (US DoE, n.d.-a). It is a key source of emissions across industry, from small food manufacturing facilities to the large manufacturing facilities in the highest emitting subsectors (alumina and aluminium, iron and steel, cement and ammonia). Process heat typically accounts for over 50% of scope 1 energy use in industry (ARENA 2019; McKinsey 2020). Decarbonising these emissions sources will have impacts across the sector.

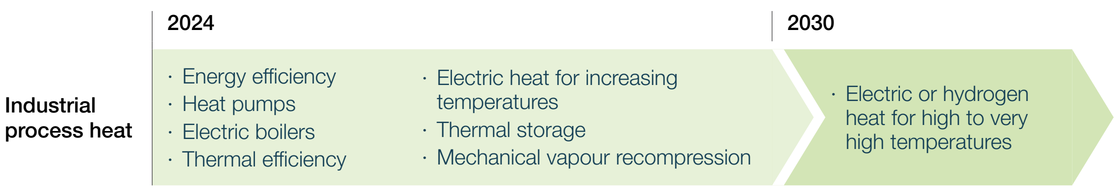
Decarbonising process heat focuses on changing how heat is generated and stored, right-sizing heat generation, improved heat recovery in systems, as well as research into lowering the temperature requirements for processes. Thermal storage may provide additional opportunities to reduce emissions or overall energy consumption.

The availability of decarbonisation solutions for the generation of process heat will depend on the temperature requirements for a given industrial process (Figure IW.1):

- Electrification of low (<100 °C) and medium temperature (100-400 °C) process heat is possible now through existing technologies (McKinsey, 2020). Heat pumps and electric boilers are commercially available and cost competitive for low temperature heat (AIETI, 2021).
- Electric furnaces for generation of high temperature (400-1,000 °C) process heat are being developed but are not yet commercially available at industrial scale for all processes (WBCSD 2021; McKinsey 2020). For some locations, solar thermal could be suitable for providing industrial heat, and is capable of heating to over 1,000 C (US DoE, n.d.-b).

Decarbonisation of very high temperature (>1,000 °C) process heat typically requires fuel switching to hydrogen or bioenergy (WBCSD, 2021; ARENA, 2019).

Figure IW.1: Prospective decarbonisation pathway for process heat



IW.2.2 Decarbonising the highest emitting subsectors within the industry and waste sector

A portfolio of technology solutions is required to decarbonise the highest emitting subsectors of industry and waste as shown in Table IW.2. The readiness of these technologies varies significantly, and there are various other barriers to their adoption (IEA 2023, 2019; AIETI 2021; MPP 2023).

Table IW.2: Priority abatement levers for key subsectors

Emissions subsector	Share of sector scope 1 emissions	Priority abatement lever	Readiness	Barriers to adoption
Alumina and aluminium	24%	Electric digestion for alumina refining (electric boilers or mechanical vapour recompression)	Range from demonstration to deployment, depending on temperature required (ARENA, 2022)	· High CAPEX · Lack of mature technologies (for medium temperature process heat at high pressure) · Insufficient supply of firmed renewable electricity
		Electric or hydrogen calcination for alumina refining	Demonstration (ARENA, 2022)	· Lack of mature technologies · High CAPEX and OPEX · Insufficient supply of firmed renewable electricity and electrolytic hydrogen
		Inert anodes for aluminium smelting	Demonstration (Rio Tinto, 2023)	· Lack of mature technologies · High CAPEX
		New cell design for aluminium smelting	Research and Development (AIETI, 2021)	· Lack of mature technologies · High CAPEX
		Secondary production	Commercial	· Limited to availability of scrap
Iron and steel	17%	Direct reduction of iron ore (DRI) in a direct reduction shaft furnace using hydrogen as a reducing agent (using natural gas before hydrogen becomes available)	Demonstration (IEA, 2023) (commercial using natural gas)	· High CAPEX and OPEX · Insufficient supply of firmed renewable electricity and electrolytic hydrogen
		Steelmaking with an electric arc furnace (EAF) powered by renewable energy	Commercial	· High CAPEX · Insufficient supply of firmed renewable electricity · Limited to ore containing high iron content
		Secondary production	Commercial	· Limited to availability of scrap
Lime and cement	13%	Electric or hydrogen kiln for clinker production	Research and Development (IEA 2023; MPP 2023)	· Lack of mature technologies · High CAPEX · Access to significant supply of renewable electricity or electrolytic hydrogen
		Material substitution	Commercial (VDZ 2021; MPP 2023)	· Limited by maximum substitution potential · Limited to availability of suitable materials
		Carbon Capture Use and Storage (CCUS)	Demonstration (IEA, 2023)	· High CAPEX and OPEX · Insufficient carbon storage or use opportunities

