MANUFACTURINGAUSTRALIA

Level 1, The Realm 18 National Cct Barton ACT 2600
E ben@manufacturingaustralia.com.au
P +61 2 6198 3285

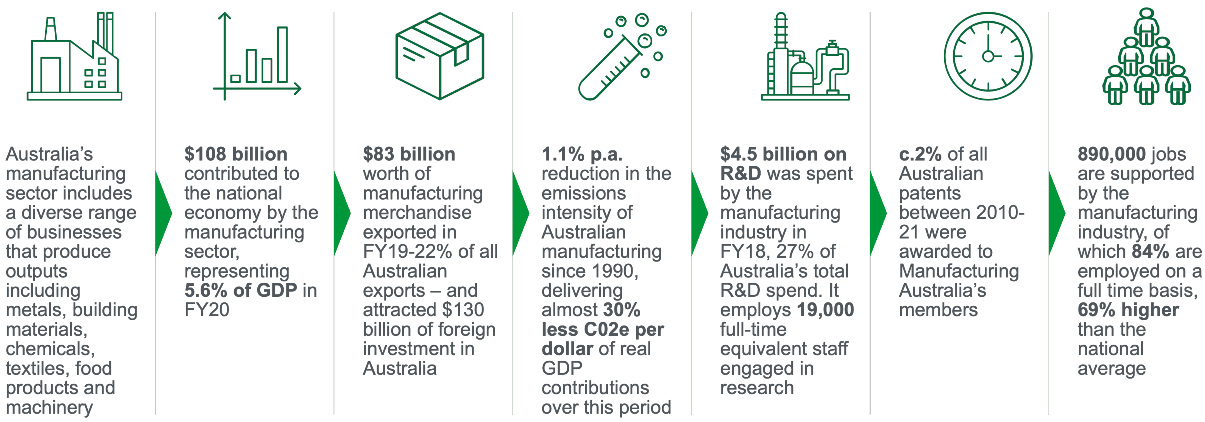
14th July 2024
Attn: Green metals consultation team
Department of Industry, Science and Resources
greenmetals@industry.gov.au

Green metals: Consultation paper response

Thank-you for the opportunity to comment on the Green metals consultation paper.

Manufacturing Australia (MA) is led by the CEOs of Australia's largest manufacturing companies: Alumina Ltd, BlueScope, Brickworks, Capral, Cement Australia, CSR, DuluxGroup, Incitec Pivot, Orora, Rheem, Sims and Tomago Aluminium. MA's member companies provide direct and indirect employment to more than 100,000 Australians, operate more than 500 manufacturing plants or smaller facilities around Australia and support more than 25,000 downstream suppliers.

In addition, these companies have direct operations in more than 30 countries globally, and export to more than 50. They are amongst Australia's most innovation-intensive businesses, having spent more than $2bn on R&D over the past decade, and with more than 50 research partnerships in place with Australian universities and the CSIRO. The exhibit below summarises the broad benefits afforded to the Australian economy from domestic manufacturing capabilities.



Source: *Low Emissions Manufacturing: Australia's Opportunities.* Manufacturing Australia/L.E.K Consulting. March 2022.
https://www.lek.com/insights/sr/low-emissions-manufacturing-australias-opportunities

Several MA members are providing separate submissions in response to this discussion paper, either in their own right or via industry-specific associations. Some of these submissions include detailed commentary on the opportunities and hurdles for low emissions metals production in their own businesses or supply chains. This submission does not seek to replicate those company or facility-specific comments. Rather, it reinforces key principles relevant across the MA membership.

Green Metals: a significant opportunity

Australia has a significant opportunity to create and retain high-quality jobs, grow its manufacturing sector and "re-shore" capabilities lost to imports, through supporting the establishment of a low emissions metals supply chain.

- Low emissions iron, steel, alumina and aluminium production are industries in which Australia can grow global market share through carefully managed investments in low emissions pathways.
- Key emissions reduction pathways include increasing circularity and metals recycling; direct electrification using clean energy; displacing metallurgical coal through gas-based direct reduced iron; green hydrogen as a process feedstock; green hydrogen for process heating; and carbon capture, usage and storage. Each of these pathways are the subject of considerable R&D investment by MA member companies.
- In the medium term, reductions in emissions will also be achieved through substitution of emissions-intensive inputs, increased recycling and re-use of materials, process changes and efficiency improvements to existing assets.
- Careful balance must be struck between pursuing opportunities for green metals production and remaining competitive with imports (a level playing field) from other jurisdictions. This involves several interconnected policy considerations, some of which are highlighted in this submission.

Level 1, The Realm 18 National Cct Barton ACT 2600
E ben@manufacturingaustralia.com.au
P +61 2 6198 3285

Demand and pricing for "green" metals: observations

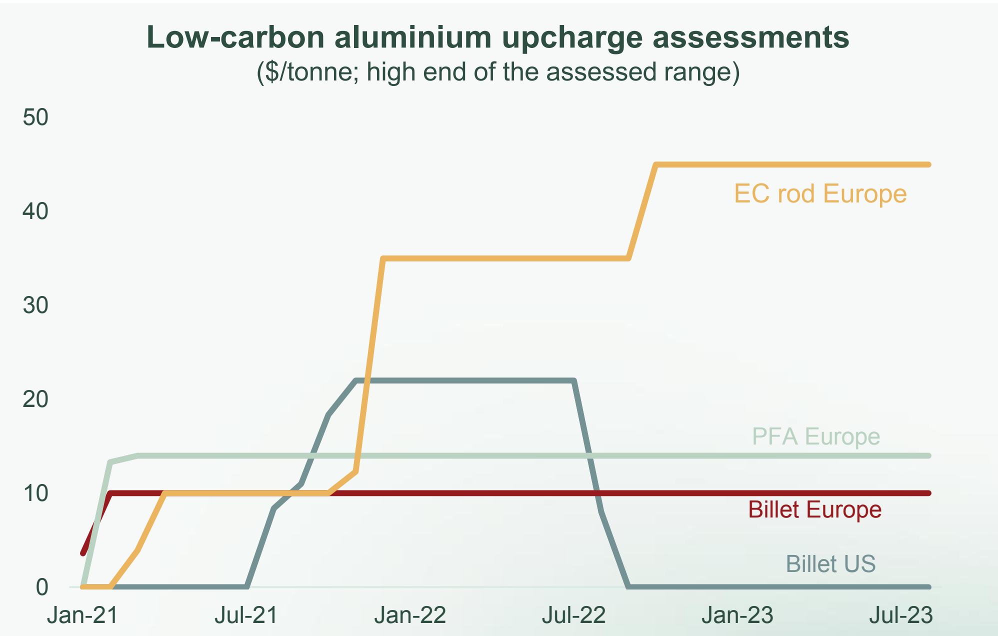
In general, supply of low carbon metal is either meeting or exceeding demand in most markets. Consumer demand for low carbon commoditised metal products remains low, where there is no distinct market for "green" metals with significant liquidity. Consequently, there is limited support for low carbon premiums in the short term, however this does not prevent it from forming in the future.

The development of these markets is likely to occur firstly in the more liquid aluminium market than in alumina or iron, and particularly for value-added products. For example, premium for electrical conductor rod in Europe increased to in excess of $40 per tonne, while extruded products are also seeing some modest premium.

MA offers the following observations for consideration:

- Alumina: Low-carbon premium remains modest relative to the price of alumina. There is no visibility on prices or liquidity, and low-carbon premium contracts are typically bilateral and confidential.
- Aluminium: Some low-carbon premiums are developing. End-users within electrical, packaging, automotive, consumer durables and building and construction sectors are driving low-carbon aluminium demand.
- Steel: Low-carbon premium remains modest relative to the steel price. Some value-added steel products are attracting modest premiums, but these are in the context of highly value-added contexts (automotive etc), not for primary steel products.

Where they are evident, premiums vary by product type and region, but are typically limited to higher value added products. In these cases, premium pricing is unlikely to be sustained as low carbon adoption becomes more commonplace. Rather, some "first movers" will enjoy a premium in the short-medium term, but that may erode over time as technology and cost hurdles for low carbon options are overcome.



Harbor assessment is for primary aluminium produced with an estimated carbon footprint of 4.0 or less kg of CO2 emitted per kg of aluminium. IAI's level 1 (scope 1 & 2); Primary Foundry Alloy (PFA); Electrical Conductor (EC)
Source: Harbor

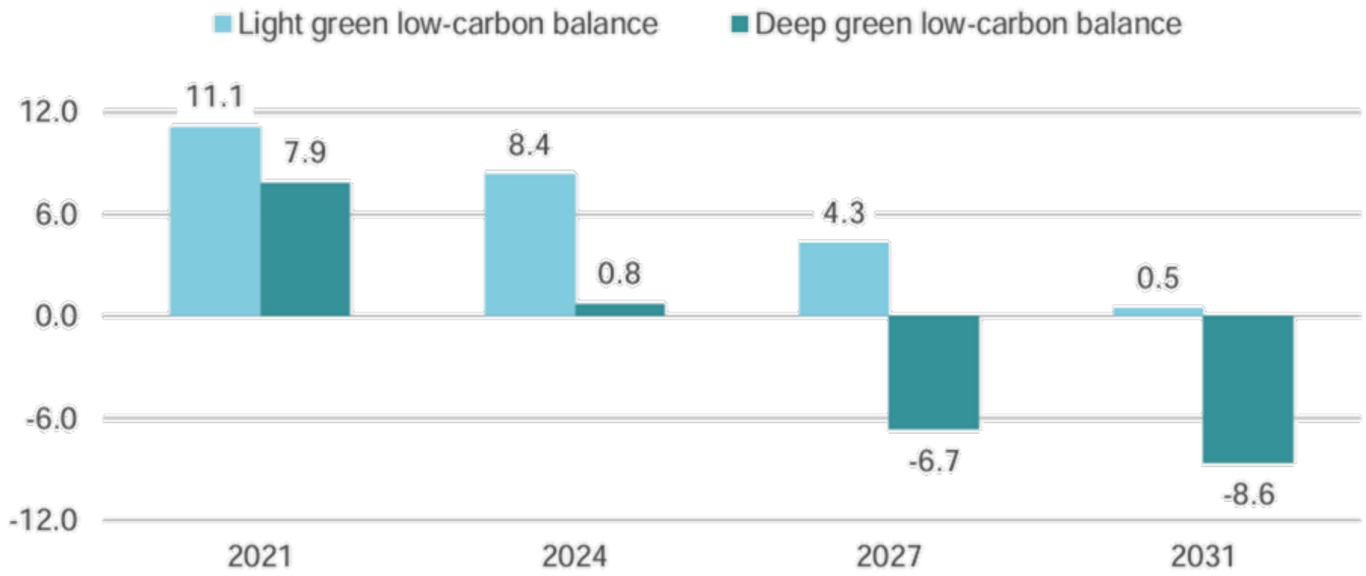
MANUFACTURINGAUSTRALIA

Level 1, The Realm 18 National Cct Barton ACT 2600
E ben@manufacturingaustralia.com.au
P +61 2 6198 3285

Low-carbon aluminium remains in surplus globally, but this could change quickly.

