ENERGY TRANSITION HUB
an Australian-German innovation partnership

From mining to making

Australia’s future in zero-emissions metal

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Key messages

- **Metal production causes 9% of global greenhouse gas emissions**, a figure that is set to rise as metal consumption increases.
- **By 2050 demand for many metals will grow substantially** – driven partly by growth of renewable energy infrastructure that relies on a wide range of metals.
- To meet increased demand sustainably, **metal production must become zero-carbon**.
- Climate action by governments, investors and large companies mean there are growing **risks to high-carbon metal production**.
- Companies and governments are paying more attention to the emissions embodied in goods and materials they buy. This is leading to a emerging **market for lower-carbon metal**, that has enormous potential to grow.
- **Australia** has an **opportunity** to capitalise on this **transition to zero-carbon metal**.
- Few countries match Australia's potential to generate renewable energy. A **300% renewable energy target** would require only 0.15% of the Australian landmass and provide surplus energy to **power new industries**.
- By combining renewable energy resources with some of the world's best mineral resources, **Australia** can become a **world leader in zero-carbon metals production**.
- By pursuing this opportunity effectively Australia can revitalise its manufacturing sector, potentially **creating over 65,000 jobs and generating over $100 billion in export revenue**.
- Zero-carbon metals exports are a smart **insurance against the risk of declining demand for Australia's coal and gas** due to international climate action.
- Australian success is not inevitable. **A Zero Emissions Metals Strategy** backed by federal and state governments would support achievement of these outcomes.

Contents

Summary

The world must undertake rapid reductions in man-made greenhouse gas emissions in order to avoid catastrophic climate change.[1] To achieve this most sectors of the economy will have to change. One important sector that has not received much attention is metal production, despite it being responsible for around 9% of global emissions – more than all cars combined.[2] By 2050 metal-related emissions could soar if we do not change the way metals are made.[3]

This potential increase in emissions is largely due to a forecast boom in primary metal consumption.[4] Greater recycling and material efficiency can constrain this boom. But such measures will not be enough to eliminate demand for primary metal.[5] Developing countries need to increase their stocks of metal to provide people with essential services such as transport, housing and communications. New metal is also central to the zero-carbon transition. Renewable energy, and related technologies such as batteries, rely on steel, aluminium, copper, lithium, cobalt and a host of other metals. Mining of fossil fuels can only end if we mine and manufacture more metal.

The need for zero-emissions metals

Innovation is required for metal producers to reduce and ultimately eliminate emissions. In the past there has been little pressure to do this as metal production takes place at an early stage of supply chains, evading the scrutiny applied to other sectors such as energy and transport. However, Section 2 shows how this is changing as governments accelerate climate action, investors demand credible carbon strategies from the firms they invest in, and more large corporations press their supply-chains to reduce emissions.

The metal sector is starting to feel the impact of these developments. Companies such as Apple, BMW and Tetra Pak have pledged to use only low-emissions aluminium[6], and construction giant Skanska UK aims to switch to zero-emissions steel before 2045[7]. Shrewder metals manufacturers are adapting: several aluminium producers have launched certified low-carbon aluminium products[8], and at least five European steel producers are exploring the substitution of coal with green hydrogen.[9 - 13]

Australia's future in zero-emissions metal

This report shows how Australia can be at the forefront of new markets in zero-emissions metals. Australia is one of the world's most significant exporters of ores of many metals, including steel, aluminium, lithium and manganese. Australia has the potential to combine its mineral resources with its excellent renewable energy potential, and make metals without the carbon emissions.

The most critical metal process to decarbonise is steel production, because it is responsible for 7% of global emissions.[14] Section 5 details Australia's potential to become a pioneering producer of zero-emissions steel. Australia is the world's largest exporter of iron ore but has a small domestic steel industry.[15] Consensus is growing that the best way to make steel without fossil fuels is with renewable hydrogen.[16] The establishment of a hydrogen-based steel industry is likely to require substantial investment and rely on large quantities of cheap renewable energy. Companies in several European countries have started on this path, but nowhere in Europe can match Australia's abundance of iron ore or renewable energy resources.

The processes for making most metals other than steel rely largely on electrical energy. Therefore the emissions associated with these metals can be greatly reduced if this electricity is derived from renewable sources. Section 5 outlines Australia's opportunity to produce two of these metals: aluminium and manganese.

Section 6 acknowledges the risks and barriers of increasing downstream processing of metals in Australia. One barrier is the intense competition among metal producers and the resulting low profit margins. This report anticipates a growing demand for low-emissions metals, but it is far from clear when this will become a mature market. Other risks include technical challenges, Australia's lack of relationships and distance from metal customers, and competition in low-emissions metals from other counties with cheap renewable energy.

If these risks can be overcome, realising the opportunities presented in this report could bring several major benefits. Firstly, they would add substantial value to the Australia's mineral resources. This report presents a scenario where Australia develops a steel sector equivalent in size to Japan's today. Under this scenario Australia would generate an additional A$84 billion in export revenue by processing just 18% of current iron ore extraction into steel.

Secondly, the report shows that the opportunities would create thousands of jobs. The opportunities outlined in Section 5 could represent over 65,000 new long-term manufacturing jobs, many in regional areas. Many thousands more workers would be needed to build new metal refineries and the renewable energy infrastructure to power them.

Thirdly, this is an opportunity to capitalise on Australia's abundance of solar and wind energy. Producing zero-emissions metal may present Australia's best prospect for exporting renewable energy resources. While there are other pathways available, such as renewable hydrogen, these rely on the creation of new markets, whereas metal markets already exist and global demand for new primary metals is likely to remain high for decades.

Finally, and perhaps most importantly, these opportunities are an insurance strategy against the possibility of falling demand for two of Australia's main exports, coal and natural gas, as international climate action intensifies.

Section 7 proposes policies to help Australian industry seize this opportunity. State and federal governments could start by collaborating on a National Zero-Emissions Metals strategy, backed up with concrete policies including financial support and incentives for downstream mineral processing. Such policies would send a clear signal of national commitment to this new industry, giving Australia a strong platform to attract investment and become a global leader in zero-emissions metals.

1. Metals - high-carbon materials for the zero-carbon world

Since the bronze age, humans' ability to make metal has been central to the growing sophistication of society. Today we are more dependent on metals than ever. Their special properties, such as strength, malleability and conductivity, are crucial to the provision of services such as housing, transport, energy and telecommunications. More metal is needed every year as the world develops and urbanises.

With the transition to a zero-carbon economy, metals are assuming an even greater importance, because they are fundamental to alternative energy technologies. Solar panels, for example, are made from silicon and 10 other metals. Wind turbines incorporate a steel tower, copper wiring and magnets containing cobalt and neodymium. Lithium-ion batteries require not only lithium but also cobalt, aluminium, manganese, nickel, copper, steel and titanium.[17]

Global metal use is likely to continue growing for several decades and demand for some metals could triple by 2050.[18] [19] Research and investment is needed to find ways to limit the environmental harm caused by this expansion: metal extraction and processing can destroy habitats and pollute air, soil and water, as well as using large amounts of water and energy.[20]

One way to limit this harm is to ensure metals are used more efficiently. This can be realised through smarter design and less wasteful manufacturing processes, as well as greater levels of reuse, recycling, repairing, remanufacturing and extending product-life.[21] Ultimately it may be possible to achieve a circular economy where metal waste is nearly eliminated, and metals are continually reused.

However, a truly circular economy will depend upon sufficient stocks of material in circulation, and it will be several decades before this is achieved.[22] Developing countries in particular do not yet have enough metal to underpin their future development.[23] Recycled metal is likely to supply much less than half of global demand between now and 2050, and perhaps as little as 15% for some non-ferrous metals.[24] [25] The remainder of metal demand will be met using virgin materials.

This means that more sustainable, and particularly zero-carbon, ways of mining and refining large quantities of primary metal are needed.[26] In particular we must eliminate the greenhouse gas emissions from metal production. All metals are energy-intensive to make (Figure 2) and metal manufacture already accounts for 9% of global greenhouse gas emissions[27]. (Figures in this report on metal-related energy and emissions relate to the manufacturing processes involved in converting metallic ores into refined metal. They exclude mining, transport and downstream processes to produce useful metal products.)

Without major changes to the way metals are made, total metal-related energy use and emissions will increase.[28] Metal-related emissions are dominated by steel production, underlining the urgent need to adopt alternative processes for making zero-emissions primary steel. For most other metal-making processes, the main energy input is electricity. Emissions from these processes can be reduced substantially simply by switching to renewable electricity without changing the basic production process. However, other aspects of metal processing emit greenhouse gases directly, so these will have to change to achieve full decarbonisation.

This report suggests how Australia could capitalise on its competitive advantages and lead the world in low-emissions metal production using renewable energy. The strategy would enable Australia to build on its success as a mining nation, to become a major producer and exporter of refined metals.