Emissions subsector	Share of sector scope 1 emissions	Priority abatement lever	Readiness	Barriers to adoption
Ammonia	8% for ammonia and derivatives	Green hydrogen for ammonia	First of a kind commercial stage	· Insufficient supply of electrolytic hydrogen or renewable electricity · High CAPEX and OPEX
		Steam methane reforming (SMR) with CCS to generate hydrogen for ammonia	Demonstration to commercial (depending on capture rate) (IEA 2023; IRENA 2022)	· High CAPEX and OPEX · Insufficient carbon storage or use opportunities
		Electric heat generation for ammonia	Demonstration (MPP, 2022)	· High CAPEX · Insufficient supply of renewable electricity
Waste	19%	Diversion of organic waste from landfills	Commercial	· High cost (in comparison to landfill) · Lack of market for products · Lack of reliable and consistent feedstock supply

IW.2.3 Alumina and aluminium

There are 6 alumina refineries and 4 aluminium smelters in Australia (AAC, 2024a, 2024b), all of which are covered under the Safeguard Mechanism (CER, 2024). These facilities are owned by Alcoa (3 refineries and one smelter), Rio Tinto (2 refineries and 3 smelters, including one jointly owned with CSR and Hydro Aluminium) and South32 (one refinery) (AAC, 2024a, 2024b; Rio Tinto n.d.). Alcoa announced the closure of their Kwinana facility early in 2024 (Alcoa, 2024).

Aluminium is produced in two main steps: the refining of bauxite into alumina, and the smelting of alumina into aluminium. Alumina refining and aluminium smelting were 80% and 20% of the scope 1 aluminium supply chain emissions in 2022, respectively (CER, 2024).

In alumina refining, digestion and calcination are the two most energy intensive steps, and together account for the largest portion of emissions associated with the refining process.

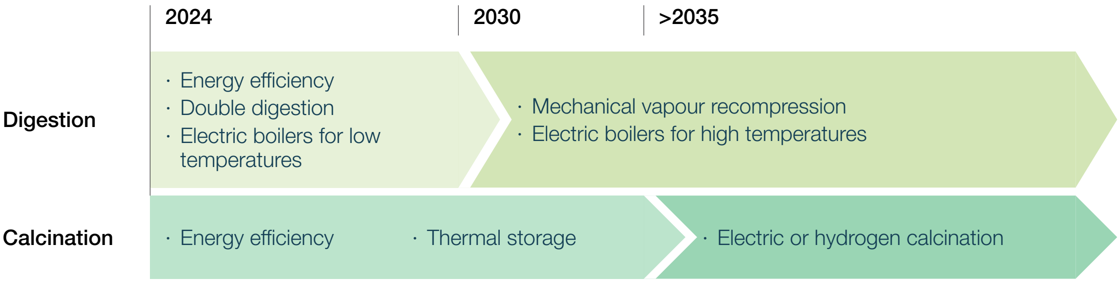
Digestion requires pressure and medium temperature heat ranging between 145-265 °C,[2] currently generated from steam from combustion of fossil fuels, and is responsible for 65% of the emissions from alumina refining (ARENA, 2022; AIETI, 2021). Electrification is the key pathway to decarbonising alumina digestion, with electric boiler technologies commercially available for the lower end of the digestion temperature range, but not yet proven at the higher pressures required for the higher end (ARENA, 2022).

Mechanical vapour recompression (MVR) is another electric digestion technology, requiring approximately one-third of the energy of electric boilers (ARENA, 2022). MVR is currently being tested at pilot scale for low temperature digestion at the Wagerup Alcoa facility (ARENA, 2023a). For bauxite ore that requires higher heat for digestion, double digestion of the ore may facilitate the use of MVR by enabling a second digestion stage to be conducted at lower temperature (ARENA, 2022; DCCEEW, 2024a).

Calcination requires high temperature heat over 800 °C, which is typically produced from natural gas, and produces 33% of the emissions for alumina refining (ARENA, 2022; AIETI, 2021). Both electric and hydrogen calcination technologies are being explored in Australia (ARENA, 2023b, 2023c). The pathway for decarbonising this step of alumina refining will be determined by availability and cost of electrolytic hydrogen and decarbonised electricity (AIETI, 2021; ARENA, 2022). Figure IW.2 details prospective decarbonisation pathways for alumina refining.

2 depending on the type of bauxite ore

Figure IW.2: Prospective decarbonisation pathway for alumina refining



Aluminium smelting is an energy intensive process that runs on electricity. Scope 2 emissions are responsible for 85% of combined scope 1 and 2 emissions from aluminium smelting. These electricity emissions will be abated through:

- energy efficiency, including through process improvements and equipment upgrades
- increasing use of scrap aluminium (known as secondary production)
- decarbonisation of Australia's electricity grids.

Box: IW.1 Aluminium smelting scope 2 emissions

Aluminium smelting emissions are dominated by scope 2 emissions, due to the large amount of electricity required to convert alumina to aluminium via electrolysis. The 4 aluminium smelters in Australia are connected to the NEM and use approximately 10% of the NEM's electricity supply (AAC 2024b, 2024c).

These smelters have long term electricity contracts that expire between 2025 and 2029, and the owners have indicated they intend to contract renewable electricity when contracts end (AAC, 2024c).