- Although demand increased sharply since 2021, low carbon aluminium supply is meeting demand
- CRU estimates ~21 million tonnes were produced in 2021 globally, rising by an average of 4.5% y/y CAGR over the following five years.
- End-users' decarbonisation goals drive demand, and goals vary dramatically by sector.
- There is limited support for a low carbon premium in the short term.

World ex. China, low-carbon market balance
(millions tonnes)



Light low-carbon scenario assumes 50%, and dark low-carbon scenario assumes 80% low carbon aluminium demand from key sectors by 2031. Key sectors are transport, construction and packaging end uses. Low carbon aluminium defined as <4t CO_2e /t Al for Scope 1 and 2 emissions.

Incentivising green metals investments:
Given the significant differences in market structure, technical and commercial barriers and investment cycles in different metals industries and businesses, there is no "one size fits all" method to drive adoption of "green" metals.

Rather, MA recommends an analytical approach that works in partnership with incumbent domestic industries to develop a comprehensive and granular understanding of the technical and commercial barriers to abatement, and to the development of "green" metals supply chains.

Such an approach should consider what mix of incentives, such as investment offsets, production tax credits, R&D support, grants and the like, is most appropriate for different industries, including measures to incentivise recycling of steel and aluminium in domestic supply chains. It should also consider the role of other adjacent policies such as carbon leakage remedies and broad-based investment incentives.

This bottom-up approach should prioritise modelling the risks to current operations and future investment by incumbent, Australian manufacturing firms and make recommendations about how to prioritise policy support.

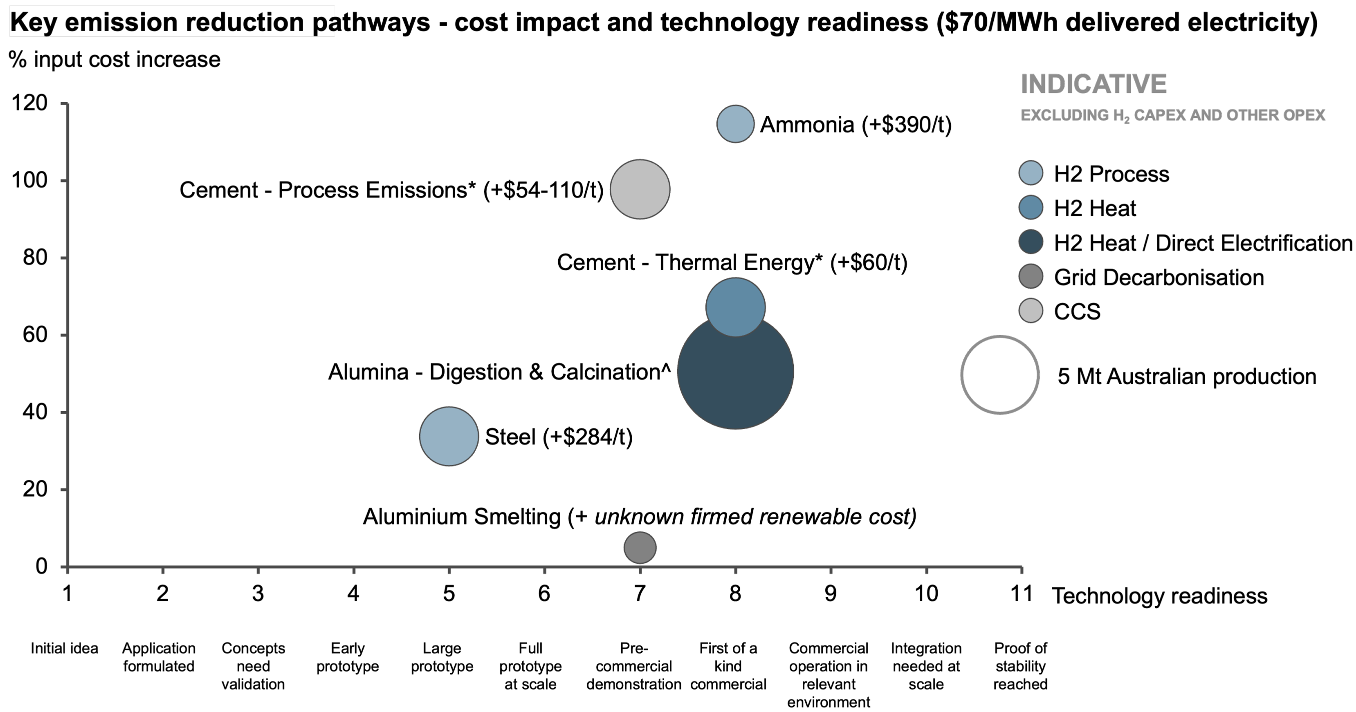
MANUFACTURINGAUSTRALIA

Level 1, The Realm 18 National Cct Barton ACT 2600
E ben@manufacturingaustralia.com.au
P +61 2 6198 3285

Overcoming technical and commercial barriers:
Low carbon metals face both technical and commercial barriers to adoption. Overcoming these barriers will involve both R&D to prove and scale emerging technologies, along with cost curve reductions to drive emerging technologies towards parity with existing technologies.

The objective of developing a green metals supply chain should ultimately be to drive down production costs to parity with existing, fossil fuel based, production costs. Reducing the delivered cost of low emissions energy will be a key enabler of green metals.

The exhibit below highlights the substantial improvements to both technology readiness and cost reductions necessary to commercialise green metals technologies.



Emissions reduction opportunities: summary
The following two tables summarise some key emissions reduction pathways, for the steel and aluminium supply chains, respectively. The tables are drawn from the 2022 Manufacturing Australia report, *Low Emissions Manufacturing: Australia's Opportunities.* Select chapters of this report are included as appendices to this submission.

MANUFACTURINGAUSTRALIA

Level 1, The Realm 18 National Cct Barton ACT 2600
E ben@manufacturingaustralia.com.au
P +61 2 6198 3285

Table 4
Potential emissions reduction for steel

Emissions reduction options	Increased efficiency	Alternative feedstock	Increased recycling	Carbon capture, use and storage (CCUS)	Breakthrough production technologies
Description	Improve efficiency of existing BF-BOF operations	Use alternate feedstocks to act as a reductant	Avoid emissions from new virgin steel production by using more recycled scrap in EAFs	Capture emissions from existing operations and either use or store CO2	Replace BF-BOF with commercial application of breakthrough steel production technologies
Examples	• Waste heat recovery • Increase scrap-to-steel ratio • Increase use of higher-quality iron ore and/or premium hard coking coal	• Using biomass as a reductant in a blast furnace • Using hydrogen as some of the reductant in a blast furnace *e.g. Charcoal is commercially used to substitute for a proportion of coal used in blast furnaces, primarily in Brazil*	• EAF plants are currently being used globally to melt scrap — accounts for c.50% of steel production outside of China • EAF based on renewable energy has the potential for significant emissions reduction	• Capturing and using CO2 for industrial uses like food and beverage manufacturing or producing biofuels or chemicals • Capturing and storing CO2 from across some or all of an integrated steel plant *e.g. COURSE50 in Japan targets 30% CO2 emissions reduction from BF-BOF by capturing CO2 from the BF gases and using a higher H_2 content to partially substitute for coke, with demonstration scheduled for 2030 and commercial implementation by 2050*	DRI-EAF process using: • Natural gas and CCUS • Hydrogen • Direct electrification *e.g. The HYBRIT project began operating a pilot plant in August 2020 in Sweden, targeting a 1Mt/year demonstration plant by 2025 at 0.025t CO2/t, assuming zero emissions electricity powering the EAF and green hydrogen feeding the DRI. The HYBRIT plant is currently producing sponge iron at pilot scale, but this technology is yet to be commercialised.*
Timing (years)	Now	0-5	0-5	5-10	10+
Status	Technology readily available	Requires a secure supply chain for biomass	Technology readily available, volume limited by scrap availability and capital investment in renewable energy. Contaminants in scrap may limit use for some steel grades. Pig iron addition may be required to produce some end products.	Not available on industrial scale, is high cost and difficult to retrofit to existing BF-BOF operations	Natural gas-based DRI-EAF is available today; however, CCUS is not at industrial scale. Hydrogen-based DRI-EAF technology currently not proven or available at industrial scale and is high cost.

Decreasing level of CO2 emissions →

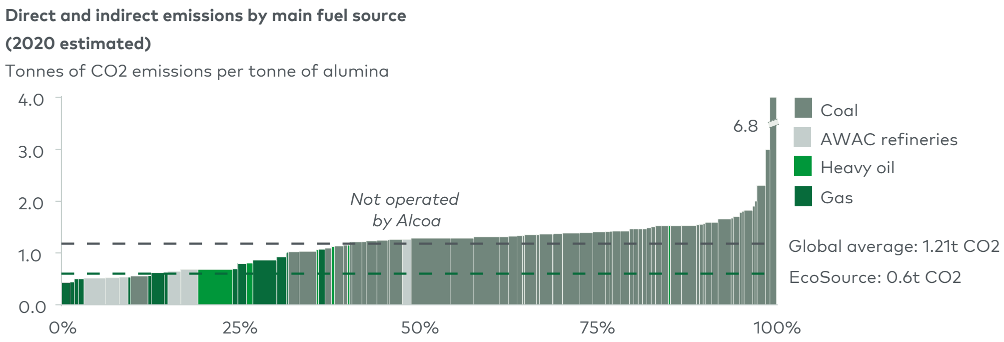
MANUFACTURINGAUSTRALIA

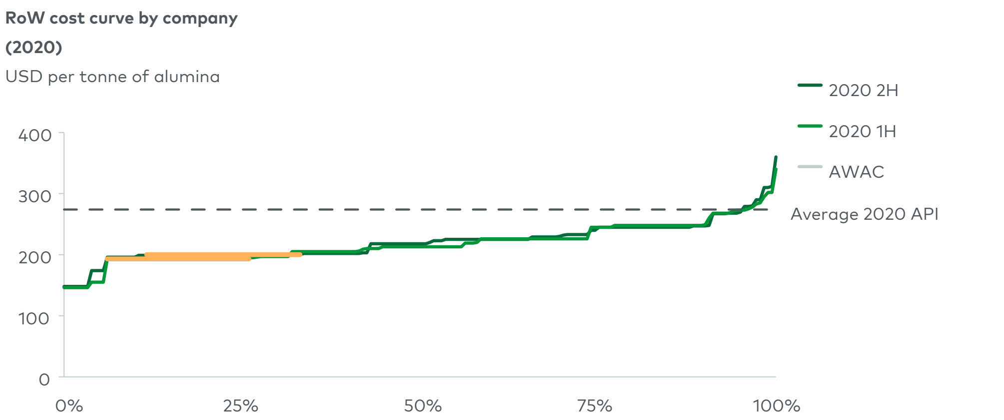
Level 1, The Realm 18 National Cct Barton ACT 2600
E ben@manufacturingaustralia.com.au
P +61 2 6198 3285

Table 6
Pathway to decarbonisation of the Australian aluminium industry

Stage	Options
Development of inert anodes*	Development of non-carbon-based anodes for potlines and roll-out across the industry
Alumina process adaptation	Development and implementation of technologies that can reduce alumina process emissions, particularly on high-pressure or high-temperature processes such as: • Digestion of bauxite • Calcination of alumina
Decarbonisation of the electricity grid	Replacement of coal and gas-fired power generation with low carbon alternatives such as wind and solar, with firming capacity to ensure regular supply to aluminium smelters. This decarbonised electricity will also support carbon emissions reduction in the extrusion manu-facturers.