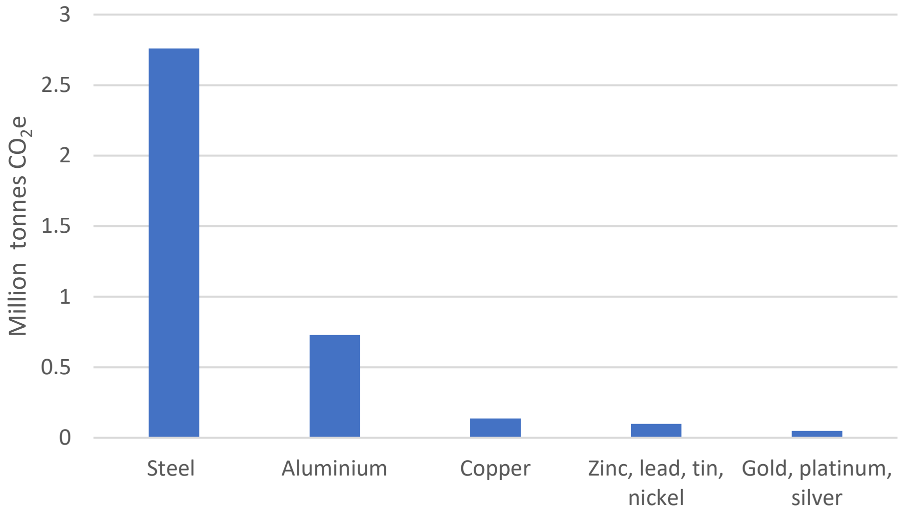

Figure 1: Carbon emissions for selected metals – total global production, 2017 [29 - 33]
(shows emissions from converting metallic ores into refined metal, excluding emissions from mining, transport and downstream manufacturing into metal products).

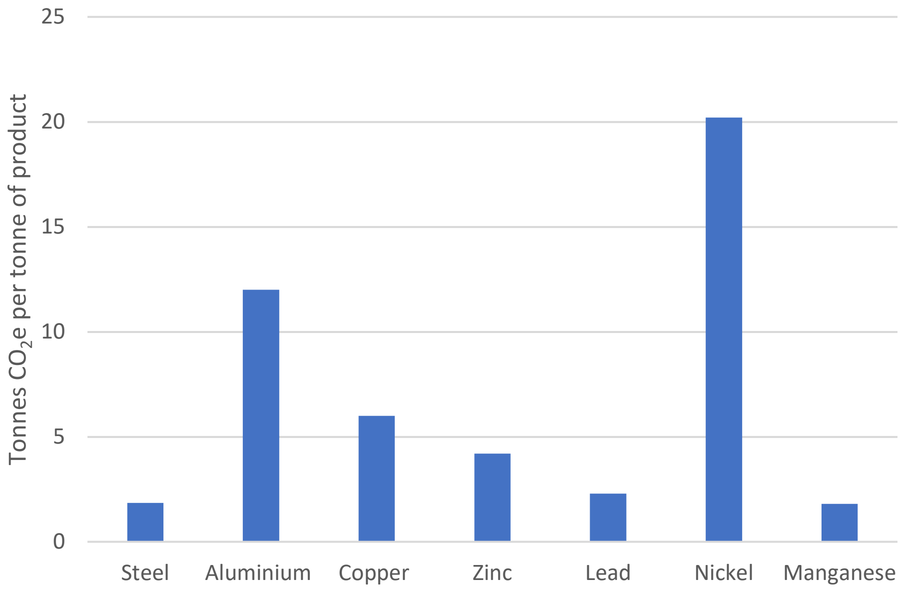

Figure 2: Carbon emissions per tonne of primary production of selected metals. [34]

2. The zero-carbon disruption: metal producers must adapt

Current methods of producing all metals entail significant greenhouse gas emissions. In the past, metal manufacturers had few incentives to curtail these emissions, but this is changing due to climate action by governments, investors and business, as described below. These global efforts to tackle climate change are starting to impact on all sectors of the economy, including metal producers.

> *"The pressure to make low carbon metal is increasing from all sides … the market, our customers, shareholders, financial markets, NGOs, you name it."*[35]
>
> Kathrine Fog, senior vice president, Norsk Hydro (aluminium producer)

2.1 Government climate action is accelerating

Through the Paris Climate Agreement every national government in the world has committed to limiting global warming to well below 2°C, and to aim for no more than 1.5°C, which requires reducing net carbon emissions to zero.[36]

Leading countries are acting to reduce industrial emissions, and manufacturers in most developed countries are now subject to a carbon price.[37] China's cap-and-trade system will progressively expand to cover 100,00 industrial plants, becoming the world's largest emissions trading scheme in 2020.[38]

Manufacturers in jurisdictions without a carbon price may nevertheless be impacted, as carbon tariffs and other corrective trade measures are now being raised by industry and politicians.[39] [40] [41] Some Australian exporters would prefer Australia to adopt its own carbon price as even fossil fuel companies like Shell, BHP, Rio Tinto and Woodside are now calling for.[42] Many businesses already plan for this by using a "shadow carbon price" when evaluating investments in Australia.[43]

2.2 Corporate climate action has become mainstream

Corporations increasingly recognise the business risks of failing to reduce emissions. Conservative financial institutions, like the Australian Prudential Regulation Authority[44] and the Bank of England[45], have warned that climate-related risks are a threat to individual businesses and the global economy.

In response, the Financial Stability Board (an international body monitoring financial stability) set up the Taskforce on Climate-related Financial Disclosures (TCFD), a global system for reporting corporate climate risks. The TCFD advises energy-intensive companies to publish analyses of the business impact of "stricter constraints on emissions and/or pricing carbon emissions", and to report on their consumption of fossil fuels.[46] By July 2019 over 800 companies had expressed public support for the TCFD's recommendations, including BHP, BlueScope, Glencore and Rio Tinto.[47]

Many institutional investors share these concerns about high-carbon business strategies. Investors have formed coalitions to demand better information about corporate carbon emissions and strategies to reduce them. One such initiative, *Climate Action 100+*, was set up by powerful investors to influence the world's largest corporate emitters to develop targets consistent with the Paris Agreement. The group has persuaded many companies to boost their climate ambition, including companies that mine, produce and use metals, such as BHP, Glencore, ArcelorMittal and Nissan.[48]

Many companies are developing emissions reduction plans through the Science Based Targets initiative (SBTi), which helps companies set targets that are consistent with the goals of the Paris Agreement.[49] To date, over 600 major global corporations have joined the SBTi, including household names such as Coca-Cola, IKEA, Mars, L'Oreal, Nestlé, Sony, Unilever and Walmart.

> *"Steel companies need to step up their game and commit to the innovation necessary to ensure they can deliver change across their businesses."*[50]
>
> Stephanie Maier, steering committee chair, Climate Action 100+

> *"By 2030 our ambition is to reduce more greenhouse gas emissions than the entire IKEA value chain emits, while growing the IKEA business. This will require a transformational change for our supply chain and how our products are designed."*[51]
>
> Torbjörn Lööf, CEO at Inter IKEA Group

2.3 Climate action affects the whole supply chain

Participants in the SBTi must commit to reducing not only their own emissions, but those of their supply chain. For example, by 2030 Unilever aims to halve emissions across its whole product life-cycle[52], and IKEA plans to reduce the average climate footprint of its products by 70%.[53] Walmart's Project Gigaton aims to reduce emissions from its global supply chains by one billion tonnes in 10 years.[54] The most ambitious, such as Volkswagen, Toyota and Skanska, aim to reduce their supply chain emissions to zero.[55 - 57]

These supply-chain targets are important, because for most companies, emissions from their suppliers greatly exceed those from direct operations.[58] This means many manufacturers will feel the impact of initiatives like the SBTi whether or not they chose to sign up.

This is adding to scrutiny of supply chains. CDP, an organisation that helps companies report on their environmental impact, has been monitoring the influence of large businesses on the emissions of their suppliers since 2008. In response to requests from members of CDP's supply chain program, over 5,500 suppliers now disclose their greenhouse gas emissions and efforts to reduce them.[59] Today less than half of these suppliers have emissions reduction targets, but more are recognising the need for change, as a lack of climate action can now mean losing business. Ten years ago, just 4% of CDP members deselected suppliers due to poor environmental performance. By 2018 this number had grown to 43%, with a further 30% considering such a policy in the near future (Box 1).[60]

> ***Box 1*** – Apple deselects suppliers that fall short on sustainability
>
> Apple works with its suppliers to improve sustainability and reduce emissions. So far 30 suppliers have committed to 100% renewable energy for Apple production. Manufacturers that fail to meet minimum sustainability standards can be removed from Apple's supply chain. In 2018 Apple terminated contracts with seven metal refiners and smelters that the company felt were uncommitted to its Supply Chain of Conduct.[61]

> ***Box 2*** – Skanska is targeting its steel emissions
>
> Skanska, a global construction firm has pledged to achieve net-zero emissions by 2050. The firm's UK arm, Skanska UK, has gone further, aiming to meet this target by 2045 including emissions from construction materials such as steel and cement. Steel alone accounts for over 25% of Skanska UK's emissions.[62] The company plans to collaborate with its supply chain to develop and procure lower carbon materials.

Whole industries are awakening to the need to tackle emissions embodied in materials. For example, the construction sector has recognised the embodied emissions of buildings often outweigh operational emissions.[63] [64] In September 2019 the World Green Building Council issued a worldwide challenge to the construction sector to achieve complete decarbonisation, focusing on embodied emissions.[65] This may lead more construction firms to follow the example of Skanska UK (Box 2) by sourcing low-carbon materials.

