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AUSTRALIA

AUSTRALIA'S GREEN IRON KEY

UNLOCKING ASIAN STEEL DECARBONISATION, SECURING AUSTRALIA'S ECONOMIC FUTURE

Acknowledgements

WWF-Australia acknowledges the Traditional Owners of the land on which we work and their continuing connection to their lands, waters and culture. We pay our respects to Elders, past and present, and their emerging leaders.

WWF is one of the world's largest and most experienced independent conservation organisations, with over five million supporters and a global network active in more than 100 countries.

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

WWF-Australia National Office

Suite 3.01, Level 3, 45 Clarence Street
Sydney NSW 2000
PO Box 528
Gadigal Country
Tel:+61 2 8000 0303
hello@wwf.org.au
wwf.org.au

Authors:
James Bowen
Director
ReMap Research

Nicole Wyche
Industry Decarbonisation Manager (Steel)
WWF-Australia

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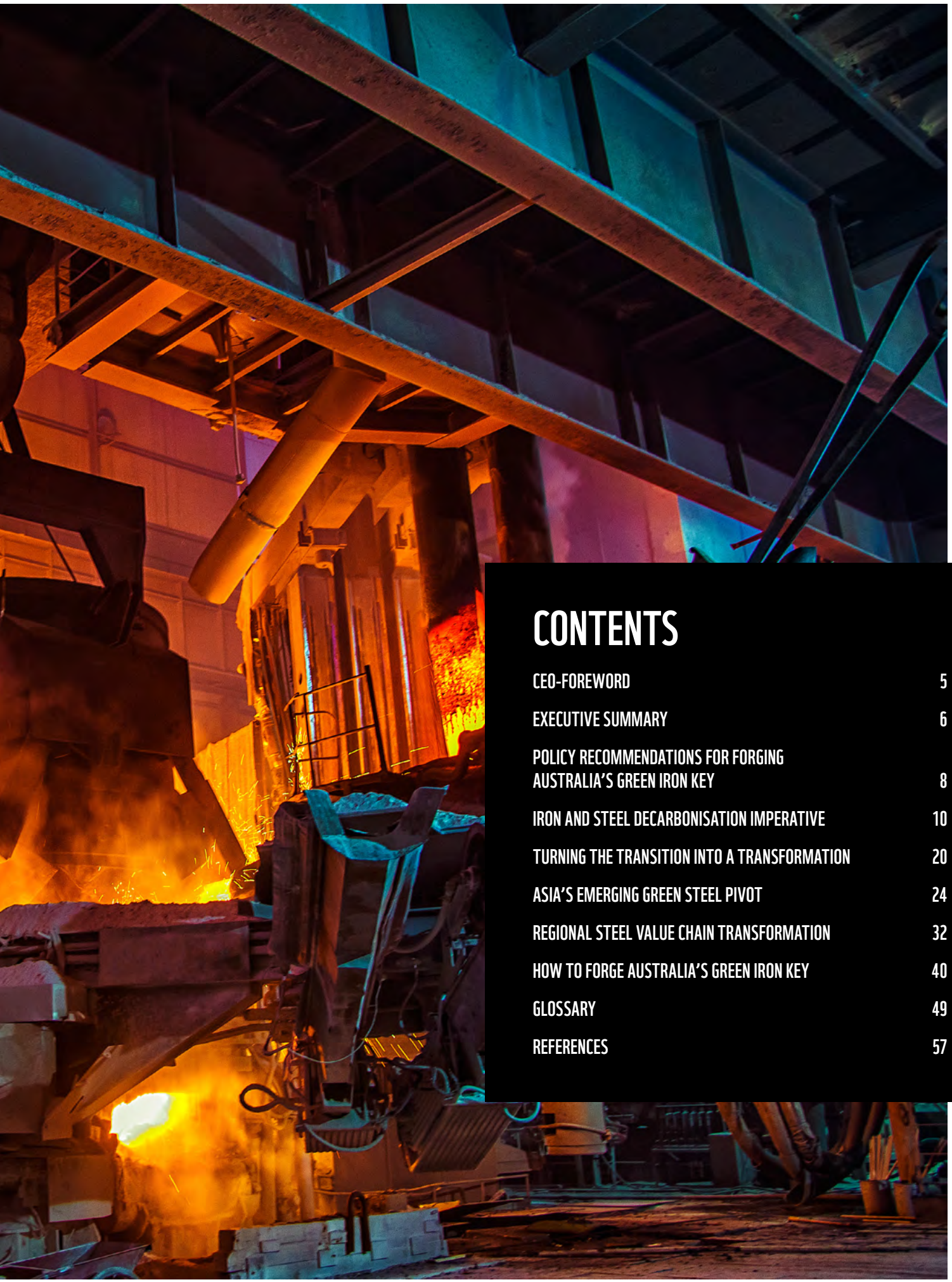

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A WORD FROM OUR CEO

WWF-Australia has a vision of Australia as a renewable energy superpower and has been an active leader, in the region and globally, on a transition to a thriving and resilient net-zero world.[78]

An economy driven by petroleum and raw material export alone will not allow us to realise this vision to transition to a regenerative economy. For Australia, this kind of business as usual has significant risks that are harming our long-term economy, the natural environment and our communities. The energy transition is a global race, and Australia needs to keep its promises to the global community while delivering just, inclusive and equitable outcomes for people and nature.