Figure 24
Alumina emissions intensity and world cost curve





Source: Alumina Limited, 2020 Full Year Results Presentation, 23 February 2021 (chart adapted); CRU, May 2021

Level 1, The Realm 18 National Cct Barton ACT 2600
E ben@manufacturingaustralia.com.au
P +61 2 6198 3285

Increasing "circular" metals manufacturing:
Continuing to enable and where possible increasing the circularity of Australia's metals industry is an important opportunity to reduce emissions from metals manufacturing and realise Australia's green metals opportunities, over both the short-medium and longer terms.

MA members have integrated circularity, by using secondary resources in their supply chains, for decades. For example, BlueScope is a significant user of processed ferrous scrap metal in its value chain, increasing processed ferrous scrap metal content in the steelmaking process at Port Kembla Steelworks, NSW from approximately 21.5% to 25% between FY19 and FY22. Sims Limited, a global leader in metal recycling, contributed, across its global operations, toward 11.6 million tonnes of avoided emissions compared to making the same amount of steel from raw materials in FY23.

As greener steel making continues to grow in Australia and around the world, processed ferrous scrap metal will continue to play a critical role in the transition, both for integrated steel mill processes and in electric arc furnaces. For this reason, MA recommends introducing export restrictions on unprocessed ferrous scrap metal to support the ongoing competitiveness of domestic metal recycling and its critical role in the Australian green steel value chain.

Broader policy environment to support green metals investment
Alongside specific measures to encourage investment in "green" metals, MA recommends economic policy reforms to boost Australia's overall attractiveness for manufacturing investment. Key focus areas relevant to this consultation include:

1. Regaining energy cost advantage through competitively priced electricity and gas for industry.
2. Ensuring a level playing field with imports through introduction of measures to avoid carbon leakage.
3. Faster investment approvals decisions through a single front door for manufacturing capital investment.
4. Accelerated depreciation of manufacturing investments.

The table below, summarises MA's broader recommendations to boost manufacturing investment.

5 recommendations to boost investment in Australian manufacturing

Single front door for large capital investments	• Centralised process with centres of excellence providing predictable, high-quality decisions (environmental reviews, specialised courts) • Dedicated government account manager with decision authority and senior Minister level sponsorship shepherding the process end to end • Commitment to rapid delivery timeframe in-line with private sector timelines (incl. promotion of pre-approved industrial zones/parks)
End-to-end view on regulations	• Safeguard against import substitution – Observe the EU carbon border adjustment tax, and adopt it, if successful (Australia as "policy taker' vs "1st principles design') – Consider minimum domestic content requirements in certain instances • Use [some of] proceeds from carbon regulation to – Support carbon abatement in hard to abate industries – Incentivise energy efficiency investments – In case of end-user subsidies for energy efficient technology, connect program with local content requirements to limit subsides flowing to foreign companies • Implement export restrictions on export of un-processed ferrous scrap metal to facilitate domestic circular industries – Availability and use of high-quality ferrous scrap metal is an immediate way to lower carbon emissions from steel production
National energy policy	• Prospective gas reserve policy for Eastern Seaboard with government action on ensuring gas availability • Proactive investments into an intelligent grid capable of handling future [more intermittent] energy supply mix • National PtX strategy and a technology agnostic review of baseload power options
Competitive manufacturing ecosystem	• University and private/public partnership R&D programs – Industrial application research (industry 4.0) funding at universities as well as education and re-training a workforce that is fit for future – Internationally competitive R&D tax incentives, with premium-rate for manufacturing-linked R&D • Technology access – Maintain free and low tariff access to technologies and intermediate goods for the Australian manufacturing sector • Develop an internationally competitive heavy engineering sector capable of assuming a master contractor role in large capital projects – Incentivise creation of the sector as the government/Australia is the ultimate client though competency building and procurement process – Facilitate a collaborative accord process between unions and industry that improves both working conditions as well as construction productivity and provides certainty for the full life of the project (employment, conflict resolution, cost)
Mitigate cost disadvantages	• Accelerated depreciation of manufacturing investments, without caps to exclude larger projects • Grant funding incentives for domestic manufacturing to be treated as non-assessable, non-exempt income

MANUFACTURINGAUSTRALIA
manufacturingaustralia.com.au

Thank-you for the opportunity to comment on the proposed design of the Safeguard Mechanism Reforms.

Yours Faithfully,

Ben Eade
Chief Executive Officer
Manufacturing Australia

Steel

Steel is vital to modern economies and is the backbone of the construction, infrastructure and manufacturing industries, with more than 1.8 billion tonnes of steel produced worldwide in 2020.[21] It is the second most abundant man-made bulk material on earth after cement,[22] and the second-largest commodity value chain after crude oil.[23] Global demand for steel is forecast to increase by more than a third by the end of[24] Steel production is highly carbon intensive. For every tonne of steel produced in 2019, 1.83 tonnes of carbon dioxide were emitted,[25] with much of this linked to the use of metallurgical coal both as an input into the steelmaking process and as the source of 75% of steelmaking energy demand. The global iron and steel sector directly accounts for c.2.6 gigatonnes of CO2 emissions annually (including process emissions), which is c.7% of global energy emissions[26] and c.2.1% of Australia's greenhouse gas (GHG) emissions.[27] In order to ensure a sustainable future, the industry must find ways to reduce its GHG emissions in support of international goals to limit further temperature increases.

1.1 Steel production today

Steel is an alloy of iron and carbon. It typically contains less than 2% carbon, and is also alloyed with other elements that determine the grade and therefore use of the steel. For example, stainless steels typically contain significant amounts of nickel and chromium.

To produce steel, oxygen must be removed from iron ore through the chemical process of reduction, where oxygen from iron oxides bonds with a reductant containing carbon monoxide or hydrogen at temperatures of c.850°C to 1,500°C.[28] The need for high temperatures and the use of carbon as a reductant result in high CO2 emissions from steel production.

There are currently two major commercial processes used for steel production, and each has substantially different CO2 emissions footprints.

Integrated steelmaking (BF-BOF)

The integrated steelmaking process using a traditional **blast furnace and basic oxygen furnace (BF-BOF)** accounts for c.73% of steel production globally and c.74% of steel production in Australia.[29] It is also the only major approach globally that produces new, 'virgin' steel.

For this process, iron is typically produced by feeding a blast furnace with sinter (iron ore fines agglomerated into a product of suitable size and strength at high temperatures using metallurgical coal) and coke (metallurgical coal that has been heated to high temperatures in the absence of oxygen to create a physically strong, porous form suitable for its role in the blast furnace). Coke reacts with the oxygen in the 'blast' to produce carbon monoxide, which acts as the reductant to remove oxygen from the iron oxides in the sinter. The energy required for smelting also comes from the combustion of the coke. The resulting liquid iron is fed into a basic oxygen furnace where oxygen is injected at high velocity to react with, and remove, excess carbon, and different alloys are added to produce the required grades of steel. Each of these steps ultimately releases carbon dioxide, either from reactions in the steelmaking process or combustion to provide thermal energy required for the process.

On average, the emissions intensity for steel produced using BF-BOF technology is c.2 tonnes of CO2 per tonne of steel product, of which 1.4t is direct emissions and 0.6t is indirect emissions.[30]

Electric steelmaking

The electric steelmaking process uses electric arc furnace (EAF) technology to produce steel, where steel scrap is the major iron feedstock material. EAFs use high currents of electricity to melt the scrap to produce steel. EAF technology accounts for c.26% of steel production globally and c.26% of steel production in Australia.[31] Scrap-based EAF has a carbon emissions intensity of 0.4t CO2/t.[32]

The quality of the steel produced via the EAF route is dependent on the source and quality of the input materials.[33] Because of this, it is often necessary to add a high-quality iron source to achieve the desired steel quality. The amount of steel production via scrap-based EAF is also limited by the availability of cost-effective, high-quality scrap steel.

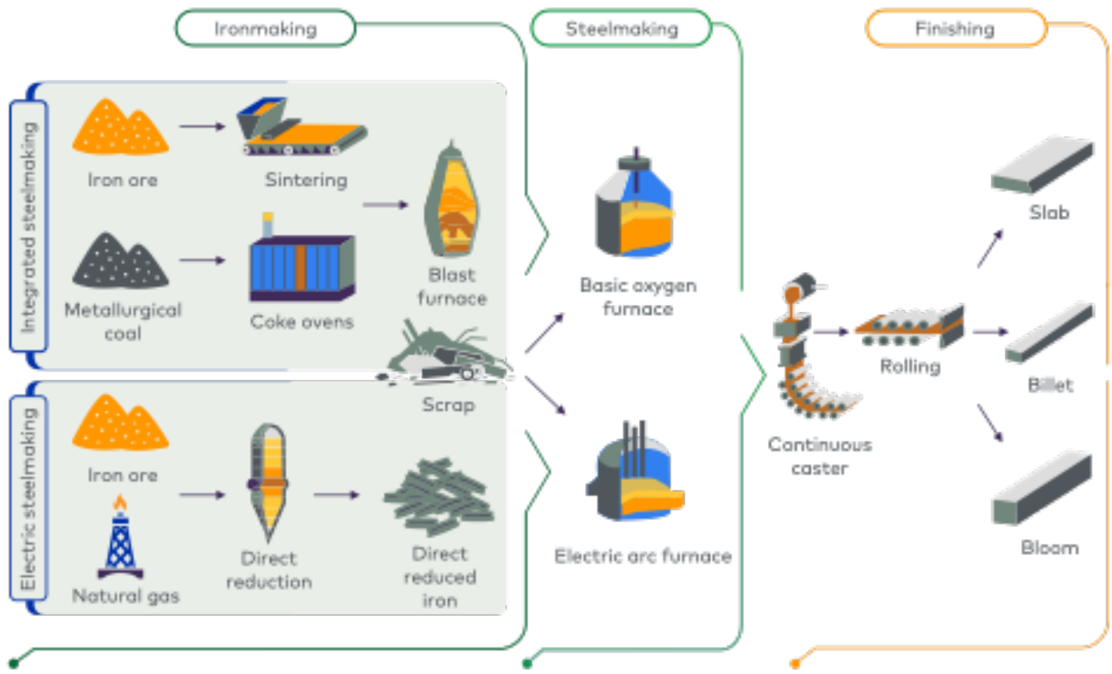
A more recent addition to EAF steelmaking is its combination with a direct reduced iron (DRI) plant, with the most common form of DRI produced via a natural gas-fired shaft furnace. DRI is made by removing oxygen from iron ore (generally in the form of lump or pellets) to produce metallic iron in the solid state, and currently relies on natural gas being reformed into carbon monoxide and hydrogen as the reductant. One hundred million tonnes of iron are now produced via DRI plants per year.[34]