The transport sector is also changing. *Drive Sustainability* is a global initiative aiming to improve the car industry's understanding of the environmental impacts of its supply chain. The initiative, which includes 11 major auto-makers, has begun by assessing 37 key raw materials used to make cars, including many metals.[66] Volkswagen intends its entire supply chain to be carbon neutral by 2050,[67] despite the difficulty of tracking over 40,000 suppliers. The first step towards this goal will be carbon neutral production of the I.D., Volkswagen first all-electric car, later in 2019. The I.D. will be made from steel and aluminium with lower embodied emissions, and Volkswagen's suppliers must confirm their smelting plants meet certain environmental standards.[68]

Government procurement can also influence the supply chain. For example, in Australia many government-led building and infrastructure projects are required to attain a sustainability certification such as Green Star. These certifications have an increasing focus on lowering the carbon emissions embodied in materials such as steel. Other examples of green government procurement are:

- The Victorian Government's social procurement framework recommends the inclusion of requirements on greenhouse gas emissions in purchase decisions.[69]
- Sweden's Transport Administration sets limits on the embodied emissions of steel and concreate used in major infrastructure projects.[70]
- The *Buy Clean California Act* sets a maximum level on embodied emissions in steel and other listed materials used in public infrastructure projects.[71]

2.4 The metal sector is starting to act on embodied emissions

Metal producers, as a key part of global supply chains, are unlikely to avoid the combined impact of the climate action described above. So far the practical consequences have been limited, with most metal manufacturers persisting with high-carbon production. Nevertheless, some have recognised the need to change and initiated low-carbon programs, with the long-term goal of eliminating emissions. The clearest efforts to date are in the two metals responsible for most emissions: steel and aluminium.

Steel – steps towards zero emissions

The decarbonisation of steel-making is vital to tackling climate change. Steel-makers are pursuing various routes to substantially reduce emissions, with most emphasis on hydrogen-based production.

Hydrogen-based steel reduction

Direct reduction of iron ore with renewable hydrogen offers the possibility of near zero-emissions steel (Section 5.1). Some firms in Europe are exploring the potential of hydrogen to supplant fossil fuels in steel-making.

- Swedish steel company SSAB is leading HYBRIT, a project focussing on hydrogen-based direct reduction. HYBRIT is currently designing a pilot plant with plans to build a commercial-scale plant by the late 2020s, and replace Sweden's existing three blast furnaces by 2040.[72]
- The world's largest steelmaker, ArcelorMittal, aims for carbon neutrality by 2050. The company plans to build a demonstration plant in Hamburg capable of producing 100,000 tonnes of steel per year through hydrogen-based direct reduction.[73]

- German steelmaker, Salzgitter, is exploring major emissions reductions through its SALCOS project. Like SSAB the company plans to use renewable hydrogen in a direct-reduction process, eventually reducing emissions by more than 85%.[74]
- Another German steelmaker, Thyssenkrupp, plans to invest US$11 billion in switching to a hydrogen-based process. The company will begin by using a proportion of hydrogen in conventional blast furnaces, with a longer-term plan for new plants to run on hydrogen alone.[75]
- Austrian steelmaker Voestalpine is partnering with other firms to supply renewable hydrogen for use in steel-making. Although initially the amount of hydrogen involved is too small to make direct-reduced iron, Voestalpine's long-term aim is to eliminate coal and coke.[76]

Electrowinning

It may be possible to make zero-carbon steel through electrowinning, an electrolytic process for reducing metallic oxides.[77] This would eliminate the need for a chemical reductant such as carbon or hydrogen. Electrowinning is used to produce several commercial metals such as aluminium, zinc and copper, and is potentially the most efficient way to make steel, reducing energy use by 31% compared to the blast furnace route.[78] There are, however, major technical challenges to overcome before electrowinning becomes a commercial proposition.

ArcelorMittal has worked since 2006 to advance the technical viability of electrowinning. The company is now leading the EU-funded *Siderwin* project to develop a pilot plant to demonstrate this alternative to steel production at a larger scale.[79] In the US Boston Metals is developing a rival electrolytic technique to make steel through high-temperature molten oxide electrolysis. The company has attracted major funding to commercialise its process, which it claims will simplify steel production while significantly reducing costs.[80]

Greening recycled steel

Steel recycled in electric arc furnaces accounts for about 30% of global production of crude steel.[81] The majority (about 60%) of emissions related to recycled steel can be eliminated by powering electric arc furnaces with renewable energy.[82] Several firms already do this and others, such as Australian company Infrabuild, see green recycled steel as central to their future strategy. The company plans to power its two electric arc furnaces with 100% renewable energy. To support these plans, Infrabuild's parent company plans to invest in 1 GW of renewable energy and energy storage infrastructure.[83] In July 2019 Infrabuild began a power purchase agreement with Victoria's largest solar farm (128 MW) to supply part of the energy required by its electric arc furnace in Laverton.

> *"We have a goal to substantially decarbonise our business by 2050. We maintain a strong focus on energy efficiency and productivity to deliver incremental improvements,* ***but this is not enough****. We know we need to look at* ***larger transformative opportunities for emissions reduction****."*
>
> *Rio Tinto, Our approach to climate change 2018*

Aluminium – a low-emissions market is developing

In the metals sector, the clearest impact of supply-chain pressures is on aluminium, due to its large embodied emissions (11.5 tonnes CO_2-equivalent per tonne[84]). High-profile aluminium customers such as Apple, Bosch, Toyota, Audi, BMW and Tetra Pak have publicly committed to using only low-emissions aluminium,[85] and the aluminium sector is adapting.

In 2018 the Aluminium Stewardship Initiative, an alliance of aluminium producers and consumers, launched a voluntary certification scheme that restricts emissions to 8 tonnes of CO_2-equivalent per tonne of metal – almost certainly unachievable for coal-fired plants.[86] Companies that fail to respond to this new market risk losing out as many of the world's largest buyers continue their push for low-carbon products.

Several producers are taking advantage of the fact that some of their smelters are powered by renewable electricity.[87] These producers, including Rio Tinto, Alcoa and Rusal have launched certified low-carbon aluminium products. The embodied emissions of Rio Tinto's *RenewAl* are only one third of the global average, and Alcoa's *Sustana* less than one quarter. Both companies have reported charging higher prices for their low-emissions aluminium thanks to rising demand from industrial customers, although the size of the premiums is confidential.[88]

Efforts are underway to tackle the aluminium industry's second largest source of emissions from the degradation of carbon anodes. These anodes are continuously consumed as they react with oxygen to form carbon dioxide. In May 2018 Alcoa, Rio Tinto and Apple together with the Governments of Canada and Quebec announced a joint venture, called Elysis, which aims to replace carbon anodes with an inert material. Elysis aims to have a commercialised product by 2024.[89]

The aluminium sector may even be able to support the transition to renewable energy. Traditionally aluminium smelters run on a constant supply of electricity, making their integration with variable renewable energy challenging. However, a new technology called Enpot enables smelters to be ramped up or down by 30%, in response to fluctuations in electricity supply. German aluminium producer Trimet has installed Enpot, and is now operating as a virtual battery storing up to 2,000 megawatt hours of electricity.[90] It is worth exploring the potential benefits of similar retrofits at Australian smelters.

> "*Our customers … want to know where and how products are made and what impact they have on the environment. We see certified sustainable aluminium as a point of differentiation, and we believe there will be a fundamental shift in demand for these products.*"[91]
>
> Tolga Egrilmezer – Vice President, Aluminium Sales, Rio Tinto

2.6.3 Low-carbon action in other metal sectors

Some producers of other metals have also launched decarbonisation initiatives. In Australia the most noteworthy project is Sun Metals' 125 MW solar farm, built to supply a third of energy required by its zinc refinery in Queensland.[92] The company is now considering adding wind power and battery storage. Section 5.3 details Element 25's plans to use renewable electricity to produce high purity manganese at a new mine in Western Australia. European producers of non-ferrous metals have set up Eurometaux, an organisation that aims to help the sector reduce emissions while keeping production in Europe. Eurometaux acknowledges that to achieve this, processes will need to be transformed, and it is developing a 2050 low-carbon strategy.[93]

3. Australia's natural advantage in the renewable energy era

This report considers Australia's opportunity to exploit its abundant resources of minerals and renewable energy by expanding metal production. Metals producers were attracted by a similar opportunity in the 20th century when many smelters and refineries were set up in Australia to exploit cheap electricity and fossil fuels.[94] But in recent years the domestic cost of electricity and natural gas has doubled[95], and metal processors have taken a hit. Financial problems have beset domestic producers of steel, lead and zinc, and plants producing alumina, aluminium and nickel have closed.[96] [97]

With the global transition to a zero-carbon economy Australia's energy advantage could return. Energy-intensive production is likely to migrate to places where renewable energy is both cheap and abundant.[98] Australia is well-placed to benefit from this development and re-energise its manufacturing sector. This opportunity is unavailable to most industrial countries as they lack the scale of renewable energy resources required to power heavy industry.