In February 2024, Rio Tinto announced the signing of Australia's largest renewable power purchase agreement (PPA) to date to supply its Gladstone operations, including the aluminium smelter, with wind energy (Rio Tinto, 2024). This agreement to source electricity from Windlab's Bungaban project follows a PPA to source electricity from European Energy's Upper Calliope solar farm. These 2 projects (2.2 GW combined) are anticipated to meet half of its Gladstone operations' electricity needs (4 GW).

Direct emissions from aluminium smelting are dominated by process emissions, which are emissions generated from chemical and physical transformations, from the use of carbon anodes as they are consumed. These emissions account for 95% of scope 1 emissions (AAC, 2023), and 15% of combined scope 1 and 2 emissions for aluminium smelting (ARENA, 2022). Decarbonising the direct emissions from aluminium smelting will require the development of inert anodes to replace the carbon anodes currently used. Inert anodes are in the research and development stage (ELYSIS, n.d.).

Figure IW.3: Prospective decarbonisation pathway for aluminium smelting

IW.2.4 Iron and steel

In Australia, BlueScope and Liberty are the primary steel producers that manufacture steel from iron ore using the blast furnace and basic oxygen furnace (BF-BOF) process (ASI, 2023). Infrabuild and Molycop produce steel from scrap using electric arc furnaces (EAF). The largest source of emissions from iron and steel production is the use of coal in BF-BOF process. Coking coal is used to provide heat and as a reductant to remove oxygen from the iron ore, generating emissions from combustion and process emissions. The two primary steel production facilities in Australia that make steel from iron ore both use the BF-BOF process.

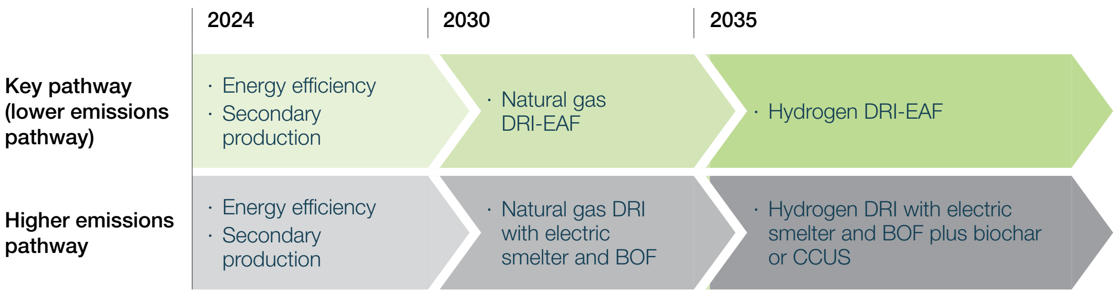
The most prospective pathway for decarbonising iron and steel production involves direct reduction of iron and an electric arc furnace (DRI-EAF) eliminating the need for coal (AIETI, 2021). The DRI process uses hydrogen or natural gas as a reductant to remove oxygen from the iron ore, and the EAF turns the resulting iron into steel using electricity. If the DRI-EAF is run using electrolytic hydrogen and decarbonised electricity, this process will avoid both combustion and process emissions. The technology and commercial readiness of the DRI-EAF steelmaking process varies depending on the fuel source and reductant being considered, and is:

- commercially available with the use of natural gas
- at the demonstration stage using electrolytic hydrogen blended with natural gas
- at the prototype stage for 100% electrolytic hydrogen (IEA, 2023).

An EAF requires high iron content materials, such as scrap steel or iron generated from the DRI processing of magnetite ore with low impurities (Shahabuddin et al., 2023). For lower grade hematite ores, electric smelter furnaces (ESF) are being piloted to remove impurities (BlueScope, 2024; Wood Mackenzie, 2024). ESF would make the DRI route applicable to a greater portion of the global supply of iron ore (76% for ESF compared to 8% EAF, (Wood Mackenzie, 2024)).

The DRI-EAF route could reduce emissions by 95%, while the DRI-ESF-BOF route could reduce emissions by 77%, when both are run on decarbonised electricity and electrolytic hydrogen (Wood Mackenzie, 2024). The use of biochar or carbon capture use and storage (CCUS) may enable deeper decarbonisation for the latter route. Figure IW.4 details prospective decarbonisation pathways for iron and steel production.

Figure IW.4: Prospective decarbonisation pathways for iron and steel production



IW.2.5 Lime and Cement

There are 7 lime and cement manufacturing facilities covered by the Safeguard Mechanism (CER 2024; CIF 2023). These facilities are owned by Adbri (4 facilities), Cement Australia (2 facilities), and Boral (1 facility).

The two main emissions sources in cement production are:

- CO_2 process emissions from the chemical reactions to produce clinker, a key component of cement
- combustion of fossil fuels for the generation of very high temperature heat (1,450 °C) to produce clinker.

Process emissions account for approximately two-thirds of emissions from cement production, and heat generation accounts for the remaining one-third (MPP, 2023).