Natural gas-based DRI-EAF results in 1.4t CO2/t in emissions.[35] As an example of underlying emissions from natural gas-based DRI-EAF, 1.0t CO2/t is the result of direct emissions, and 0.4t CO2/t is indirect emissions from electricity generation.[36]

1.2 Australian context for steel

Australia accounts for less than 1% of global crude steel production and is a net importer of steel[37] — in 2019, Australia produced c.5.5Mt of crude steel, and domestic crude steel consumption was c.6.1Mt.[38] Australian steel producers therefore compete against imported steel, including from China, where c.56% of global crude steel production occurred in 2020. Other major import competitors include South Korea, Taiwan, India and Japan.[39] Although Australia is a net importer of steel, BlueScope exports up to approximately 800,000 tonnes of steel products per annum from Australia, with principal export markets including North America and South East Asia.[40]

Figure 19
Iron and steelmaking processes



Source: 'BHP, Pathways to Decarbonisation', 5 November 2020 (diagram adapted)

While Australia's steel industry is small relative to other countries, it is a significant employer and contributor to the economy. The Australian steel supply chain, from iron and steel production through to downstream fabrication, employed 113,000 people in 2019-2020[41] and generated annual revenue of c.$29 billion.[42]

The Australian steel industry consists of two main steel producers, including: **BlueScope Steel** (flat steel products), **GFG Alliance's Liberty Primary Steel** (hot rolled structural and rail long steel products), and GFG Alliance's **InfraBuild** (reinforcing products, merchant bar, and pipe and tube).

Amongst these producers, crude steel is only produced by BlueScope and GFG Alliance, both of whom have significant existing capital assets deployed:

- **BlueScope Steel** operates an integrated blast furnace and steel mill located at Port Kembla, New South Wales (NSW), that has an annual production capacity of approximately 3.1Mt of crude steel. Steel coating and painting plants are located at Springhill (adjacent to Port Kembla Steelworks), Erskine Park, New South Wales (NSW); Hastings, Victoria (VIC); and Acacia Ridge, Queensland (QLD). BlueScope also operates pipe and tube manufacturing facilities in Adelaide and Brisbane, and national networks of distribution and rollforming facilities.[43]

- **GFG Alliance's Liberty Primary Steel** operates an integrated blast furnace and steel mill located at Whyalla, South Australia (SA), that has an annual production capacity of c.1.25Mt of cast steel and hot rolled products.[44] **InfraBuild,** its construction steel maker, operates electric arc furnaces in Sydney, NSW, and Laverton, VIC, with an annual steel production capacity of c.1.5Mt, as well as four rod and bar rolling mills.[45]

1.3 Challenges in transitioning to net zero emissions

There are several challenges to achieving the goal of net zero emissions in the Australian steel industry that are not simply addressed by adopting general zero-emissions technologies used in other sectors like electrified transport or renewable electricity for current electricity requirements.

a. Technology readiness and choices

There is significant research and development being undertaken globally to identify and implement technologies to reduce/eliminate the emissions from the manufacturing of steel. The potential approaches to emissions reduction vary in their technology maturity (readiness), complexity, cost and level of CO2 reduction. The following table provides examples of the potential emissions reduction approaches, categorised under five main headings.

Efficiency and alternative feedstock options only reduce CO2 emissions rather than eliminate emissions completely. These options could be effective interim steps that can be implemented in the short term but are unlikely to be a long-term solution.

Increased recycling using the EAF process, commonly used today to recycle scrap, can utilise renewable energy to produce steel with very low or almost zero emissions. However, scrap metal is in finite supply and the expectation is that there is insufficient supply of scrap to meet total global steel demand. The International Energy Agency (IEA) forecasts that by 2050 only c.36% of global steel will be produced via scrap-based electric furnaces under the Stated Policy Scenario, given scrap availability and total steel demand.

Carbon capture, use and storage (CCUS) is another potential option for decarbonisation; however, there are several challenges for its application in the steel industry:

- Integrated steelmaking has multiple sources of CO2 across the plant (e.g. sintering and coke production, blast furnace, basic oxygen furnace) with varying concentrations, making capture diffuse, difficult and expensive
- Carbon capture and storage (CCS) is best implemented where there is a storage basin for the CO2 available in close proximity to steelmaking facilities; gas transport (e.g. by pipeline or ship) adds to the cost of the solution

Table 4
Potential emissions reduction for steel

Emissions reduction options	Increased efficiency	Alternative feedstock	Increased recycling	Carbon capture, use and storage (CCUS)	Breakthrough production technologies
Description	Improve efficiency of existing BF-BOF operations	Use alternate feedstocks to act as a reductant	Avoid emissions from new virgin steel production by using more recycled scrap in EAFs	Capture emissions from existing operations and either use or store CO2	Replace BF-BOF with commercial application of breakthrough steel production technologies
Examples	• Waste heat recovery • Increase scrap-to-steel ratio • Increase use of higher-quality iron ore and/or premium hard coking coal	• Using biomass as a reductant in a blast furnace • Using hydrogen as some of the reductant in a blast furnace *e.g. Charcoal is commercially used to substitute for a proportion of coal used in blast furnaces, primarily in Brazil*	• EAF plants are currently being used globally to melt scrap — accounts for c.50% of steel production outside of China • EAF based on renewable energy has the potential for significant emissions reduction	• Capturing and using CO2 for industrial uses like food and beverage manufacturing or producing biofuels or chemicals • Capturing and storing CO2 from across some or all of an integrated steel plant *e.g. COURSE50 in Japan targets 30% CO2 emissions reduction from BF-BOF by capturing CO2 from the BF gases and using a higher H_2 content to partially substitute for coke, with demonstration scheduled for 2030 and commercial implementation by 2050*	DRI-EAF process using: • Natural gas and CCUS • Hydrogen • Direct electrification *e.g. The HYBRIT project began operating a pilot plant in August 2020 in Sweden, targeting a 1Mt/year demonstration plant by 2025 at 0.025t CO2/t, assuming zero emissions electricity powering the EAF and green hydrogen feeding the DRI. The HYBRIT plant is currently producing sponge iron at pilot scale, but this technology is yet to be commercialised.*
Timing (years)	Now	0-5	0-5	5-10	10+
Status	Technology readily available	Requires a secure supply chain for biomass	Technology readily available, volume limited by scrap availability and capital investment in renewable energy. Contaminants in scrap may limit use for some steel grades. Pig iron addition may be required to produce some end products.	Not available on industrial scale, is high cost and difficult to retrofit to existing BF-BOF operations	Natural gas-based DRI-EAF is available today; however, CCUS is not at industrial scale. Hydrogen-based DRI-EAF technology currently not proven or available at industrial scale and is high cost.

Decreasing level of CO2 emissions →

For these reasons, the application of CCUS within steelmaking is more complex than in some other emissions-intensive industries, and therefore less likely to become the preferred decarbonisation technology pathway for Australian producers.

Hydrogen-based DRI-EAF (H_2 natural gas for thermal energy and as a reductant in BF-BOF steelmaking and natural gas-based DRI, respectively. Minor emissions arise from the use of certain process equipment, and a small amount of coal which must be used in the manufacturing process.[46] However, the technology is currently only at the pilot stage of development.

Given the early stage of technology development and deployment, the IEA estimates that only c.8% of worldwide production capacity by 2050 (Sustainable Development Scenario) will be produced utilising H_2 DRI-EAF technology. BF-BOF iron and steelmaking will still comprise between c.30% (Stated Policies Scenario) and c.52% (Sustainable Development Scenario) of worldwide production capacity by 2050.[47] Therefore, finding ways to make BF-BOF iron and steelmaking significantly less emissions intensive will be almost as important as developing breakthrough technologies.

b. Delivery of cost-competitive energy

Globally cost-competitive low/no emissions energy will be a key factor in driving the decarbonisation of the steel industry.

Alternatives to the current BF-BOF process (e.g. DRI) will significantly increase demand for energy in the form of either hydrogen and/or natural gas (in combination with CCUS), which replaces coal to reduce the iron ore. Production of steel using EAFs will also require zero emissions electricity to power the EAF.

For example, the H_2 DRI-EAF process requires hydrogen to be produced via electrolysis using renewable electricity or via steam methane reforming of natural gas in combination with CCUS. The energy required to produce 3.1Mt of steel would be 12.1TWh. This is approximately 22% of the total renewable electricity generated in Australia in 2019.[48]

c. Development of alternative reductant supply chains

The size and cost of these supply chains are significant. For example, to produce 4.35Mt of 'green' steel, equivalent to BlueScope's Port Kembla and GFG Alliance's Whyalla annual production, c.310kt of hydrogen would be required. This in turn would require c.1,600MW of electrolysis-based hydrogen production, which is equivalent to approximately eight of the world's largest currently planned electrolysis plants (e.g. in May 2020, Shell announced plans for a 200MW electrolyser in Rotterdam by 2023).[49]

The cost of hydrogen will also need to decrease dramatically to incentivise the adoption of 'green' steel technology. The current price of hydrogen from electrolysis in Australia is estimated at between $6.50/kg and $7.50/kg, but this is forecast to fall to $2.00/kg to $3.50/kg by 2030. To achieve cost parity (on an operating cost-only basis) with hard coking coal at $175/tonne, hydrogen would need to be priced at $0.65/kg.