3.1 Australian renewables are low-cost, and getting cheaper

In most countries solar PV and wind are now the cheapest sources of new electricity generation.[99] In Australia solar PV and wind are not only cheaper than new fossil fuel generation[100], but highly-competitive with renewables in other industrialised countries (Figure 3).[101]

Many new Australian wind and solar projects supply energy below A$60 per megawatt- hour (Figure 3).[102] For example, in 2018 the Victorian Government awarded contracts for six new wind and solar farms to supply at A$53-56 per megawatt-hour – well below the market average. [103]

Some Australian businesses, including large manufacturers such as BlueScope are cutting their energy costs by signing power purchase agreements for renewable energy.[104] Others are simply building their own renewable installations, such as Infrabuild which plans to build 1 GW of solar PV. [105]

To achieve a 100% renewable mix most manufacturers will need to supplement wind and solar PV with a reliable source of energy that is not weather-dependent. Multiple cost-competitive options exist to supply this firm dispatchable renewable energy, and these are available at roughly 1.5 to 2 times the cost of variable renewable energy.[106] This means renewable energy can now compete directly with fossil fuels for dispatchable power. CSIRO has found that solar power is cost-competitive even with the addition of two hours of battery storage or six hours energy storage via pumped hydro.[107] According to the CSIRO, by 2030 solar PV backed up with two hours of battery storage will be around half the cost of gas generation.[108]

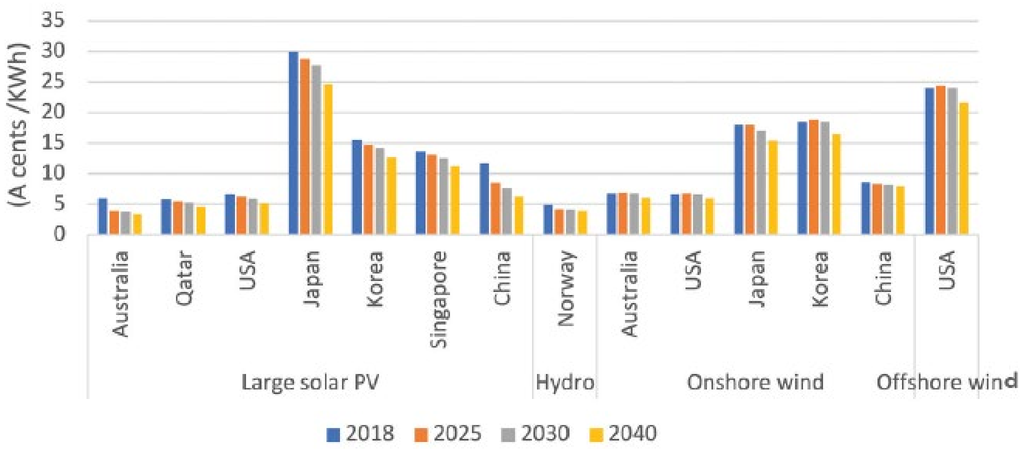

Figure 3: LCOE of renewable technologies in selected countries 2018-2040; source: Energy Transition Hub, Data sourced from ACIL Allen 2018, based on data from CSIRO 2018, IRENA 2018, IEA 2015.

3.2 In Australia, renewable energy is not just cheap, but abundant

Australia is in the enviable position of having the capacity to generate far more renewable electricity than could ever be needed. The Australian Energy Market Operator has estimated that, in the regions covered by the National Electricity Market, the potential for renewable generation is about 500 times greater than current demand.[109]

In contrast, many countries will find it hard to generate enough renewable energy to displace current fossil fuel consumption. Compared to Australia, these countries have greater existing and projected energy demand relative to their capacity to generate renewable energy, and less land suitable for generating renewable energy. This makes it much harder to switch to 100% renewable energy at the same time as massively increasing electricity generation for use in industry.

For example, China has installed more solar and wind capacity than any other country – over 400 GW by 2018.[110] The Chinese Government plans to invest a further US$750 billion to nearly treble renewables deployment by 2030.[111] But even with this level of investment, renewables are expected to supply only 20% of China's primary energy consumption in 2030.[112] Unlike Australia, it would be virtually impossible for China to become 100% renewable in 10 years, let alone produce surplus renewable electricity to power major new electrical loads.

Other industrial countries have even poorer renewable resources. For example, in Japan and the UK the levelised cost of solar energy in 2018 was around US$150 per megawatt hour[113] – several times more than the Australian benchmark. In the UK, a lack of land and sunshine means even the most aggressive implementation of solar PV would generate insufficient energy to supply the country's transport sector.[114]

With the transition to renewables the location of energy sources will become more important. Unlike fossil fuels, renewable energy cannot be transported long distances at low cost. In the zero-carbon era manufacturing is likely to migrate to countries like Australia with local access to plentiful renewables.

3.3 100% renewable energy is just the beginning

Australia's natural advantages mean an industrial renaissance powered by renewables is a realistic option, even if it requires a large increase in electricity generation. The elimination of fossil fuels from electricity generation (a 100% renewable energy target) is already within reach.[115] In 2018, energy firms installed over 4 GW of solar PV and wind capacity in Australia. By the end of 2018, 14.5 GW of new renewable generation was under construction or financially committed.[116] At these rates of deployment the Australian grid would be 100% renewable by 2032.[117] It is likely that with a more supportive policy framework this point would be reached even sooner.

But Australia could aim beyond a 100% renewable energy targets. For example, a 300% renewable energy target would take up only 0.15% of the Australian landmass[118] – or less than 5% of the area of the Galilee coal basin.[119] With renewable generation at this scale, Australia could produce energy-intensive exports for the post-fossil fuel global economy. Green hydrogen is one such export with broad support.[120] This report highlights another, potentially greater, prospect: using renewable energy to manufacture refined metals for the global market. The appeal of this opportunity is that it combines Australia's renewable energy potential with its exceptional mineral resources.

4. Australia's exceptional mineral resources

Australia has an abundance of valuable minerals. It is the world's largest exporter of iron ore, bauxite and lithium, and among the top three producers of the ores of many other metals including zinc, gold, manganese, titanium and rare earth metals.[121]

With the transition to a zero-carbon global economy, the importance of Australia's mineral sector is assured. Australia produces most of the 16 minerals used in solar panels,[122] as well as nine of the 10 elements required to produce lithium-ion batteries.[123] It is also the world's second largest producer of rare-earth elements used in electric vehicles, wind turbines, fuel cells, batteries and fibre optics.[124]

Mining giant: manufacturing midget

Given its resources, it is not surprising that Australia has a long history of mineral processing. But the nation's downstream processing industry is tiny compared to the size of its mining sector. Most Australian minerals are exported for processing overseas: Australia converts less than 1% of its iron ore into steel and processes just 7% of its manganese ore.[125]

This focus on mining over downstream processing means Australia captures only a small portion of the ultimate value of its products. For example, a unit of iron ore is worth at least five times more when converted into steel.[126] It has been estimated that Australia earns only 0.5% of the ultimate value of its exported lithium ore, with the remainder captured by companies overseas that refine lithium or manufacture lithium-ion batteries and their components. [127] Overall the value of Australia's exported ores and minerals is eight times greater than its refined metal exports.[128]

Australia's mineral processing potential

This raises the question: could Australia build on its success as a miner to become a world-leading mineral processing sector? This opportunity was highlighted recently by the Australian Government's *Resources 2030 Taskforce* which recommended that governments "develop strategies to enhance and grow competitive downstream processing industries in key regional centres."[129]

International experience shows that local access to resources does not necessarily lead to comparative advantage in mineral processing. [130] Resource-rich countries that have tried to promote greater downstream industries have had mixed results.[131] This is partly because efficient and low-cost modern transport has minimised the barrier of distance and eroded the advantage of local access.[132]

However mineral resources are not Australia's only asset. Other national attributes that contribute to a comparative edge in downstream processing include available land; a stable and competitive economy; trusted governments; good trade relationship with countries in East Asia; access to low cost finance and engineering expertise.[133] Australia also has a proven ability to add value to minerals through downstream processing: it is the world's second largest manufacturer of alumina, and significant producer of aluminium, zinc, lead, nickel and copper.[134]

Table 1: Australia mines a significant proportion of many of the world's metals.[135 - 144]

Mineral	Chief locations	Ore production* – ('000 tonnes)	% of global ore production	Global position – ore production	Global position – ore reserves	Domestic production	
						Refined metal output ('000 tonnes)	% of ore processed within Australia
Iron ore	WA	880,000	37%	2nd	1st	3,800 (primary steel)	0.6%
Bauxite	WA, QLD	87,500	28%	1st	1st	20,000 (alumina)	46%
Alumina	WA, QLD	20,000	15%	2nd	n/a	1,600	7% (of bauxite) 16% (of alumina)
Manganese	NT, WA	4,100	22%	2nd	4th	170	10%
Lead	QLD, NT, NSW	450	10%	2nd	1st	170	38%
Gold	WA	0.31	10%	2nd	1st	0.31	100%
Lithium	WA	6	18%	2nd	6th	0	0%**
Zinc	QLD, NT, NSW	940	7%	3rd	1st	500	53%
Nickel	WA, QLD	170	8%	5th	2nd	85	85%[145]
Rare earths		20	12%	2nd	6th	-	0%
Copper	All	950	5%	6th	3rd	500	53%
Cobalt	WA	5	4%	4th	2nd	-	0%

**Denotes mass of elemental metal in ore except for iron ore, bauxite, alumina and manganese where it denotes total mass.*

***A lithium processing plant in Kwinana will begin operation in 2019, and there are advanced plans for other lithium processing plants in Western Australia.*

5. Australia's opportunities in zero-emissions metal

The diverse processes for transforming minerals into useful products have one thing in common – they require a lot of energy. To meet the demands of a zero-carbon economy, this energy will need to be renewable.