Near-term opportunities to reduce emissions from cement production include:

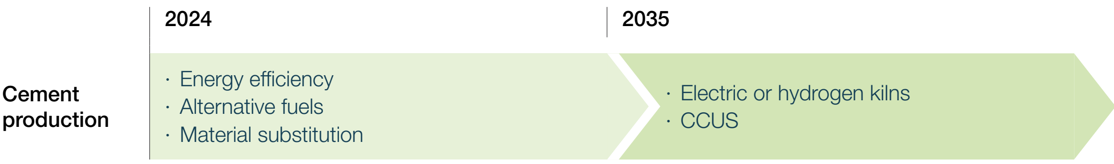
- energy efficiency, including through process improvements and waste heat recovery
- use of alternative fuels in place of fossil fuels in cement kilns
- material substitution to reduce the amount of clinker in cement.

Figure IW.5 outlines a prospective pathway for decarbonising cement production that results in maximum abatement through:

- electric or hydrogen powered kilns
- further material substitution to reduce the amount of clinker in cement
- CCUS to capture process emissions.

Process emissions associated with current cement production techniques cannot be abated without CO_2 capture, use or storage. CCS is unlikely to be used in the Australian cement industry, due to the distance from most existing cement facilities to appropriate CO_2 storage facilities (GA, 2023a). The Australian cement industry is exploring CCUS opportunities, including through a feasibility study for generating methanol from proposed captured CO_2 produced from Cement Australia's Gladstone facility (CSIRO, 2022).

Figure IW.5: Prospective decarbonisation pathway for cement production



Box: IW.2 Removal, capture, use and storage

Carbon dioxide removal

Engineered forms of carbon dioxide removal (CDR) include direct air capture (DAC), mineral carbonation, and biochar. These early-stage CDR technologies remove carbon from the atmosphere, and most also require the development of geological storage for the captured CO_2.

The quantity of CO_2 removed by these technologies remains small globally (Smith et al., 2024). Costs of capture remain high, in some cases around USD 700/tonne of CO_2 removed, e.g. for DAC (Smith et al., 2024). DAC also has high energy requirements (e.g. Casaban and Tsalaporta, 2023), and land requirements estimated at around 0.26 square meters per tonne CO_2 (Climeworks consultation, 2024).

With strong policy and financial support, novel CDR could reach the megatonne-per-year scale by the 2030s.[3] For that abatement to contribute to meeting Australia's targets, approaches such as biochar, DAC, enhanced weathering and mineral carbonation would need to be included in national greenhouse gas inventories.

Other technology options such as large-scale modifications of environments through ocean alkalinity enhancement and ocean fertilisation remain at early stages of R&D. However, they are of interest because of their global potential to reach gigatonne scale (Bach et al., 2024).

To achieve megatonne-scale uptake of novel engineered CDR in Australia, a rapid acceleration of funding support will be needed, both for basic research and for implementation of pilot projects, as recommended by the authority in previous reports (CCA, 2023a, CCA, 2023b).

3 This estimate derives from consultation for this report and from the CSIRO Report, 'Australia's carbon sequestration potential,' Australia's carbon sequestration potential - CSIRO

Carbon capture and storage

Point-source capture of CO_2, known as carbon capture and storage (CCS), could play an important role in reducing emissions.

Access to storage sites is critical to enable adoption of CCS. However, policies will be needed to ensure that CCS is deployed by industries that are critical for Australia's energy transition, rather than prolonging the life of fossil fuel-based equipment that could be transitioned to zero emissions alternatives.

At present, CCS remains expensive and at small-scale, but it has been deployed for decades and has potential to be scaled up. The Safeguard Mechanism is a key policy driver, requiring annual net emission reductions of 4.9% for covered facilities. Industries that emit a comparatively high concentration of CO_2, such as natural gas processing, hydrogen production (from gas) and cement, are most suited to implementation of CCS and should be prioritised by industry and government for assessment of the potential to adopt CCS at scale.

Carbon capture and use

Carbon capture and use (CCU) is another process expected to play a role in a future carbon removal industry. The capture of point source emissions can support scaling of CCU while atmospheric capture develops to be deployed economically at scale. The fact that some industries (e.g. aviation, cement, and chemicals) may not be able to fully decarbonise for some time gives rise to the possibility of new industries emerging, utilising captured CO_2 to make a range of products (Srinivasan et al., 2021). The use of CO_2 as a feedstock for manufacture of products such as synthetic gas, biomethane, and long-lived products such as bricks or cement is small today, but these uses may scale up as Australia approaches net zero emissions. As the ARC Research Hub for Carbon Utilisation and Recycling (2024) noted in its submission, new industries based on carbon capture will be necessary as the gradual phase out of fossil fuels removes them as critical feedstocks.

IW.2.6 Ammonia

There are 8 ammonia facilities in Australia, and they are covered by the Safeguard Mechanism (CER, 2024). These facilities are owned by Incitec Pivot (3 facilities), Orica (2 facilities), Yara (1 facility) and Wesfarmers (1 facility).

Ammonia is most commonly produced through a method known as the Haber-Bosch process which reacts nitrogen with hydrogen. The major sources of emissions in ammonia production are process emissions from making hydrogen using steam methane reforming (SMR), and generation of heat for the SMR and Haber-Bosch processes.