Establishing the required capacity and infrastructure at the scale necessary to enable hydrogen-based steel production would significantly influence the feasibility and timing for 'green' steel manufacturing in Australia.

d. Availability of suitable and competitive raw inputs

A key challenge in adopting DRI technology is domestically sourcing cost-effective iron ores of the right grade to produce the required pellets for DRI. The DRI steelmaking process currently requires the use of iron ore pellets with 67% to 68% iron (Fe) content. Pellets are often made from magnetite ore, or friable hematite, and the ores are typically beneficiated to generate a product with low impurities (e.g. below 3% in contaminant materials such as silica and alumina). Today, only an estimated 24% of global iron ore production is pelletised, with the remainder being directly shipped lump and fines currently unsuitable for DRI processes. Pelletisation and ores with higher iron ore content increase the cost of raw inputs versus the BF-BOF process today.

A project has recently been announced (Primetals Technologies' hydrogen-based fine-ore reduction (HYFOR) pilot project) to trial DRI technology that can directly use fine iron ore concentrates from beneficiated ore (without the need for a pelletising process). However, this will still need to be proven at scale and could impact the timing of 'green' steel technology adoption.

e. Rate of global steel industry decarbonisation

The rate at which the steel industry decarbonises globally will vary greatly by region. There is unlikely to be a single low or zero emissions iron and steelmaking technology adopted worldwide. BHP considers that regional decarbonisation pathways will not easily converge due to differences in the age of existing infrastructure, availability of low carbon fuels, domestic carbon policies and net steel trading positions.

The decarbonisation transition period may disrupt any views of a level playing field across global regions. Given the Australian steel industry is trade exposed with markets often distorted by subsidies, trade barriers and overcapacity, the adoption of emissions-reduction technologies during this transitionary period will be influenced in practice by the level of incentives/disincentives relative to other regions.

f. Capital intensity

The steel industry is highly capital intensive, with assets that have long (often multi-decade) lifetimes. The replacement value of existing assets (i.e. BF-BOF) globally is estimated in the range of US$1.5 trillion to US$2.0 trillion based on the 1,350Mt of steel produced today, yet the average age of the global blast furnace fleet is only 13 years, with an expected technical life of 40 years.[50] More than half of global iron and steelmaking capacity is in emerging economies, with much of it only installed in the last 10 to 20 years. Accordingly, there is significant sunk investment in existing technology.

Capital cost for the construction of a new H_2 DRI-EAF is estimated to be broadly comparable to the cost of a new BF-BOF. However, this does not include capital for the construction of a hydrogen manufacturing plant — this could add a further US$375 million to US$950 million to the total cost of a new plant.

This means that a shift in Australian steelmaking technology requires significant investment. The total capital cost to replace Australia's existing BF-BOF steel production assets with H_2 DRI-EAF technology would be in the range of US$4 billion to US$6 billion, excluding hydrogen infrastructure.

The incentive to spend this capital is also challenged. There is no incremental volume or operational benefit expected from investing in H_2 DRI-EAF vs the BF-BOF technology — in fact, hydrogen-based DRI-EAF is expected to have 25%-35% higher operating costs than BF-BOF. There is, of course, technology development risk associated with investing this capital before the technology is proven commercially. This makes it very challenging for steelmakers to invest in emerging and breakthrough technology that will bring about material emissions reductions while remaining economically viable.

1.4 Steel pathways to net zero

H_2 DRI-EAF steel production is currently considered to be the most prospective long-term technology answer for large-scale decarbonising of the steel industry. However, the adoption of hydrogen-based steel will take many years, and a number of intermediate technology options will be required to reduce emissions while hydrogen-based technology matures and is commercially proven at scale.

Based on the multitrillion-dollar installed capital base of the global steel industry that is today based on BF-BOF technology and the criticality of steel to future global development, there is a significant incentive to find a technically and economically viable solution to decarbonising steel production without requiring a wholesale shift to H_2 DRI-EAF production. As such, the below pathway represents a view of how steel can be decarbonised based on the current view of technology, while still leaving open the potential for future breakthrough technology developments to change the pathway (for example, to decarbonise existing BF-BOF infrastructure).

Given this and other considerations in this report, the pathway to the decarbonisation of the Australian steel industry is based around three stages.

At each stage of the pathway the technical complexity and capital requirements increase from the previous stage, enhancing the potential risk.

Table 5
Pathway to the decarbonisation of the Australian steel industry

Stage	Options
Enhance	Energy and resource efficiency: • Renewable electricity • Waste gas recovery • Increased scrap utilisation • Higher-purity ores
Bridge	Reconfiguration of existing assets: • Biochar as pulverised coal injection replacement • Hydrogen injection as partial coal substitute
Breakthrough	Implementation of breakthrough technologies: • Hydrogen DRI-EAF

Case study: Existing emissions reducing efforts in the Australian steelmaking industry

The Australian steel industry has already started on the journey to decarbonisation and has implemented a number of emissions-reducing initiatives.

22 Turbo Alternator Project

Generation of electricity from the No. 1 Power House facility at the Port Kembla Steelworks ceased in July 2015, as it had become uneconomical due to the age and condition of equipment and the cost of natural gas. The No. 4 Alternator was one piece of equipment from the facility which was considered to have remaining life. The decommissioning of the No. 6 Blast Furnace in 2011 resulted in No. 21 and No. 22 Turbo Blowers at the No. 2 Blower Station becoming redundant. The steam turbines on these machines were in good condition, with the controls on No. 22 making it the more suitable for driving an alternator.

The aim of the project was to relocate the No. 4 Alternator to the No. 2 Blower Station and power it with the No. 22 Turbo Blower's steam turbine. The 'new' machine would be known as the 22 Turbo Alternator (22TA).

The benefits from this project include improved efficiency and reliability of electrical power generation within the steelworks, utilisation of excess by-product fuels which were previously flared to produce steam for the alternator (GHG reduction benefits) and reduction of electricity purchased from the NSW grid.

The 22 Turbo Alternator has been operational since September 2017.

(Continued)

Relevant data for the full financial years since then are:

FY	Ave generation (MW)	Total generation (MWh)	NSW grid intensity (tCO2e/ MWh)	GHG reduction (tCO2e)
2019	9.89	86,658	0.82	71,060
2020	9.42	82,555	0.81	66,870
2021	10.28	90,090	0.81	72,973

Finley PPA

In FY2018, BlueScope concluded an energy strategy review for its Australian operations. A key outcome included signing a seven-year, 233,000 megawatt hour (MWh) per annum Power Purchasing Agreement with ESCO Pacific for a new 500,000 panel solar farm at Finley, New South Wales. The agreement is one of Australia's largest corporate PPAs and equivalent to 20% of BlueScope's Australian purchased electricity demand.

1.5 Australia's future competitiveness with low emissions steel

High-level analysis suggests that H_2 DRI-EAF steelmaking is approximately 25%-35% more expensive on an operating cost basis today than traditional BF-BOF production.

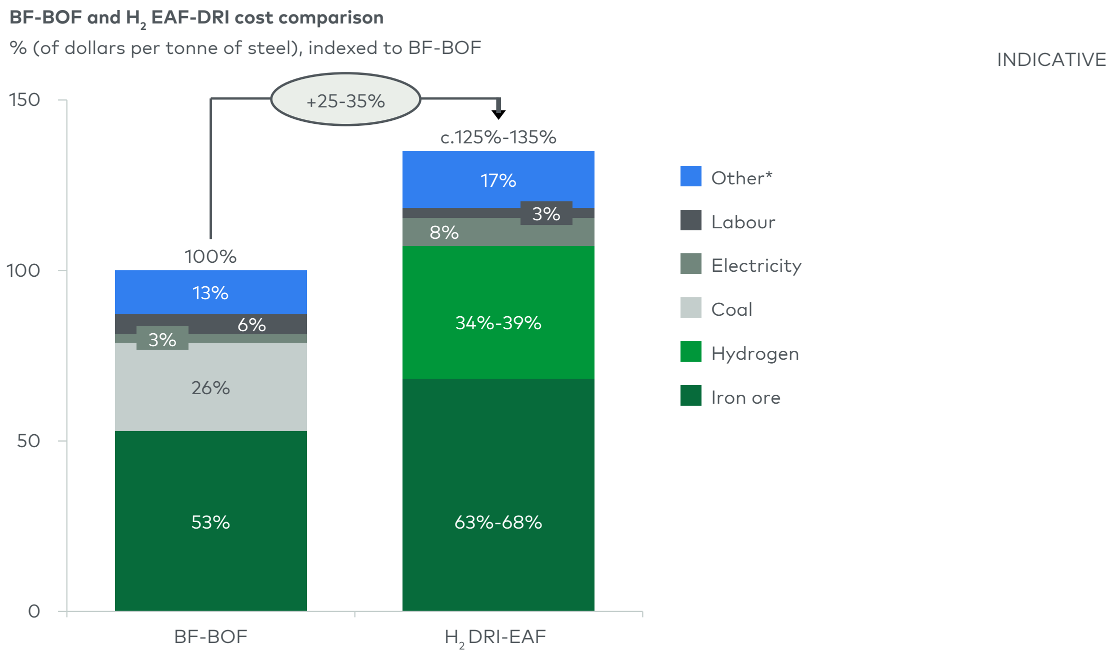
The differential in operating costs between BF-BOF and H_2 DRI-EAF production is largely driven by the price of coal and hydrogen, and the following chart provides the relevant sensitivities:

Over the longer term, Australia should have a number of natural competitive advantages in a decarbonised world that align it to being a competitive player in the global steel market, namely:

- A combination of solar and wind resources that should be able to provide Australia with an energy cost advantage
- Access to high-quality iron ore, albeit with some need to focus more on beneficiation of ores rather than extracting and exporting if BF-BOF ceases to be the primary global method of steel production
- Proximity to countries where steel demand is forecast to be high (e.g. Vietnam, Malaysia, Thailand and Indonesia)

There may also be potential to grow the Australian steel industry in the transition to net zero through exports. Previous analysis by the Grattan Institute has estimated that it may be more economical to produce 'green' steel in Australia and ship the finished product to countries with large downstream manufacturing such as Japan and Indonesia, which have inferior renewable resources, rather than ship the natural resource (i.e. iron ore) for further processing in those countries. Grattan estimated a 7% increase in market share in the global steel market would create an additional 25,000 jobs.