Australia's potential to use its renewable energy to process minerals is increasingly recognised by investors and industry experts. One high-profile champion of Australian industry's renewable advantage, Sanjeev Gupta, owner of Infrabuild (formerly Liberty OneSteel), has said,

> "*We see Australia with its incomparable energy resource – as the natural home for expansion of energy-intensive industry, with renewables to play an integral role*."[146]

Several Australian metal producers are backing this vision with investment. Infrabuild's parent company, GFG Alliance plans a billion dollar renewable energy program, which the company expects will cut electricity bills at Infrabuild's steelworks by 30%.[147] Sun Metals' investment in a 125 MW solar farm to supply its zinc refinery has helped to justify a $300 million expansion, creating hundreds of jobs.[148] And BlueScope Steel has signed a contract to take power from a solar farm.[149]

The opportunity to increase downstream processing

Other companies are investing to expand downstream processing in Australia. For example, two of the world's largest lithium producers — Tianqi (China) and Albemarle (US) are investing in lithium processing in Western Australia.[150] Tianqi's lithium refinery in Kwinana is expected to create 500 construction and 175 full-time production jobs.[151]

Also in Western Australia, a start-up called Element 25 funded by ARENA plans to use renewable electricity to produce high purity manganese. The company is implementing a new low-energy process developed with the CSIRO to become Australia's first producer of high purity manganese, a material used in alkaline and lithium-ion batteries.[152] Element 25's pioneering venture shows the way forward for Australian metal production: innovative processes powered by renewable energy.

"Renewable energy is the way that Australia can once again become a cheap energy superpower and industries like aluminium smelting will relocate onshore."[153]

Kobad Bhavnagri, Head of Bloomberg New Energy Finance in Australia

"Electrification of energy is an economic and scalable way to de-carbonise … and this may result in Australia being able to attract energy intensive industries (such as aluminium smelting and manufacturing) that see low electricity costs as giving them a competitive edge"[154]

Humayun Tai, Senior Partner, Mackinsey & co.

Aiming high: one scenario for Australia

This section presents some scenarios for an expanded Australian metal production sector powered entirely with renewable energy, focussing on opportunities with three metals – steel; aluminium and manganese. These scenarios are outlined in Table 2 and explained in more detail on the following pages.

In these scenarios, the opportunity is to export over $A110 billion in energy-intensive refined metals, adding nearly A$80 billion to the revenue from current metal ore exports. In the early years of this industry Australian metal producers may be able to sell low-carbon metals at a premium, to overseas customers with emissions reduction commitments (Section 2). These producers could then benefit from first-mover advantage as the whole world moves to a zero-carbon economy.

The industries explored in the scenarios could be comfortably supplied with metal ore already mined in Australia and exported with little or no processing. The scenarios for aluminium and manganese explore the possibility of 50% of Australia's currently mined ore being processed domestically. The steel scenario explores the possibility of 18% of Australia's iron ore production being refined domestically – enough for a steel industry as big as Japan's in 2018. This is because refining 50% of Australia's iron ore is perhaps too ambitious in terms of energy requirements.

Several other metals that Australia mines in considerable quantities could be added to this list. Metals such as zinc, copper and nickel can be made through electrolysis, and the majority of emissions from their manufacture can be eliminated simply by using renewable electricity.

Table 2 summarises the possible size of the new industries considered in our scenarios – the mass of metal product, the size of the inputs of ore and renewable energy, and the additional revenue and jobs the new industry would create. These industries could increase the export revenue from Australia's resources, creating thousands of jobs in the process. They are industries that, unlike fossil fuel exports, have a role in the zero-carbon world. Increased revenue from exporting refined metal, rather than ores or concentrates, could counterbalance any reduction in coal exports due to climate and energy policies in Australia's Asian trading partners.[155 - 158]

Table 2: Scenarios: Potential size of new Australian metal refining industries powered by renewable energy (table summarises the scenarios considered in Sections 5.1 – 5.3)

Metal	Potential refined output (million tonnes)	Ore input		Revenue (A$ billion)		Renewable energy input (TWh)	New jobs
		Million tonnes	% of current extraction	Refined metal output	Added to ore**		
Steel	100	160	18%	$83.7	$65.2	400	50,000
*Aluminium**	10	43	50%	$27.5	$15.2	116	15,000
Manganese	1	2	50%	$2.4	$1.3	4	1,600

**Aluminium inputs refer to bauxite. Required alumina input is 20 million tonnes, 100% of Australian production.*
*** Extra revenue from generated compared to 2018.*

5.1 Iron & steel

Steel is the world's most important metal, used in large volumes to make machinery, vehicles, ships, buildings and infrastructure. Steel is also the second-most polluting industrial material after cement, causing 7% of global greenhouse gas emissions.[159] Without action this proportion is set to rise in line with forecast increases in steel consumption.[160] While the contribution of recycled steel will grow, total primary production from iron ore is unlikely to decline before 2050.[161] [162] Steel production methods must therefore undergo fundamental change to eliminate emissions.

In the most common primary steel process, iron is first produced in a blast furnace, and then refined into crude steel in a basic oxygen furnace. More than 80% of the energy to drive this process is derived from coking coal, which not only provides the heat required but also plays a chemical role reducing iron ore to iron. Making steel this way produces emissions of around 1.8 tonnes of CO_2 per tonne of crude product (Figure 4).[163]

Hydrogen-based steel production

Every year more than 60 million tonnes of primary steel are made through an alternative process called direct reduction, which requires no coke or coal.[164] Direct-reduced iron is converted into steel in an electric arc furnace. Overall this process route and has 40% fewer emissions than the blast-furnace method (Figure 4).[165]

Direct reduction uses syngas, a mixture of hydrogen and carbon monoxide, usually made from natural gas. The two leading direct-reduction technologies, Midrex and Energiron, both use syngas with a high proportion of hydrogen. Energiron facilities use up to 70% hydrogen, and trials have shown the technology can be designed to run on hydrogen alone, creating the possibility of emissions-free steel production.[166] Hydrogen-based production has emerged as the most promising route to zero-emissions steel.[167]

Iron-making with pure hydrogen has already been proven at a commercial-scale. From 1999 to 2006 a facility in Trinidad produced direct-reduced iron using fluidised bed reactors and pure hydrogen as the reductant.[168] The Trinidad facility had an annual capacity of 500,000 tonnes, but the underlying technology, called Circored, could be scaled up to produce 2.5 million tonnes per year, in line with today's largest direct-reduction plants.[169] The hydrogen for the Circored plant was sourced from natural gas, but it could equally be produced by electrolysing water with renewable electricity.

Direct-reduction with green hydrogen would eliminate most of the emissions from steel production. For truly zero-emissions steel the energy requirements of both the direct-reduction facility and the electric arc furnace would also need to come from renewable sources.[1] Several European steel-makers foresee renewable hydrogen playing a central role in future production (Section 2).

Energy requirements of zero-emissions steel

Conventional steel production through the blast furnace route requires around 5,000 kWh (18 GJ) per tonne of crude primary steel (including energy for sintering iron ore and making coke and lime).[170] [171] One benefit of hydrogen-based steel production is that it can reduce this energy input, partly because of lower temperature requirements. Modelling carried out by a team at Lund University based on conventional Midrex reduction shaft technology showed that an energy input of

[1] Zero-emissions steel would also require a non-fossil fuel source of carbon added to the electric arc furnace to reduce impurities and provide steel's carbon component, as well zero emissions fluxes. The University of NSW and Liberty OneSteel developed Polymer Injection Technology which enables around 10% of the coke normally used in an electric arc furnace to be replaced with waste tyres, plastic or biomass.

4,231 kWh (15.2 GJ) per tonne of primary steel is possible, including energy for pelletising iron ore and rolling hot steel.[172]

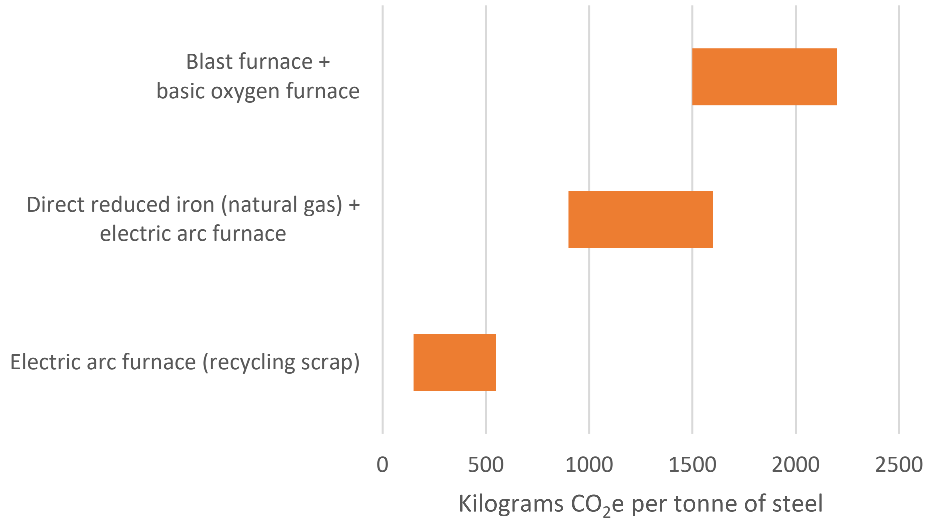

Figure 4: Carbon intensity ranges of three most common production routes to crude steel[173]

Economics of zero-emissions steel

The Swedish consortium working on hydrogen-based steel production (HYBRIT – see Section 2) estimates that at today's prices it would cost 20-30% more than conventional steel.[174] However, they expect this cost difference to disappear as renewable electricity prices fall and the penalties for carbon emissions become more severe.[175] The team estimate HYBRIT would be economically viable today with a carbon price of €44 to €67 per tonne.[176] This estimate is similar to analysis by Lund University that found hydrogen DRI would be viable at a greenfield site at a carbon price of €52.[177]

These assessments are highly contingent on the cost of renewable electricity that both teams assumed to be around A$60/MWh. However, at good sites in Australia wholesale renewable electricity is likely to be available at only A$40/MWh by 2030.[178] [179] Renewable electricity at this price could reduce the abatement cost of zero-emissions steel to €25 (A$40) per tonne of CO_2.[180]

A hydrogen-based steel works could further reduce costs by providing services to the electricity grid. Both electric arc furnaces and electrolysers allow for flexible operation – potentially enabling steel works to earn extra revenue by reducing electricity use at times of high demand, or even using stored hydrogen to generate electricity for the grid.