Hydrogen production through SMR separates hydrogen from methane, resulting in CO_2 process emissions. Process emissions account for approximately 65% of the emissions associated with ammonia production, and the combustion of fossil fuels for the generation of heat is responsible for approximately 33% (IRENA, 2022).

Figure IW.6 shows a prospective pathway to decarbonise ammonia production that involves the use of electrolytic hydrogen feedstock produced through electrolysis and electric heat generation (AIETI, 2021). An alternative production route with less abatement potential involves the use of CCUS (DCCEEW, 2022) with SMR hydrogen production and electric heat generation (AIETI, 2021).

To reduce emissions intensity of ammonia production, electrolytic hydrogen can be substituted into the existing processes up to 20% before any retrofitting or plant upgrades are required.

Figure IW.6: Prospective decarbonisation pathway for ammonia production

	2024	2035
Key pathway (lower emissions pathway)	· Energy efficiency · Substitution of grey hydrogen feedstock with green hydrogen	· 100% green hydrogen feedstock · Electric heat generation for Haber Bosch
Higher emissions pathway	· Energy efficiency · Increasing use of CCUS with SMR hydrogen production	· Electric steam generation for heat · CCUS with SMR for all hydrogen production

IW.2.7 Waste

There are approximately 1,200 landfills receiving waste in Australia (DCCEEW, 2024b, 2022). Waste management has become more concentrated over the last decade with the 21 largest landfills receiving approximately 50% of landfilled waste (DCCEEW, 2024b). The sector is dominated by several large companies, but there are also many smaller operators that specialise in specific markets (DCCEEW, 2022).

Methane is produced when organic waste is broken down by microorganisms in an anaerobic environment, such as in landfill. Methane from the decomposition of organic matter in landfill represents around three-quarters of the emissions from the waste sector. Other emissions from the waste sector include emissions from wastewater, which makes up about 20% of emissions, and biological and thermal waste treatment, which make up the remainder. Consequently, reducing methane emissions from landfill will have the largest impact on emissions in the waste sector.

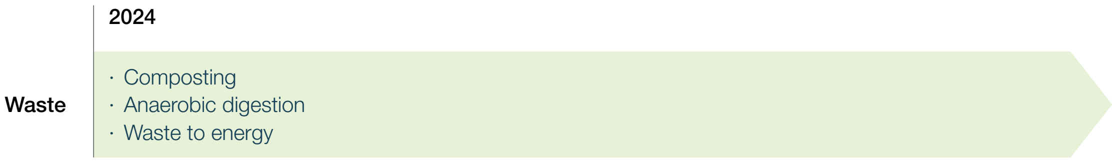
Diverting organic waste from landfill to low-emissions treatment options prevents the generation of methane and therefore remains the most effective pathway to decarbonise the sector. While landfill gas capture rates can reach 85-90% in a well-engineered, closed landfill, capture rates are much lower in open landfills. In Australia, landfill gas capture rates have plateaued in recent years even with current government incentives through the ACCU scheme (DCCEEW, 2024b). Landfill gas capture will remain an important part of the emissions reduction technology mix to reduce emissions of methane that cannot be abated by diversion in the short to medium term.

A mix of technologies for the processing of organic waste will be required, and these are likely to consist of composting, anaerobic digestion and combustion of waste to generate energy. These technologies are all available now.

From a circular economy perspective, composting and anaerobic digestion allow for the recovery of materials. Composting allows recovery of nutrients when the compost is applied to land. Anaerobic digestion is a process of microorganisms breaking down organic waste in the absence of oxygen to produce methane and organic byproducts. The methane can be captured and combusted to produce energy on-site or, where feasible, transported for use as energy in industrial processes. The byproducts of anaerobic digestion can be applied to land to recover their nutrients.

Processing organic waste through composting or anaerobic digestion can reduce emissions by over 90%, compared to landfill (NSW EPA, 2023). Further emissions reductions can be achieved through the use of composted products to displace other fertilisers and use of biomethane to produce low-emissions energy. Energy production from waste combustion could play a role where the waste cannot be used in one of these treatments, for example due to contamination.

Figure IW.7: Prospective decarbonisation pathway for organic waste



W.2.8 Other industry

Manufacturing and synthetic gases make up the bulk of the remaining emissions in the industry and waste sector. Emissions from the manufacturing sector are dominated by combustion of fossil fuels used to produce on-site electricity and process heat. Decarbonising process heat is temperature dependent. Electrification of low temperature heat is cost competitive with heat generated through combustion of fossil fuels (AIETI, 2021). A study on Australian industrial process heat indicated approximately 50% of the industrial heat requirement was 250 °C or below, and 40% was above 800 °C (ARENA, 2019). High temperature processes include the production of glass, bricks, sugar, and other chemicals.