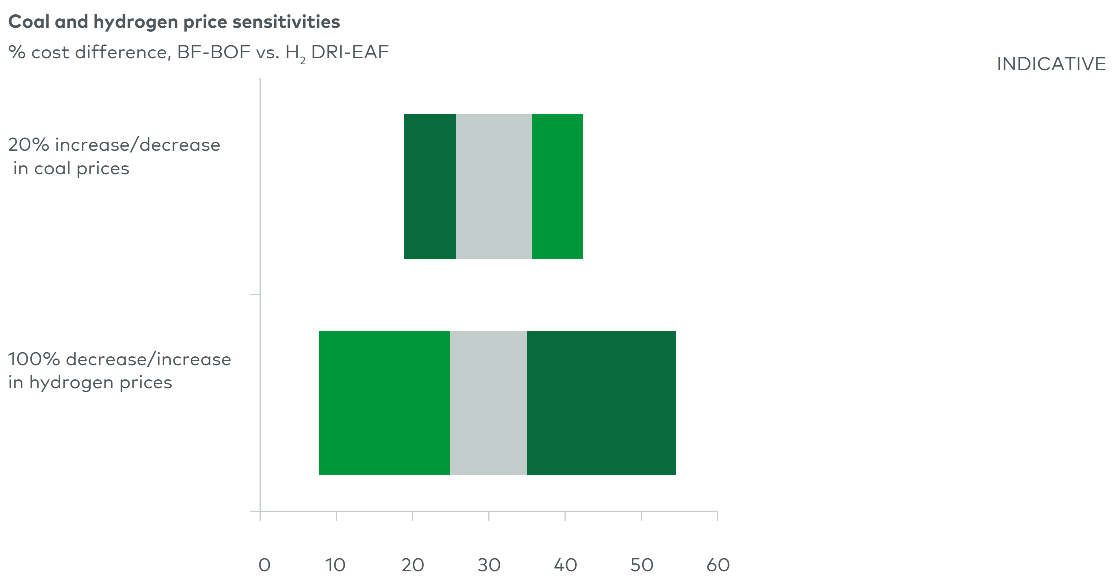
Figure 20
BF-BOF and H_2 DRI-EAF cost comparison



*Other includes ferroalloys, fluxes, electrodes, coal transport, iron ore transport, refractories, industrial gases, by-product credits, thermal energy Analysis as of July 2021

Source: Grattan Institute, Start with Steel; JP Morgan 2021 Green Steel; L.E.K. analysis

Figure 21
BF-BOF and H_2 DRI-EAF, coal and hydrogen price sensitivities



Notes: Analysis as of July 2021

Source: Grattan Institute, Start with Steel; JP Morgan 2021 Green Steel; L.E.K. analysis

However, maintaining and growing the Australian steel industry cannot be taken for granted — key enablers of Australian steelmaking competitiveness in a transition to net zero are:

- A policy environment that facilitates investment both in new steel capacity based on breakthrough technology and in emissions reduction upgrades during the remaining life of existing capacity
- Low-cost 'green' hydrogen, with development of a green hydrogen industry underpinned by high rates of renewable power generation and globally competitive delivered electricity costs

Equivalent treatment of domestic industry versus global competitors, recognising that in practice:

Not all regions are moving at the same pace towards green steel outcomes and emissions reduction obligations

Decarbonised steel is likely to be more expensive to produce than steel using existing technology

Some governments will provide high levels of support for their steel industries

- Increased differentiation between low emissions steel production and higher emissions steel and, where appropriate, government leadership in procuring low emissions steel that meets Responsible Steel™ global standards
- Developing raw material supply chains for future low emissions steel production

Aluminium

Aluminium is an important material for modern economies and is used for a wide variety of applications in transportation, construction, electrical, consumer goods, and food and beverage sectors. It has a range of favourable characteristics, including its light weight, ease of shaping, high strength-to-weight ratio, corrosion resistance, electrical conductivity, heat dissipation, aesthetic properties and recyclability.

In the 2019-2020 financial year, alumina/bauxite and aluminium metal were Australia's eighth- and seventeenth-largest exports by value, respectively, and aluminium was Australia's highest-earning manufacturing export.[51]

The aluminium sector today is a significant source of carbon emissions, accounting for c.6% of Australian emissions[52] (c.2% globally).[53] Production of primary aluminium requires significant quantities of electricity (typically c.14MWh per tonne of primary aluminium smelted), with aluminium sometimes described as 'solid electricity'.[54]

2.1 Aluminium production today

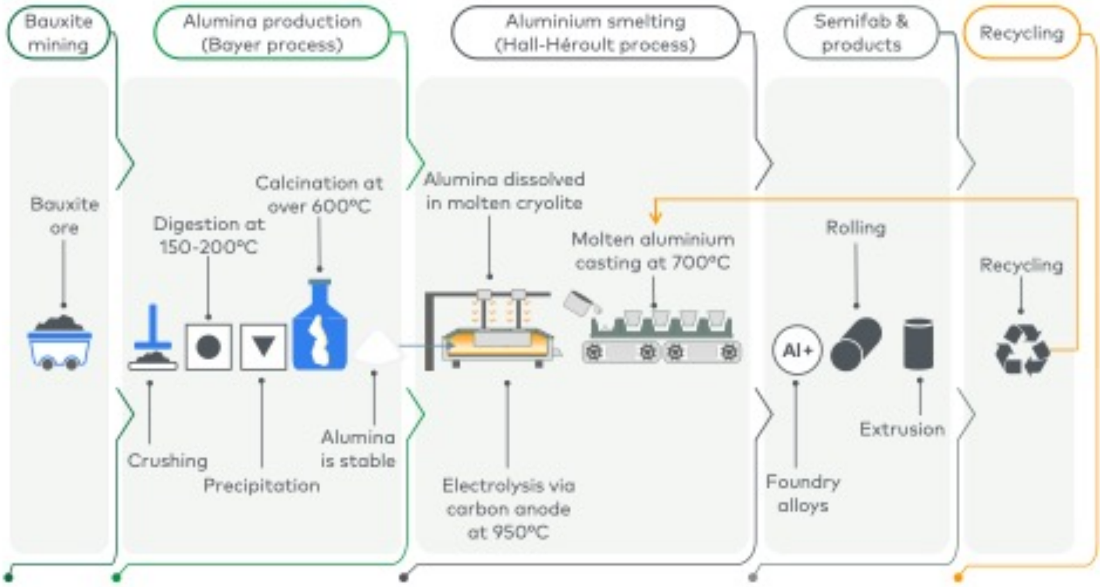
Aluminium is a metal that is produced from bauxite ore following two key stages.

The first stage is production of alumina from bauxite. Once extracted from the ground, bauxite is converted into alumina (aluminium oxide) using the Bayer process. Crushed bauxite is placed into a digester that dissolves the alumina content of the ore in a sodium hydroxide solution under pressure at 150°C-250°C. The solution is then cooled, and impurities and bauxite residues settle and are pumped into storage dams. The alumina-sodium hydroxide solution is filtered and then placed in a precipitator to form alumina crystals through mechanical stirring, seeded with previously precipitated alumina. The precipitated alumina is washed and then dried through calcination at more than 1,000°C, forming alumina — a dry, white aluminium oxide powder.

Alumina can be exported from an alumina refinery to aluminium smelters globally as either the dry aluminium oxide powder or the intermediate hydrate product that is produced prior to calcination.

In the second stage, alumina is converted into aluminium metal using electrolytic reduction in the application of the Hall-Héroult process. Alumina is dissolved in molten cryolite (sodium aluminium fluoride) in an electrolytic cell called a 'pot'. The pot is lined with carbon blocks and insulating bricks that form the cathode, while a carbon anode is used to conduct electricity into the pot. Multiple pots form a 'potline' where current flows into a pot from its positive anode, through the cryolite to the lining of the pot, and then on to the anode of another pot and throughout the rest of the potline in this fashion. The high electrical current flowing through the potline splits the aluminium and oxygen

Figure 22
Aluminium production process



Source: The Australian Aluminium Council, How Aluminium Is Made and Taylor Collision, Capral Limited (CAA) (diagram adapted)

from the alumina while maintaining the temperature of the process at around 950°C. Molten aluminium is periodically tapped from the pots and transported to a casthouse for casting into ingots, slabs, billets and t-bars at around 700°C.

Carbon emissions result from both alumina production and aluminium smelting:

- **Alumina production** releases 0.71t of CO2e for every tonne of alumina in Australia[55] (equivalent to c.1.4t CO2e for every tonne of primary aluminium produced), which is significantly lower than the global average of c.1.21t of CO2e per tonne of alumina.[56] Natural gas and coal are used to generate the heat and pressure required for digestion of the bauxite, and the volume of the bauxite and sodium hydroxide results in this step accounting for c.70% of alumina production emissions. The calcination process broadly accounts for the other 30% of alumina emissions, with the high temperatures for calcination achieved through the application of heat from gas-fired boilers.
- **Aluminium smelting** releases 12.57t of CO2e for every tonne of aluminium in Australia (on average), largely due to the generation of electricity required to produce the necessary current.[57] The carbon intensity of production reflects the carbon intensity of electricity generation in the proximate location to where the aluminium is produced and therefore varies across Australia (and the world). A smaller amount of direct emissions (including perfluorocarbon)

of 1.85t of CO2e per tonne of aluminium is released through the slow.[58] These anodes are made from petroleum coke and pitch and are often produced on-site today using thermal energy from natural gas.

Electrical efficiency is a key driver of the economic performance of an aluminium smelter, and producers periodically invest to apply more advanced potline technologies to improve efficiency. The modular nature of smelters with multiple potlines enables trials of new technologies and progressive upgrades to occur in existing plants.[59]

While being large users of electricity, primary aluminium smelters can also play a stabilisation role in electricity networks as a major source of network inertia. Smelters can quickly vary their energy consumption to respond to electricity market conditions and outages, and their demand can be an order of magnitude larger than any other major user on the network. Smelters can change the electrical current on potlines or rotate current through different potlines to reduce load, or rapidly shut down in an emergency to stabilise the grid. The ability for smelters to shed load does have limitations, as smelters cannot shut down for more than a few hours without ample warning, as the cryolite will turn solid and destroy the potlines.[60] Nonetheless, the flexibility of smelters to rapidly change their electricity demand provides the grid with an important stabilisation capability for use in emergencies.

2.2 Australian context for aluminium

Australia plays a critical role in the global market for alumina and aluminium, and the industry is expected to become more important as 'lightweighting' continues to impact transport and other industries in a net zero carbon world.

Australia is the largest producer and second-largest exporter of bauxite globally, the second-largest producer of alumina (but largest exporter), and the sixth-largest producer of primary aluminium. In 2020, Australia produced c.102Mt of bauxite (of which 37% was exported), c.21Mt of alumina (of which 84% was exported), and c.1.6Mt of aluminium (of which 90% was exported).[61]

Global aluminium prices are largely determined at the London Metals Exchange (LME) and have ranged from US$1,460/t to US$2,630/t over the last decade.[62] Regional premia can apply (e.g. Midwest, Japan) as well as product premia for shape and quality. Alumina pricing is also determined globally, with a number of benchmark indices (such as Platts, Fastmarkets and CRU) used as reference prices.

This important trade position means that significant carbon emissions are created in Australia for production that is then fabricated and used overseas.