Australia's opportunity – a zero-emissions steel industry based on hydrogen

Section 2 profiles the plans of several European steelmakers to position themselves at the forefront of the transition to zero-carbon economy. So far there are no similar plans in Australia and yet there are few, if any, better places to make steel with renewable hydrogen. Australia is the world's second largest miner of iron ore, and yet less than 1% of this is converted into steel, with the rest exported.

By combining exceptional resources in both iron ore and renewable energy, Australia has an opportunity to become a pioneering producer of zero-emissions steel. This new industry could be based in Western Australia, which possesses the vast majority of Australian iron ore, as well as some of the country's best renewable potential due to the co-location of solar and wind resources in places like the Pilbara. However, steel plants could be located anywhere in Australia with good transport links and renewable energy resources.

Figure 5 presents one scenario for a future zero-emissions steel industry in Australia: an industry that converts 18% of iron ore output into 100 million tonnes of crude steel per year, similar in size to Japan's current steel industry.[181] In this scenario, this industry adds around A$65 billion to the revenue from Australia's iron ore (Figure 6), consuming about 423 TWh of electricity each year to make renewable hydrogen and provide the heat and power required by direct reduction and electric arc furnaces. It could also provide 50,000 on-going jobs in the steel industry, plus thousands of others in the construction and maintenance of 160 GW of solar and wind energy.

	INPUT	Plant/Jobs	OUTPUT
Steel	Iron ore input: 160 MT Renewable electricity: 423 TWh Renewable capacity: 160 GW	40 plants 50,000 jobs	Crude steel: 100 MT Revenue from steel: A$84 billion Increased revenue from 160 MT iron ore: A$65 billion

Figure 5: Scenario: an Australian zero-emissions steel sector

**Notes and assumptions for Figure 5:*

Iron ore input: 1T steel requires 1.6T iron ore.[182] Renewable electricity input: 1T steel via hydrogen reduction route requires 4.23 MWh electricity.[183] Renewable capacity: Assumes mixtures of solar and wind with average capacity factor of 30%. Number of plants: Assumes average capacity of 2.5MT/yr, equivalent to largest existing direct reduction plants.[184] Jobs: Each plant assumed to need 250 staff to run H-DRI operations [185] [186] plus 833 staff for EAF mini mill operations [187]. In addition, it assumes 6630 workers are required nationally for to produce hydrogen required for this amount of steel.[188] Revenue from steel compared to iron ore: 2018 average prices - iron ore A$95/t; steel A$838/t.[189]

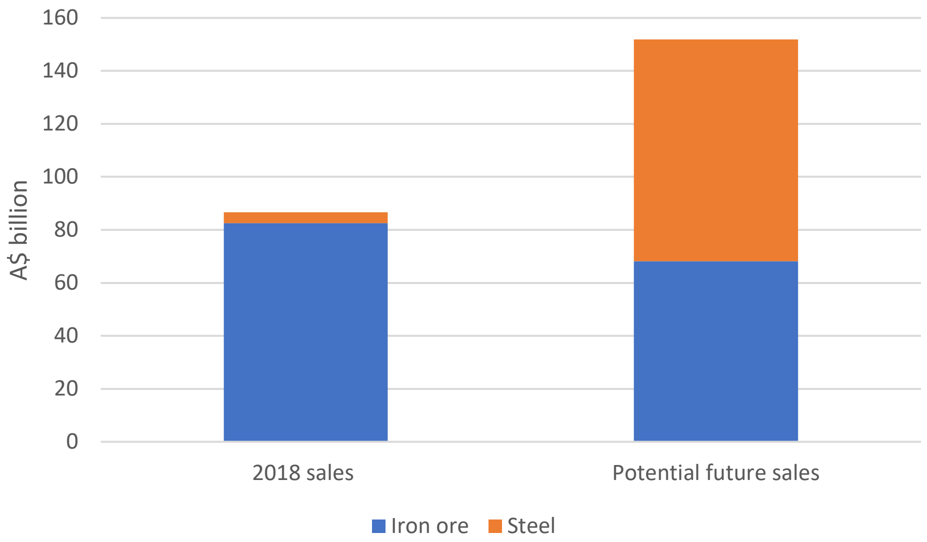

Figure 6: Converting 18% of iron ore into steel would almost double the revenue from Australia's iron & steel exports (*using 2018 average prices - iron ore A$95/t; steel A$838/t*[190]).

Increasing domestic steel recycling

In Australia 90% of metals wastes are recovered for recycling[191] – including nearly 5 million tonnes of steel. About 3.2 million tonnes this steel scrap is recycled in Australia's three electric arc furnaces or fed into Australia's two blast furnaces.[192] However, a large proportion of steel scrap is sent overseas for recycling – 1.7 million tonnes in 2017.[193] Exports are highest from Queensland and Western Australia as these states lack steel plants.[194]

This exported steel scrap could instead be recycled domestically in electric arc furnaces powered by renewable energy. This is a relatively straightforward way of both increasing domestic steel production and kickstarting the green steel sector in Australia.

5.2 Aluminium

After steel, aluminium is the second largest metal market in the world, worth US$56 billion in 2017.[195] Aluminium also has one of the highest levels of embodied emissions of the mass-market metals – a global average of about 11.5 tonnes CO_2 per tonne.[196]

Most of these emissions are from electricity generation[197] as aluminium smelting is an electrolytic process, requiring on average 14.5 MWh of electricity per tonne.[198] Another quarter of the emissions come from the degradation of carbon anodes during electrolysis, and perfluorocarbon emissions from the electrolyte. The rest of the emissions come from the production of alumina, the key raw material for aluminium smelting (Figure 7).

These average figures mask big differences in the embodied emissions of aluminium produced around the world. Smelters powered by hydropower in Canada, Russia, Norway, Iceland and Tasmania reduce emissions by around 70%.[199] In Australia three of the four smelters are powered by mostly coal-fired electricity, making Australian production more carbon intensive than average.[200]

There is growing concern about the embodied emissions of aluminium and increased demand for more sustainable options. Apple now aims to use only aluminium produced using hydropower and other companies such as Bosch, Toyota, Audi, BMW and Tetra Pak have all committed to using lower-emissions aluminium.[201] In response companies such as Rio Tinto and Alcoa have certified low-emissions products for which they charge a premium.[202] [203] Parts of the industry are also working on eliminating the second largest source of emissions from degradation of carbon anodes (Section 2).

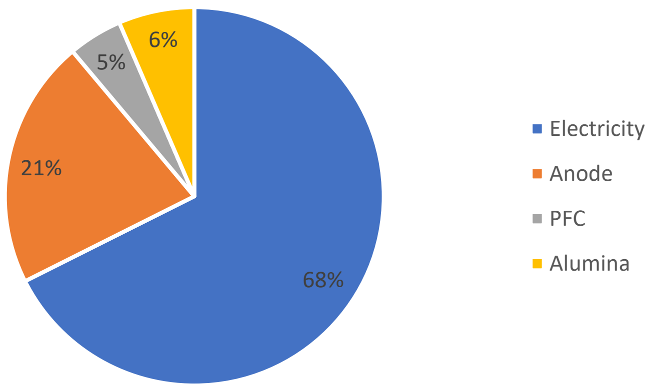

Figure 7: Emissions from global aluminium production are dominated by electricity[204]

Box 3 **–** Australian research to reduce emissions from alumina production

Alumina production consumes a quarter of all fossil fuel energy used by industrial heat processes in Australia, causing more direct emissions than any other manufacturing sector.[205] [206]An ongoing ARENA-funded study, involving Alcoa and the University of Adelaide, is exploring the potential of concentrated solar thermal to supply some of the heat for alumina processing.[207] Early findings are that it could replace 29- 45% of gas without major changes to existing equipment.

Australia's opportunity – a zero-emissions aluminium industry

Almost all aluminium is made from bauxite. Australia mined 88 million tonnes of bauxite in 2017, more than any other country.[208] Australia is also the second largest manufacturer of alumina, the key raw material for aluminium smelting (20 million tonnes in 2017).[209] Australia processes only 15% of this alumina into aluminium, with the rest exported.[210] Aluminium processing occurs at four smelters which, in 2017, used 25 TWh of electrical energy – 20% of which was renewable.[211]

The commercial viability of aluminium plants rests substantially on the cost of electricity, which typically accounts for around a third of the total cost of production. As shown in Section 3, the cost of renewable energy in Australia is now among the lowest in the world, and set to get cheaper. With the growing size of renewable energy projects in Australia, the large power demand of aluminium smelters is no longer a barrier. For example, Sun Cable plans to install 10 GW of solar PV and many gigawatt hours of energy storage in the Northern Territory. Though Sun Cable plans to export its electricity, a similar project of this scale could power several aluminium smelters.

Australia's opportunity is to use its cheap renewable energy to produce far more aluminium. Figure 8 outlines one scenario for a future aluminium industry with an annual output of 10 million tonnes, a seven-fold increase compared to 2018 (Figure 8). An industry of this size would consume 50% of Australia's current bauxite output and 100% of its alumina production.