Emissions from synthetic gases occur across a number of sectors including industry, the built environment, transport and electricity (DCCEEW, 2015). Synthetic gases include:

- hydrofluorocarbons (HFCs) used in refrigeration, air conditioning, aerosols, firefighting materials and medical inhalers
- sulfur hexafluoride (SF_6) used in electricity distribution
- nitrogen trifluoride (NF_3) used in the semiconductor industry, in chemical lasers and as high energy fuels
- perfluorocarbons (PFCs) produced as by-products from aluminium production.

HFCs comprise the largest portion of emissions from synthetic gases (96%), followed by PFCs (2%), and SF_6 (1%) (DCCEEW, 2024b).

As a party to the Kigali amendment, Australia began phasing down HFC imports in January 2018. The phase down of annual imports of bulk HFCs is due to reach an 85% reduction from baseline by 2036 (DCCEEW, 2021).

Box: IW.3 Hydrogen

Hydrogen, and its derivatives, can play a significant role in the net zero pathways of four sectors (see Table IW.3). For this to come to fruition, development of the hydrogen industry in Australia will need to be a high priority in the government's net zero plan. The government has already indicated this will be the case through its Future Made in Australia initiatives and the development of a new National Hydrogen Strategy.

Table IW.3: Uses for hydrogen and its derivatives across sectors

Sector	Uses for hydrogen and its derivatives	
Transport	Road	Hydrogen powered heavy trucks for long and heavy freight tasks
	Rail	Hydrogen powered rail in addition to electrification
	Shipping	Ammonia and methanol (derivatives of hydrogen) powered heavy shipping
	Aviation	Sustainable aviation fuel (which can be derived from either hydrogen, or biomass and waste) to decarbonise most of aviation
Electricity and energy	Hydrogen could be blended with, or replace, gas in peaking generators used to firm renewables	
Resources	Hydrogen could be used to decarbonise natural gas and LNG operations	
Industry	Hydrogen will be an important alternative to electrification of high to very high temperature process heat or to replace high emitting feedstocks	

Most hydrogen produced in Australia uses the steam methane reforming (SMR) process. Hydrogen is labelled blue when this CO_2 is captured and stored. Electrolytic hydrogen is produced using electrolysis powered by electricity.

The authority heard from industry stakeholders that many intend to use blue hydrogen to decarbonise their operations because it is currently lower cost and more readily available than electrolytic hydrogen. Several major natural gas and LNG producers told the authority they intend to use blue hydrogen as a key lever to decarbonise their operations, despite electric drives and boilers being commercially available. They cited a preference to run existing gas turbines on hydrogen rather than replacing them with electric drives and challenges in electrifying brownfield facilities as reasons for preferring hydrogen to electrification.

IW.3 Barriers, opportunities and enablers

IW.3.1 Technological constraints

Many of the technology solutions to decarbonise the industry sector are not yet mature. Prospective technologies include those to decarbonise high temperature processes, such as alumina calcination and cement production, and direct reduction of iron using hydrogen.

Depending on the technology and commercial readiness of each solution, targeted support is required to accelerate the demonstration, commercialisation and deployment of technologies, noting Australia will be a technology leader for some emissions reduction activities and a fast follower for others. Several submissions to the authority's issues paper noted the importance of technological advances and increasing the pace of deployment of key technologies:

> *'The challenges of availability and integration of abatement technology for some industrial activities is expected to be a relevant issue, at minimum, through the mid-2030s'*
>
> AIGN submission, 2024

> *'Investment in research and development, particularly pilots and demonstrations, could advance industry's ability to deploy technologies earlier and ensure Australia builds the capabilities, expertise and workforce it needs.'*
>
> Climateworks submission, 2024

IW.3.2 Green premium

> Significant investments are needed to replace and retrofit large industrial assets, power energy intensive processes, and replace high emitting feedstocks.

Continued technology advancement will contribute to lower costs. It is important investment decisions do not lock in emissions, result in stranded assets or add to the cost of decarbonisation.

Markets for low emissions products are still developing, lacking depth in demand and supply. Governments can boost demand through their own procurement activity and incentivise shifts in consumer preferences, and encourage supply through support for technology innovation, production and through regulatory measures. Efforts to reduce embodied emissions from buildings and infrastructure could drive demand for low emissions steel, cement and aluminium. Certification schemes will also support procurement for green metals and materials that use captured CO_2, while supporting international trade.

IW.3.3 Planning, approvals and coordination

> Low emissions industrial precincts could be a key enabler for decarbonisation of emissions intensive industries.

They can provide shared infrastructure, and help build economies of scale, including for:

- increased decarbonised energy generation, with transmission capacity of appropriate size to meet future energy demands from electrification
- hydrogen production and local distribution
- biofuel production, including biomethane generated from horticulture and other organic waste
- carbon management technologies, including CCUS and carbon dioxide removal (CDR)
- storage and reuse of heat.

The co-location of facilities can catalyse investment, foster innovation and increase export opportunities, collaboration, and job creation. Governments can play a coordinating role for planning and investment in shared infrastructure to enable the development of low emissions industrial precincts (CEDA, 2024).