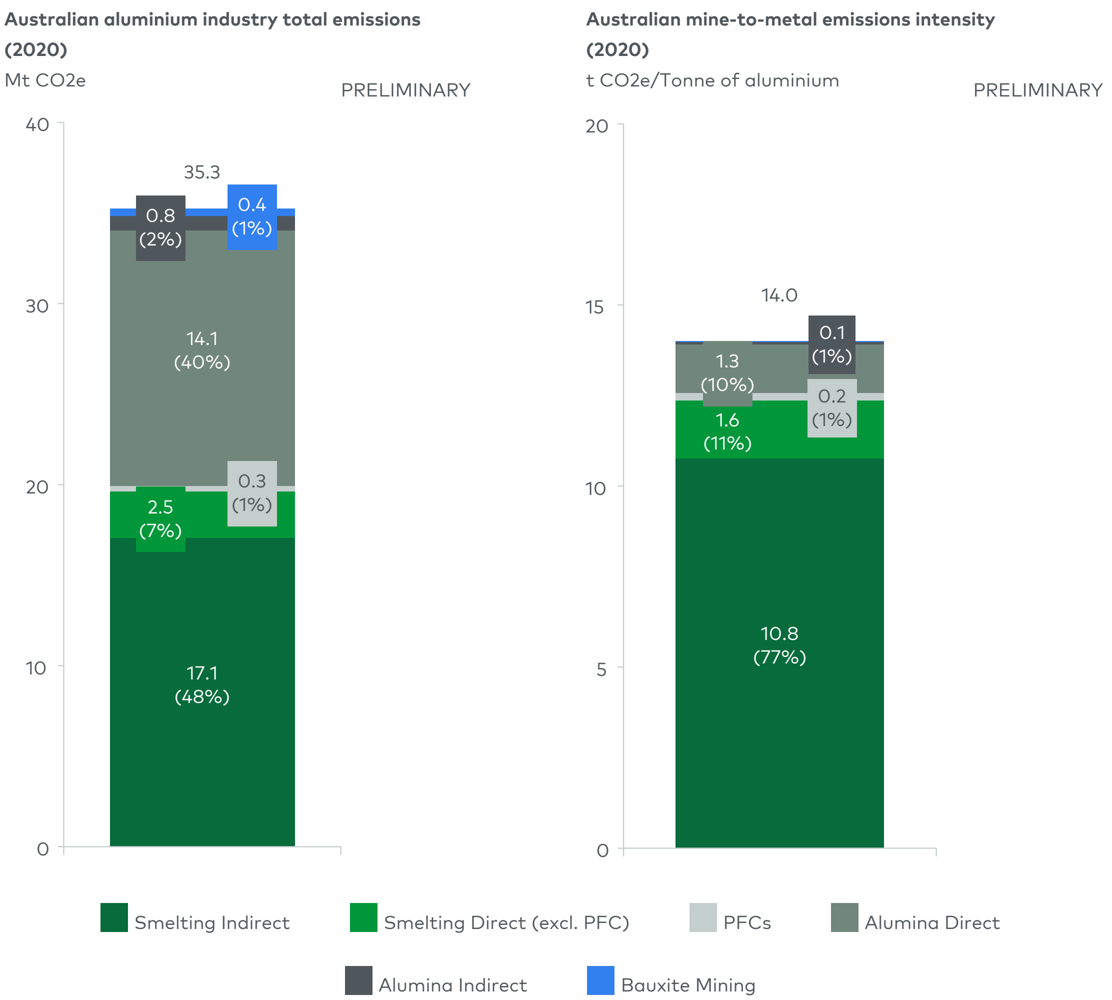
Australia's absolute carbon emissions for alumina and aluminium production are relatively evenly balanced as a result of Australia producing and exporting much more alumina than it consumes in aluminium production, while the emissions from Australian aluminium production on a per tonne basis (including emissions for the alumina used in this aluminium production) are much more heavily weighted to emissions from electricity used in smelting than is the case for combined emissions from all Australian alumina and aluminium production.

Australia has four primary aluminium smelters across four states:

- **Tomago Aluminium** is located at Tomago near Newcastle, NSW. It is an independently managed joint venture between Rio Tinto, CSR, and Hydro Aluminium, and has been operating since 1983. It produces 590kt of aluminium per annum, of which 90% is exported to the Asia-Pacific region.[63]

Figure 23

Australian aluminium industry total (left) and mine-to-metal emissions intensity (right)



Source: Australian Aluminium Council, Australia's Aluminium Industry, March 2021 and Australian Aluminium Council, Sustainability Data 2000 to 2020

- **Boyne Smelter** is located at Boyne Island near Gladstone, Queensland. It is a joint venture led by Rio Tinto with six other parties and has been operating since 1982. It has a capacity of more than 500kt per annum.[64]
- **Portland Aluminium Smelter** is located at Portland on the south-western coast of Victoria. It is a joint venture between Alcoa of Australia (Alcoa Corporation and Alumina Limited), CITIC, and Marubeni Aluminium Australia,[65] and has been operating since 1986. It has a nameplate production capacity of 358kt per annum and produces ingot.[66]
- **Bell Bay Aluminium** is located at Bell Bay near Launceston, Tasmania. It was the first aluminium smelter built in the southern hemisphere and has been operating since 1955. It produces approximately 190kt per annum of ingot, block and t-bar.[67]

Aluminium is particularly well suited to being recycled because it loses none of its quality parameters during recycling and so can be recycled forever. Scrap remelt also has significantly lower carbon intensity than the creation of primary aluminium.

Australia has only one post-consumer aluminium remelt facility, the Weston Aluminium facility in Kurri Kurri, which produces a variety of products including deoxidants, base metal sows and Aldex. There is also a pre-consumer remelt facility within the G James operations for recovery of scrap from its own extrusions facility. More than 95% of Australian-generated[68] aluminium scrap is exported to remelt facilities overseas where the combined economics of energy costs, separation of aluminium grades and overall logistics costs make it more attractive. It is very difficult to use recycled material in primary aluminium smelters, as the contamination of scrap (including any water, oils and other contaminants) can be disruptive to production and may cause explosions.

Aluminium is also used in Australia to fabricate extruded products such as door and window frames, truck bodies, marine vessels, solar panel rails, and screening and fencing. Aluminium billet is heated to around 450°C and then extruded via a ram through a shaped die to create the desired profile shape. Australia has a domestic extrusion capacity of approximately 160,000 tonnes per annum. Capral Aluminium is Australia's largest extruder and operates manufacturing plants across five states. In contrast to Australia's export of aluminium metal, over 30% of Australia's extruded aluminium products are imported[69] and have been considered 'dumped' from some markets at below cost.

The Australian domestic extrusion manufacturing industry has consistently suffered injury from dumped imports. Anti-dumping and countervailing duties having been in place since 2010 on certain Chinese exporters, and currently there are dumping measures in place from certain exporters from China, Malaysia and Vietnam.[70] This unfair competition continues to affect industry members' ability to re-invest capital.

2.3 Challenges to transitioning to net zero emissions for aluminium

While the specific decarbonisation challenges for alumina and aluminium differ, there are several aligned themes in terms of developing a net zero pathway.

- **Alumina — zero emissions technologies for process heat and pressure.** The temperatures required for the Bayer process are high in an industrial sense, higher than the temperatures achieved by electrical heat pumps. Cofired coal-gas-based boilers and gas-fired calciners are the key technology used today to achieve the necessary process temperatures, resulting in emissions.
- **Primary aluminium — firm and competitive zero emissions electricity from the grid.** The major component of emissions for primary aluminium production is scope 2 emissions from electricity provided from the grid, and these generators and emissions are not controlled by the smelter. In NSW, over 75% of electricity in FY2021 was supplied by coal-fired power stations, resulting in relatively high levels of carbon emissions.[71] These emissions vary by state, with over 75% of Tasmanian electricity supplied by hydro and only 16% sourced from other markets and generators relying on fossil fuels. In other markets, such as New Zealand and Canada, electricity supplied is typically hydro dominated, resulting in significantly fewer carbon emissions per tonne of aluminium.[72,73] Many aluminium smelters globally are tied to captive power sources, some of which are fossil fuel fired, which poses a specific challenge for decarbonisation for those smelters[74] versus those tied to a grid that is decarbonising over time.
- **Primary aluminium — technologies to eliminate emissions from anodes.** A smaller component of aluminium smelting emissions results from the use of carbon-based anodes in the potlines that degrade over time as part of the electrolytic process.
- **Aluminium extrusions — firm and competitive zero emissions electricity from the grid.** The major component of carbon emissions from extrusion activities is in usage of electricity and gas, which is determined by the emissions of the electricity and gas supplied.

a. Technology readiness

Decarbonisation of the electricity network supplying primary aluminium smelters is the largest potential opportunity for carbon emissions reduction, and the technologies for this transition are well known. Firming of the electricity supply is critical for the efficient operation of aluminium smelters.

The replacement of carbon-based anodes with inert anodes has been developed over a number of years. Rio Tinto and Alcoa have convened a joint venture called ELYSIS, which is expected to commercialise its inert anode technology by 2024. The joint venture has announced that the Alma smelter in Quebec will be used as the prototype facility for the ELYSIS technology.[75] Other competitors, including Rusal, have also begun test deliveries of inert anode technologies to reduce carbon emissions to less than 0.01t of CO2/tonne of aluminium.[76]

Replacement of cofired coal-gas boilers in alumina refining is more challenging, as the potential for conversion to renewable-based electricity is unlikely to achieve the required process temperatures. An additional challenge is that full electrification of an alumina refinery can result in demand from the refinery significantly outstripping supply of renewable power in some (but not all) regions. However, alternatives are being tested for both the bauxite digestion and alumina calcination processes.

For bauxite digestion, Alcoa of Australia has recently announced technical and commercial studies on a technology known as mechanical vapour recompression (MVR), supported by ARENA. Mechanical vapour recompression involves electrifying steam production to displace fossil fuel-derived thermal energy, substantially boosting production efficiency and lowering associated emissions. Should the studies be successful, Alcoa of Australia announced that it plans to install an MVR module on its Wagerup alumina refinery by the end of 2023. The technology has the reported potential for reducing carbon emissions in alumina refining by 70%, as well as reducing water use intensity. There is also some early-stage research for the use of electric boilers for bauxite digestion.[77] In March 2020, Brazil's largest aluminium producer, CBA, introduced a new wood-chip biomass boiler at its alumina refinery to replace its natural gas and oil-fired boilers, lowering emissions from 0.51t to 0.33t CO2e/tonne of alumina.[78] Norsk Hydro has invested in a fuel-switch project to replace heavy fuel with natural gas at its Alunorte alumina refinery in Brazil, with an estimated emissions reduction of 600,000t CO2e per annum.[79]

For alumina calcination, a potential process alternative is to replace the gas calciners with green hydrogen-based boilers. Rio Tinto is currently undertaking a feasibility study into this alternative with the support of ARENA. ARENA has also funded research, led by the University of Adelaide, into concentrating solar thermal (CST) technologies to generate the industrial process heat required for alumina smelting.[80] There are limited technology options for electrification of process heat for calcination; however, there is some early-stage research to enable retrofits to current systems to use electricity.[81]

b. Delivery of cost-competitive energy

The delivery of cost-competitive and renewable electricity is the most important challenge for the primary aluminium sector to resolve in achieving a net zero outcome. On a per tonne basis, electricity is the source of over 80% of emissions for aluminium production in Australia and is therefore the largest potential area for reduction on a path to net zero.[82] Australia exports the majority of its aluminium into a globally traded market. As prices are largely set at the LME, profitability of an aluminium smelter reflects the cost position of each smelter on the cost curve. Profitability over the long-term price cycle will determine the ability of the smelter to remain operational.

c. Reliable delivery of cost-competitive energy

However, cost-competitive energy must also be consistently available, and 'firming' of electricity delivery will be a critical component of decarbonisation for aluminium. Smelting is most efficient when operations are stable, and aluminium producers need a network where variability in electricity delivery can be removed. As mentioned above, aluminium smelters have an important role to play in network inertia and stability; however, this is a secondary role, as smelters see increased inefficiency with each electricity interruption.