This enlarged aluminium industry would increase the revenue from Australia's alumina output by over A$13 billion in today's prices, consuming 115 TWh renewable energy (11.5 MWh per tonne with efficient production techniques).[212] The industry could also provide around 15,000 on-going manufacturing jobs, plus tens of thousands more to build and operate 44 GW of renewable energy.

Achieving this scenario would involve the construction of 10 new large aluminium smelters, in addition to the four already in operation. All smelters would be fitted with inert anodes to avoid emissions from anode degradation, and would be designed for flexible operation to complement a renewable energy system. In this scenario, existing smelters are modernised and powered with 100% renewable energy.

	INPUT	Plant/Jobs	OUTPUT
Aluminium	Alumina input: 20 MT[213] Renewable electricity: 115 TWh Renewable capacity: 44 GW	14 smelters 15,000 jobs	Aluminium: 10 MT Revenue from aluminium: $27.5 billion Increased revenue from 20 MT alumina: $15 billion

Figure 8: Scenario: An expanded Australian aluminium sector using renewable energy

**<u>Notes and assumptions for Figure 8</u>:*

Alumina input: 1T aluminium requires 2T alumina.[214] Renewable electricity input: Efficient production requires 11.5 MWh electricity per tonne.[215] Renewable capacity: Assumes mixtures of solar and wind with average capacity factor of 30%. Number of smelters: Existing 4 smelters collectively producing 1.6MT per year plus 10 large new ones with average capacity of 0.84MT/yr.[216] Jobs: Based on 1000 employees at Tomago, NSW.[217] Revenue from aluminium compared to revenue from alumina: 2018 average prices - alumina A$359/T[218]; aluminium A$2,754/T.[219]

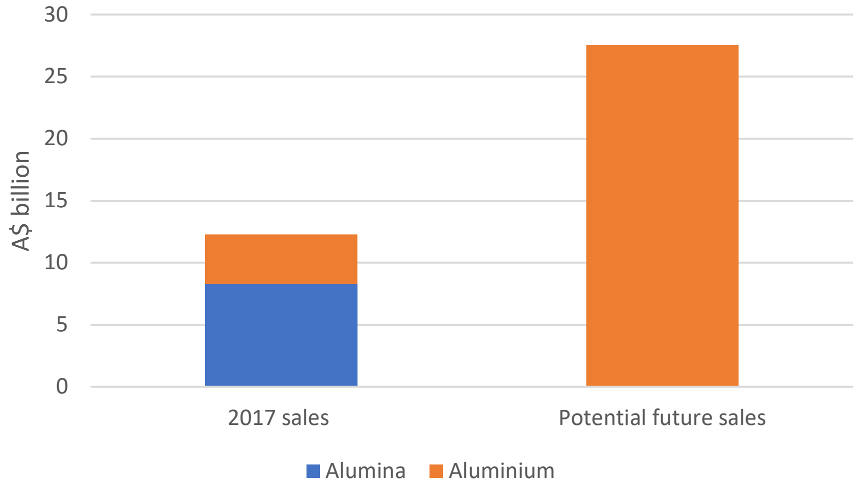

Figure 9 Converting 50% of currently mined bauxite into aluminium would almost double its revenue.

5.3 Manganese

About 85% of manganese is made into ferromanganese or silicomanganese – alloys that are a vital component of most steel, improving its strength and hardness.[220]

Manganese alloys are produced in an electric arc furnace using coke as a reducing agent.[221] On average the manufacture of 1 tonne of ferromanganese/silicomanganese produces 3.6/6.1 tonnes of carbon dioxide emissions, which are mostly related to electricity consumption.[222] The TEMCO plant in Tasmania, is able to half these emissions by running on low-carbon hydroelectricity.[223]

The remaining 15% of manganese is processed into types of high-purity manganese, such as manganese sulphate, electrolytic manganese metal and electrolytic manganese dioxide. These materials are used in alkaline and lithium-ion batteries, as well as some speciality metal alloys. The market for these materials, which are typically worth about 50% more than manganese alloys, is expected to boom, driven by growing demand for batteries.[224]

Australia's opportunity – a zero-emissions manganese industry

Australia supplies nearly one fifth of the world's manganese – 4.1 million tonnes of ore in 2017-18.[225] Most of Australia's manganese comes from the GEMCO mine on Groote Eylandt (3.4 million tonnes) in the Northern Territory.[226] A smaller mine at Bootu Creek produced 0.8 million tonnes in 2017-18,[227] and exploration licences have been granted for several potential manganese mines in the Northern Territory and Western Australia.[228]

Australia derives little value from processing manganese ore. Some of GEMCO's output is sent to the TEMCO manganese alloy plant in Tasmania,[229] but about 90% of Australian manganese ore is shipped overseas for processing. (Some minimal refining of lump ore takes place domestically.) Australia has an opportunity to create new industries in making manganese alloys and high-purity manganese.

New manganese alloy smelters powered by renewable energy

Australia could use renewable energy to transform manganese ores into higher value alloys with low embodied emissions. The scenario presented in Table 3 envisages two new manganese smelters. Like the existing TEMCO smelter, each new smelter would produce 170,000 tonnes of manganese alloy per year, divided equally of ferromanganese and silicomanganese. The two new smelters combined with the TEMCO one would have with an output capacity of 510,000 tonnes, consume 1,185,000 tonnes of manganese ore (29% of Australian production). This would add around A$630 million to the revenue relative to exporting unprocessed manganese ore.[230]

Manganese alloys are produced in electric arc furnaces, requiring 2,400/4,000 kWh of electricity per tonne of ferromanganese/silicomanganese.[231] The proposed smelters would have a combined electrical power requirement of 300 MW. Assuming annual production of 510,000 tonnes and operation at 65% capacity, they would consume 1,600 GWh of electricity per year. This energy could be provided by renewable energy capacity of around 600 MW.

The two new smelters would provide 800 permanent jobs[232] and hundreds more during construction. Construction and operation of this renewable energy infrastructure could create about 1500 temporary jobs and another 75 permanent positions.

Producing high-purity manganese with renewable energy

Demand for high-purity manganese products is likely to grow, driven partly by the explosion in the market for lithium-ion batteries. Australia could capitalise on this demand as high-purity manganese is a higher-margin product than manganese ore or alloy, fetching prices above A$3,000 per tonne.[233]

As with manganese alloys, the energy to produce high-purity manganese can be renewably sourced. CSIRO has developed an innovative low-energy process that removes the need for manganese ore to be roasted at up to 1,000°C.[234] With the new process the production of manganese sulphate requires very low energy input as it the reactions take place at ambient temperature and atmospheric pressure.[235] Electrolytic manganese metal is produced in a second stage – an electrolytic process called electrowinning. This second stage can be powered with renewable energy as the energy input is mostly electrical.

There are currently no Australian producers of high-purity manganese, but now at least two companies in Western Australia plan to commercialise the CSIRO process. Pilbara Metals Group, aims to produce 40,000 tonnes a year of manganese sulphate (as well as lithium manganese oxide).[236] Element 25 plans to produce around 100,000 tonnes per year of electrolytic manganese metal (EMM) using ore from a new manganese mine in WA.[237]

Element 25 is particularly interesting as it aims to use a high proportion of renewable energy. A pre-feasibility study showed that a 50% renewable energy mix would be cost-effective, despite access to a nearby gas pipeline.[238] Subsequent analysis suggests that a 90% renewable share may be even more advantageous, delivering energy at a lower cost than Chinese competitors.[239] Element 25 is exploring how to accommodate this higher level of renewables by combining flexible operation with energy storage options.[240]

Our scenario explores an Australian industry producing 400,000 tonnes of EMM per year (Table 3). This would require 860,000 tonnes of manganese ore[241] (21% of current production) and add A$1.0 billion to its value (Table 3, Figure 10). This scenario involves four new plants, each with a capacity equivalent to the Element 25 project. These facilities could provide around 800 permanent jobs, and up to two thousand more during construction.[242]

The production of 1 tonne of electrolytic manganese metal requires 6,500 kWh of electrical energy.[243] Plants producing 400,000 tonnes per year would have a combined power requirement of 400 MW and annual energy consumption of 2,600 GWh per year. This energy could be provided by renewable energy capacity of around 1000 MW. Construction and operation of this renewable energy infrastructure would create about 1000 temporary jobs and another 50 permanent positions.

Table 3: Scenario: An expanded Australian manganese sector

Mineral	Output (tonnes)	Revenue from output ($ billion)	Increased revenue compared to ore ($ billion)	Renewable energy (GWh/yr)	New permanent jobs
Manganese alloys	510,000	$1.06	$0.63	1,600	800
High-purity manganese	400,000	$1.32	$1.01	2,600	800

Notes on Table 3:
Output: 1T manganese alloy and 1T high-purity manganese require 2.2T and 2.15T of manganese ore respectively. Increased revenue: 2018 average prices – manganese alloy A$2,079/T[244], Electrolytic manganese metal A$3,300[245]. Renewable energy: Jobs: Based on staff numbers at TEMCO manganese plant[246] and estimates of future employees from Element 25 and Pilbara Metals Group[247].