> *'Shared infrastructure is recognised as a key enabler of private investment, and industrial hubs are being considered to support decarbonisation'.*
>
> AIGN submission, 2024

'Developing Renewable Energy Industrial Precincts to co-locate industrial activities with large-scale renewable electricity generation can minimise the need for new transmission and better streamline delivery of the large amounts of energy required for electrified mining and manufacturing'.

The Climate Council submission, 2024

IW.3.4 Supply chain constraints

> Coordination and planning are required to ensure availability of energy, and raw, recycled or recovered material, and access to infrastructure.

- **Decarbonised electricity** – Electrification of industrial processes and potential onsite production of hydrogen will lead to increased demand for decarbonised electricity. Information about expected and anticipated industrial loads and timing will be important to plan for electrification. For example, current alumina production consumes around 220 PJ of energy from gas and coal, which may require 3-5 GW of firmed electricity, depending on the technology (AAC, 2023).

'Government needs to ensure that throughout the transition all industry has firm, ongoing supply of high amounts of energy.'

Australian Steel Institute submission, 2024

'The biggest opportunity for industry is to expedite the scale and pace of Australia's electricity transition.'

Australian Aluminium Council submission, 2024

- **Electrolytic hydrogen** – Industrial facilities that require hydrogen as a feedstock or for high temperature heat will need a secure supply of hydrogen. Electrolytic hydrogen is currently not available at the scale or cost required for industrial use.
- **Alternative fuels** – Alternative fuels could be used for some industries, particularly for near-term emissions reductions while technologies for high temperature heat mature. There will be challenges in securing these fuels at the scale, cost, and consistency required. Biofuels could be used in industry, but there is competing demand for these fuels across the economy, and the supply is limited (MPP, 2024). Natural gas is likely to be used to reduce the emissions intensity of steel production and enable the investment in DRI-EAF assets until electrolytic hydrogen becomes available.
- **CO_2 transportation or storage infrastructure** – For facilities that could capture CO_2, there may be limited storage opportunities related to the facility location. This could include lack of pipelines for transporting CO_2, or no suitable storage sites in close proximity.
- **Iron ore type** – The lowest emissions route for iron and steel production, DRI-EAF, requires magnetite ores. However, approximately 96% of Australian iron ore exports are hematite, which is not currently suitable for this process (GA, 2023b). Research is being done to develop processes for these ores to be used in low emissions steel making (HILT CRC, 2024). Australia has magnetite deposits, which are suitable for DRI-EAF, but they require processing to reduce impurities before they can be used in steel making (GA, 2023b).
- **Scrap steel and aluminium** – The use of scrap metals for secondary production is dependent on its availability. Reducing the volume of scrap metals that are exported may facilitate higher domestic recycling. The total volume of local scrap metal is not sufficient to replace current domestic production volumes.
- **Supplementary cementitious materials (SCMs)** – The most common SCMs used to replace cement in concrete are fly ash and slag. These are produced from coal-fired power plants and steel production. Supply of these will reduce as these plants decarbonise.

Materials circularity in the industry sector can reduce the amount of new materials required for production processes and can reduce the emissions gap required, allowing more time to deploy more expensive technologies (Material Economics, 2018). In addition to reducing energy use and embedded emissions in products, a more circular industry sector would realise co-benefits such as reduced pollution and waste and reducing use of natural resources. Opportunities in the industry and waste sector include greater recycling of metals, cement, glass and organics. The transition to a more circular economy can be facilitated by investment in recycling infrastructure, building markets for recovered materials and increasing information on availability of supply of byproducts and waste materials.

IW.3.5 Information and data gaps

Decarbonisation roadmaps serve as a blueprint for adopting new technologies in emissions-intensive industries that require significant planning and investments, particularly for large scale assets. Given the small number of high emitting facilities within each subsector of industry, industry led roadmaps could facilitate collaboration and knowledge sharing between companies that would otherwise be competing, and enable facility owners to derisk investments by reducing uncertainty around timing and technology options to decarbonise.

Separate collection of organics from both households and commercial sources allows for greater diversion of organics from landfill and can reduce the risk of contamination in the organic waste stream. Although separate organics collection is being rolled out across most states, the authority heard from stakeholders that availability of food and garden organics collection remains uneven and contamination remains an issue. Education on the correct use of separate organics bins also remains important to reduce contamination.