Alumina refineries already provide some degree of demand response to electricity networks, and this capacity may increase should technologies to increase electrification of the alumina refining process be implemented.[83] The additional benefit of alumina refineries in demand response over aluminium smelters is that they do not have the same concerns regarding potline freezing.

d. Rate of global industry decarbonisation

As the primary driver of carbon emissions for aluminium production is the underlying emissions of the supplied electricity, the differential rate of decarbonisation globally may impact the cost position of smelters differentially. While some smelters are already supplied by low carbon electricity, others, such as those in Australia, are ultimately supplied by higher carbon electricity generation. The decarbonisation transition period may disrupt any views of a level playing field across global regions, with distortions due to subsidies, trade barriers and overcapacity impacting the relative competitiveness of Australia versus its peers.

2.4 Aluminium pathways to net zero

As described above, the most important activity for decarbonisation of the Australian aluminium industry is the decarbonisation (and associated firming) of the electricity grid. However, there are other steps that will be important to achieving a net zero emissions position and can be taken by the aluminium industry itself in the shorter term.

2.5 Australia's future competitiveness with low emissions aluminium

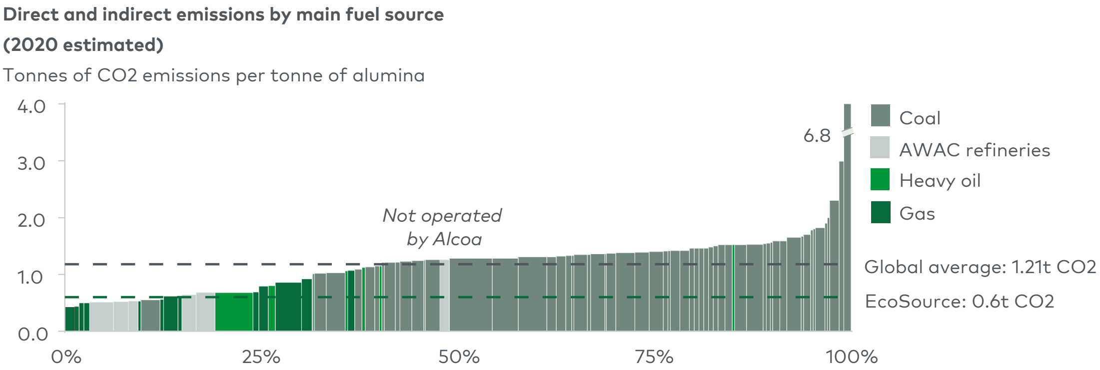
As discussed above, Australia's aluminium industry is heavily trade exposed. With 37% of bauxite, 84% of alumina and 90% of primary aluminium exported, the success of the industry is predicated on maintaining a competitive relative cost position versus global peers and maintaining absolute cost competitiveness against the cycle of global aluminium prices.

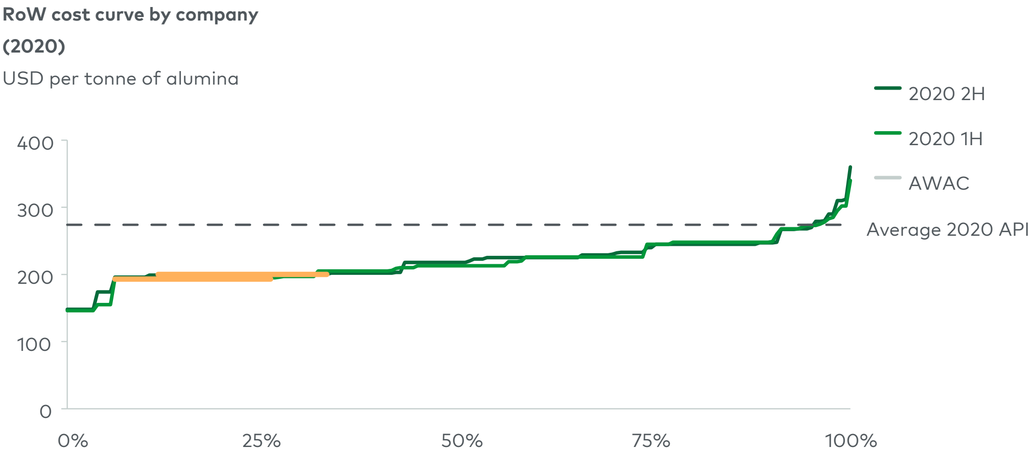
In today's environment, AWAC (Alcoa World Alumina and Chemicals), the world's largest bauxite miner and producer of

Table 6
Pathway to decarbonisation of the Australian aluminium industry

Stage	Options
Development of inert anodes*	Development of non-carbon-based anodes for potlines and roll-out across the industry
Alumina process adaptation	Development and implementation of technologies that can reduce alumina process emissions, particularly on high-pressure or high-temperature processes such as: • Digestion of bauxite • Calcination of alumina
Decarbonisation of the electricity grid	Replacement of coal and gas-fired power generation with low carbon alternatives such as wind and solar, with firming capacity to ensure regular supply to aluminium smelters. This decarbonised electricity will also support carbon emissions reduction in the extrusion manufacturers.

Figure 24
Alumina emissions intensity and world cost curve





Source: Alumina Limited, 2020 Full Year Results Presentation, 23 February 2021 (chart adapted); CRU, May 2021 alumina outside China, reports the lowest CO2 emissions intensity amongst major alumina producers.[84] AWAC's cash costs for alumina production in 2020 were in the lowest quartile of the global cost curve at $199/tonne of alumina.[85] Any differential increase in costs in response to further decarbonisation of the production process could impact the competitiveness of AWAC's alumina compared with its global peers.

The current cost curve for primary aluminium production is exceptionally flat in comparison to other global commodities such as iron ore (shows a strong cost increase in the third and fourth quartiles that insulates lower-cost producers from significant margin decline in low price environments). According to industry commentators, a cost increase of c.15% can shift an aluminium smelter's cost position from the attractive first quartile into the less attractive third quartile. And the cost curve is constantly changing in response to raw material cost levels, any production cost benefits achieved, exchange rates, new/mothballed capacity and production levels.

As over c.30%-40% of the costs for aluminium smelting are for electricity, the relative cost of electricity is often the determining factor for the cost curve position, and therefore profitability, of aluminium smelters.[86] Electricity prices for aluminium smelters are therefore highly confidential and commercial terms are not published globally. For the Australian aluminium industry to remain viable, it must therefore continue to source electricity at globally competitive prices.

Absolute profitability across the global price cycles can support a vibrant Australian aluminium industry. Over the last 10 years, prompt LME aluminium prices have ranged from c.US$1,440/t to c.US$2,630/t. At low aluminium prices, there is a substantial risk that third and fourth quartile aluminium smelters would be operating on a cash-negative basis. During the last non-COVID-19 price trough (2016), approximately 50% of aluminium smelters were believed to be cash negative.[87]

For Australian aluminium smelters to remain profitable across the cycle, competitive 'firm' electricity prices will be required. While the marginal cost of wind and solar generation is accepted to be the lowest available, future firmed energy prices for industry are still expected to sit at around $75/MWh electricity (average of Snowy FID NSW spot forecast[88] and Marinus NEM resource price forecast[89]). Investments in transmission and distribution could increase the cost of industrial electricity prices further. This is not a commercially competitive proposition for aluminium smelting in the current market. Firmed renewable electricity prices for aluminium smelting will most likely need to be less than $45/MWh to ensure profitability across the aluminium price cycle.

Differential policy response globally will provide the final driver of future competitiveness for Australia's aluminium sector. The pace of decarbonisation of the sector in Australia will most likely differ from international peers. Some competitors, such as those in Canada, already have lower carbon intensity due to their high reliance on renewable energy in the form of hydropower. Peers with captive fossil fuel power will find decarbonisation much more challenging. In some regions, including the US and EU, the application of carbon border adjustments is intended to account for carbon pricing for goods from countries that are yet to transition to low carbon electricity sources. Australian aluminium is typically exported to the Asia-Pacific where carbon border adjustments are not currently in operation. However, slow transition of the Australian electricity generation capacity towards an increasingly renewable base could result in alumina and aluminium exports being exposed to potential international border adjustments. Likewise, imports from countries with high carbon intensity could impact the ability of local extruders to compete should local transition to lower carbon energy be achieved rapidly and without the application of local border adjustments. The transitional period is difficult to map and will bring with it new competitive challenges for the Australian aluminium sector.

The aluminium manufacturing sector in Australia is dependent on a number of other stakeholders to ensure that it can remain competitive, profitable and vibrant within an Australian context. In summary, a number of key enablers must be achieved, including:

- Continued access to a globally competitive electricity pricing regime that allows it to remain in the lower two quartiles of the aluminium production cost curve
- Decarbonisation of the electricity generation base to allow access to renewable electricity sources, on a firmed basis, for primary aluminium and aluminium extruders and alumina refineries (once technical challenges are overcome)
- Continued support from government and research organisations that allows the industry to resolve the outstanding technical challenges for low carbon aluminium production, including new alumina technologies for bauxite digestion and alumina calcining, and hydrogen hubs
- Encouragement through policy for participants to work together as an industry to solve the carbon emissions issues that have been identified
- Positive engagement with the global trade community to ameliorate any impacts from foreign cross-border adjustments
- Equivalent treatment of domestic industry versus global competitors, recognising that in practice, not all

regions are moving at the same pace towards green aluminium outcomes and that some governments will provide high levels of support for their aluminium industries

- An efficient and effective Australian anti-dumping regime that does not require Australian manufacturers that are suffering harm to incur undue costs and effort to obtain remedies