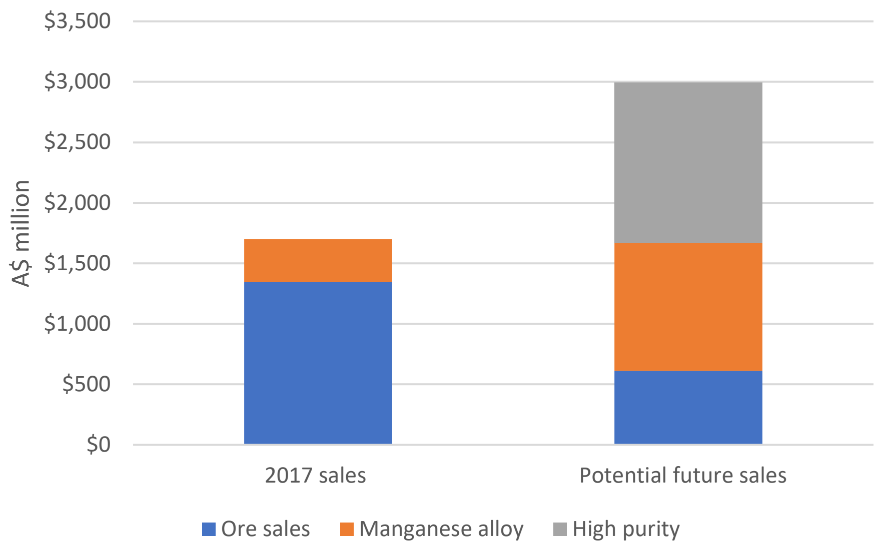

Figure 10: New processing plants could add over $1 billion to Australia's manganese export revenue.

6. Risks and barriers

This report highlights the opportunity for Australia to develop a thriving zero-emissions metal sector. But success is not automatic and there are undeniably barriers and risks to overcome.

The scenarios presented depend on large investment. They would require around 200 GW of new renewable energy infrastructure, costing A$400 billion in today's prices. The metal refineries themselves might cost another A$100 billion, as a rough estimate. To provide funds on this scale, investors will need to be confident of a future return, despite technical and economic uncertainties.

A similar situation was faced by the LNG industry 10 years ago. On the one hand, oil and gas companies had identified huge gas reserves off Australia's coast. On the other hand, there were significant technological challenges to extracting, handling and transporting the gas, as well as uncertainty about future demand. A successful LNG export industry would depend on new trading relationships and continued deferral of strong climate action. Despite these risks the industry was able to raise more than A$200 billion to fund LNG mega-projects in Australia.[248]

The example of LNG does not guarantee Australia's success in zero-emissions metals. But it does suggest the right approach is to recognise the scale of the opportunity, as well as the challenges. Some of the major risks and barriers are listed below. The significance of each of these risks and barriers is likely to differ across sectors: in some cases, technical barriers may be relatively low, but supply chain relationship may be a higher barrier, and the reverse in others.

- ***Fierce competition in metals***. Current conditions in international metal markets make it hard for many Australian metals producers to compete. Profit margins are low or non-existent due to over-capacity in the global production of many metals. Many producers benefit from government subsidies or cheaper labour. Conditions are even tougher for new smelters and refineries that must compete with older plants whose initial capital costs have been paid off.
- ***Market risks***. Competition with existing metal producers matters less if distinct markets develop for low-emissions metals that attract a price premium. This report argues such markets are likely to develop due to climate commitments by countries and companies. However, so far only the aluminium sector shows clear signs of developing a distinct market for low-emissions products, and we can only speculate as to how quickly other metals will follow.
- ***Supply chain relationships.*** Many existing producers of refined metals have long-standing relationships and synergies with customers, creating a major barrier to newcomers. Also long-term supply contracts for metal ores may restrict their availability for domestic processing. These factors may affect the level of processing that it is cost-effective to locate in Australia.
- ***Distance from end-use markets*** given domestic metal demand is too small to sustain expansion.
- ***Technical risks***. While the technologies presented in this report are well-developed, some are not fully-commercialised, or else not proven at a large scale. Likewise, inert anodes have not yet been demonstrated in a commercial aluminium smelter. The development of these technologies adds time and risk to any zero-emissions metal strategy.
- ***Competition in zero-emissions metals.*** Other countries have embryonic low-emissions metals strategies and more will follow. Some, such as Canada and Norway have access to cheap renewable energy. Australia will need to move quickly and resolutely to compete.

  Exchange-rate risks. The Australian dollar tends to rise during mineral commodity booms, making Australian manufactured exports more expensive and less competitive.

More analysis of these risks and barriers is needed to ensure future investment in the zero-emissions metals industry has the best chance of success.

7. Policies and actions

This report highlights an opportunity to capitalise on an abundance of renewable energy and mineral resources. However, Australia's success is not guaranteed. Other countries have access to cheap ore and renewable energy, and some foreign governments provide strong incentives for metal producers to develop lower carbon processes. For example, all the low-carbon steel research and pilot projects outlined in Section 2 are backed by public funds.

Here we outline some actions and policies that governments and companies could consider with the aim of establishing a world-leading zero-emissions metal industry in Australia. Further work is required to establish the expected net benefits of each of these possible approaches.

1. Launch national zero-emissions metal strategy

Governments could develop a coordinated zero-emissions metal strategy, setting a clear direction for Australia to become a leader in this new industry. This strategy would be backed up with concrete policies designed to promote the industry and attract investment. The goal would be to boost manufacturing jobs and export revenue, while reducing global emissions from metal refining.

The current support for the hydrogen industry provides a partial model for a future zero-emissions metal strategy. Governments are developing a national hydrogen strategy and funding numerous hydrogen research projects across Australia. A similar approach could help Australia seize the opportunity to lead in the zero-emissions metal sector. In developing a national zero-emissions metal strategy, governments should engage industry and consult widely with stakeholders to ensure obstacles are identified and addressed.

2. Financial support for downstream processing of minerals

Reinventing metal production requires substantial investment that individual companies may be reluctant to provide on their own, because of the risks of related to innovation and new markets. There is, therefore, a strong case for governments to support the industry with bold investment and fiscal decisions, such as:

- tax rules that reward innovation and long-term investment, such as accelerated depreciation
- grants for research and pilot projects for technologies with significant growth potential
- long-term loans at favourable rates
- supporting infrastructure such as transmission lines and freight railways.

ARENA and CEFC do provide some funding of this type but it is not currently stimulating the development of low-emissions metal production that is occurring elsewhere. For Australia to lead in this area it should substantially increase R&D investment. The pilots emerging in other countries illustrate the scale of government support that might be required. For example, the Swedish Government has allocated over A$80 million to hydrogen-based steel production[249] and the EU has awarded around A$11 million in funding to explore steel production by electrowinning[250]. This latter funding is just a small fraction of the EU's allocation of A$45 billion to climate action research under the Horizon 2020 program.[251]

3. Establish procurement policies that prioritise low-emissions metals

Governments and companies can use their considerable spending power to support the development of a market in low-emissions metals. For example, state governments could set thresholds for the embodied emissions in steel used in any public infrastructure project. This threshold could become progressively more stringent until it reaches zero.

Such a policy would reduce the investment risk for a steel-maker aiming for lower emissions by providing a major source of demand. There are already some government policies that enable this approach. For example, the Victorian Government's sustainable procurement policy aims to minimise emissions through performance standards on public projects worth over $20 million.

4. Create incentives for downstream processing of minerals

Some countries promote domestic processing of minerals through policy and regulation, with the goal of extracting more value. Such policies require careful analysis before implementation, and Australia can learn from an extensive international history of successful and unsuccessful interventions. Some policies of this type are outlined below, ordered according to an increasing level of market intervention:

Differential levies on processed and unprocessed minerals. Governments could charge higher levies on unprocessed minerals compared to processed minerals. At the national level this might mean export taxes on unprocessed minerals but tax credits for refined metals. At the sub-national level, it would mean applying different royalty rates according to the degree of processing – a system which already operates to a limited extent in some states.

Domestic reservation policy. Australia could establish a domestic reservation policy for minerals, akin to Western Australia's natural gas policy. The policy would require a proportion of some minerals to remain within Australia until they are processed into metals. This would have the effect of reducing the cost of minerals to entities with an interest in downstream processing.

Enforce local processing. A robust form of intervention would be simply to require mining companies to carry out some mineral processing within Australia. A similar policy was pursued by the Western Australian Government in the 1990s and more recently by countries including South Africa, Chile and Indonesia.[252] Before approving new or expanded mines, the government could impose conditions requiring a level of downstream processing within Australia.

5. Develop of a Guarantee of Origin scheme for zero-emissions metals

As metals pass through complex supply chains end users often do not know where and how the crude product was made. This poses a challenge for the market in low-emissions metals. One solution is to create a labelling scheme to provide information to customers about the source of metal and the emissions related to its production.

The European Union has developed this type of 'Guarantee of Origin' scheme for green hydrogen, and the first contracts using the certification have been agreed.[253] The COAG Energy Council Hydrogen Working Group is considering how a similar scheme could work in Australia.[254]

6. Government promotion of successful trading relationships

As noted in Section 6, producers of refined metals have existing relationships and synergies with their customers. This network of relationships creates a barrier to new metal producers, which the Australian Government can partially overcome by negotiating strong trading arrangements with other countries. Government agencies such as Austrade can also help by connecting Australian businesses with overseas customers.

7. Industry actions

Mining companies and metal producers could set ambitious emissions reduction targets, following the example of many global corporations. Such targets will improve their standing with customers and investors concerned about high-carbon strategies. With these targets in place, companies can develop strategies to progressively reduce emissions from metal production, ultimately to zero.

Producers and purchasers of metals could collaborate to develop thriving markets in green metal production. This should include the creation of collective industry emissions targets, as well as supporting green metal standards and certification.

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