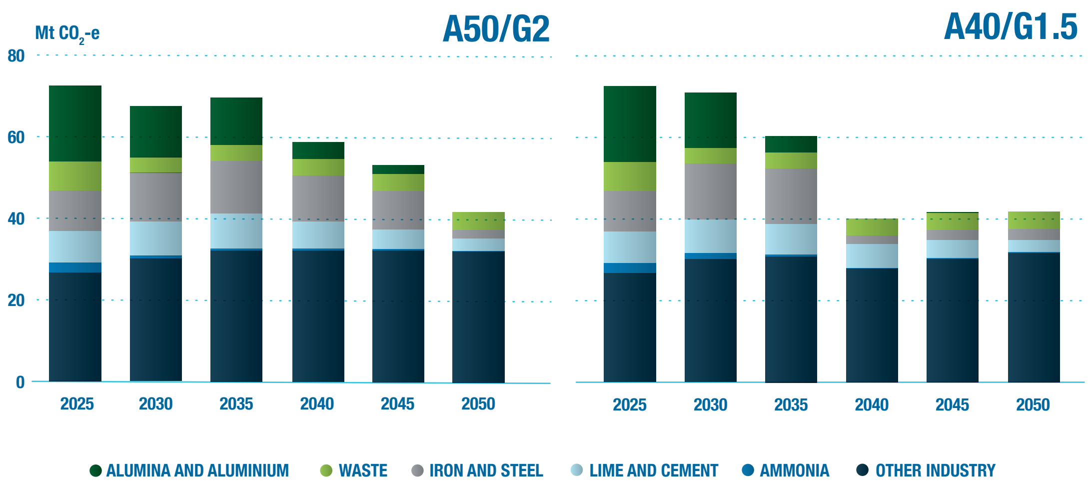
IW.4 Emissions pathways

Projected emissions from CSIRO's AusTIMES modelling (A50/G2 and A40/G1.5 scenarios) for the sector are shown in Figure IW.8.

In CSIRO's modelling of the industry sector the largest abatement came from the alumina and aluminium subsector, followed by iron and steel. Increased emissions from other industry could reflect increased production and less take up of abatement technologies applied for these emissions in the model.

In CSIRO's modelling final energy use for the sector shows no coal use, and almost 60% reduction in the use of natural gas from 2025 to 2050. Electricity demand approximately doubles in the A40/G1.5 scenario, and hydrogen demand grows from 0 PJ to over 250 PJ in both scenarios.

Figure IW.8: Modelled industry and waste sector emissions breakdown by subsector, under A50/G2 and A40/G1.5 AusTIMES modelling scenarios, 2025-2050



Source: CSIRO modelling in AusTIMES commissioned by the Climate Change Authority

A comparison between the authority's estimates of emissions in 2050 from the ground-up analysis and modelling are presented in Table IW.4. Based on the authority's internal analysis informed by Worley (CCA, 2024b), 44 Mt CO_2-e of emissions could be abated in the sector by 2050. In general, there is broad agreement between ground-up estimates and modelled results. The authority's ground-up estimates reflect potential emissions reduction pathways to net zero through implementation of priority technology levers. The analysis took into account estimated timing and emissions reduction potential for each decarbonisation lever.

Table IW.4: Projections of emissions reductions to 2050 using estimates from AusTIMES modelling and ground-up analysis

Reference: emissions in 2022 were 64 Mt CO_2-e	Projected emissions reductions to 2050 (Mt CO_2-e)*		
	AusTIMES modelling (A50/G2)	AusTIMES modelling (A40/G1.5)	Ground-up estimate**
Alumina and aluminium	19	19	15
Iron and steel	8	7	8
Lime and cement	5	5	5
Ammonia	2	2	5
Waste***	3	3	6
Other industry	-5	-5	5
Total	31	31	44

**Abatement was calculated as the difference between base year emissions and the projected 2050 emissions from each model. In AusTIMES the base year for the abatement calculation is 2025 and in ground-up estimates the base year for estimates was 2022. In both scenarios, the modelling results show higher emissions in 2025 compared to emissions reported in the 2022 inventory, partly due to differences in how the sector's emissions boundary was defined, as discussed in Appendix B.*

***Ground-up analysis assumes emissions from each subsector are due to material sources of emissions associated with production. For example, emissions from the iron and steel subsector are assumed to be from blast furnaces and basic oxygen furnaces used to produce primary steel. It does not reflect emissions from shaping steel or melting scrap steel. It also assumes production is constant.*

****Waste flows and stocks were not modelled. Modelled emissions reduction in the waste sector is primarily from change in energy use while the ground-up estimate only considers change in waste stock.*

The authority's ground-up analysis indicates there could be 20 Mt CO_2-e of remaining emissions in the industry and waste sector in 2050. In comparison, CSIRO's modelling results show 42 Mt CO_2-e remaining in 2050 under both A50/G2 and A40/G1.5 scenarios.

The amount of residual emissions in the sector is contingent on the abatement potential and the uptake rates of decarbonisation technologies. These uptake rates depend on technology and commercial readiness, cost and asset lifecycle.

Near-term emissions reduction opportunities exist for all subsectors. The authority has found that, in general, many owners of assets that are liable under the Safeguard Mechanism intend to pursue these near-term decarbonisation opportunities to meet their obligations. Asset owners are likely to pursue the most cost-effective direct emissions reduction opportunities, and more expensive options will be assessed against costs for purchasing offsets. Policy certainty for Safeguard obligations beyond 2030 could provide more guidance around expectations for industry in the 2030-40 decade.

If all available and expected key technologies are deployed by 2050, residual emissions in industry and waste are expected to be attributable to:

- cement production, due to incomplete capture of CO_2 from process emissions
- waste, due to the difficulty of achieving a 100% reduction in organic waste to landfill, and the complete capture of methane from landfills and wastewater.[4]

4 Emissions from the decomposition of waste can continue decades after it is deposited in landfill

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