As an international network in over 100 countries, WWF works to reduce emissions, build resilience, and ensure that the clean energy transition is fast, best and just:

1. A fast transition meets agreed-upon international targets for emissions reduction and positions Australia and our regional partners for a prosperous future in the net-zero economy.

2. A best transition protects our planet's life support systems – we must deploy joint solutions to solve the energy, nature and climate crises.

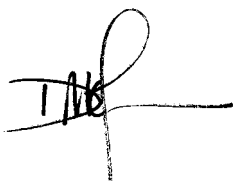
3. A just transition incorporates equity for all people (including First Peoples) and nature throughout and after the transition. Undertaking a 'just transition' of systemic change at scale "... depends on environmental and social policies being mutually reinforcing, not contradictory".[1]

Global momentum in green iron ore and steel is rapidly building. WWF advocates for rapid and future-proof decarbonisation of the entire steel value chain and has developed a green iron and steel regional cooperation program between Australia and East Asian steel-making economies.

The projected most likely scenario for the steel industry transition is a decoupling of the current practice of integrated iron and steel-making. Instead, iron will be produced where the cheapest renewable energy and the lowest-emission reductants (renewable hydrogen) can be generated while retaining steel product manufacturing where these industries currently exist.

With fast and deliberate action, Australia could be the centre of green iron production. We call this the 'green iron key' that unlocks the green steel potential. Activating the key requires deploying leading fossil-free technologies and cooperative diplomacy to best coordinate the transition of our economy and that of our iron ore trading partners for mutual benefit.

It's imperative that we work with our regional partners on this decarbonisation journey. At the same time, we need accountability, enabling legislation, incentives and market support that enables this evolution and delivers genuine community engagement and benefits together with nature positive. But it is important that we act now—we have one shot to activate this green iron key.



Dermot O'Gorman
CEO, WWF-Australia

EXECUTIVE SUMMARY

Decarbonising iron and steel production is vital to limiting global warming to 1.5°C in line with the Paris Agreement. The steel sector alone is responsible for up to 9 per cent of global greenhouse gas (GHG) emissions.[2]

As a leading supplier of iron ore, coal and fossil gas for the industry, Australia must play an active and responsible role in decarbonising the sector. Emissions from the use of these commodities in steel-making are enormous, with emissions from iron ore use alone approximately double Australia's total domestic emissions from all sectors.[3] Viable technological pathways for producing 'green iron and steel'[i] exist and continue to evolve, but considerable investment and policy support are required to deploy these and put the industry on track to reach net-zero emissions before 2050.

The world remains overly dependent on carbon-intensive iron and steel production. But there are important signs of change and opportunities to accelerate it. Now is the time to invest in pathways to develop a green iron and steel industry. To continue with polluting steel manufacturing technologies, around 71 per cent of ageing conventional infrastructure (blast furnaces for iron-making) each need billion-dollar maintenance in this decade.[4] Industry leaders in Sweden are instead investing in the fast-approaching low-emission economic future by building low-emission steel-making plants[5], with other countries following suit. Automotive manufacturers are increasing their appetite for green steel and this is putting pressure on steel manufacturers around the world.

Greening the steel supply chain presents Australia with both challenges and opportunities. Iron ore is Australia's most valuable export commodity. This market, currently dominated by bulk shipments of largely unprocessed hematite ore, will change markedly in response to the demand for greener iron and steel. The contaminant levels of hematite ores make Australian hematite ores incompatible with available green steel technologies (see Information box 3), creating a major risk to Australia's economic future. Green steel compatible magnetite ores, previously seen as less economic to mine, will become important sources of high-grade iron-making feed until processing solutions for hematite ores emerge. Locations with magnetite and other suitable high-grade iron ores will become logical places to begin green iron manufacturing.

Greening iron and steel will trigger a restructure of steel-making. Asian economies that dominate steel-making and steel product manufacturing are likely to remain dominant steel producers. However, the current practice of producing iron for steel-making and steel products in the same location will be decoupled, as high-emission iron-making blast furnaces are phased out and replaced with technologies powered by renewable energy. Energy-intensive iron-making will need to be located closer to abundant iron ore, renewable energy and renewable hydrogen[ii] supplies. Australia remains well-placed to emerge as a major green iron producer, a multi-billion-dollar industry, starting with manufacturing green iron from magnetite iron ore processing and from hematite iron ore when technology allows.

Asia will largely determine the fate of iron and steel decarbonisation. Asian economies, led by China, dominate global steel output by carbon-intensive blast furnace-based production. Asian economies have pivoted towards green steel slowly but are increasing their commitments due to increasing decarbonisation and net-zero requirements. Key industry players have their own emissions reduction targets and are beginning to invest and transition their businesses to achieve net-zero goals.

Australia could forge a 'green iron key' to help unlock economic development and decarbonisation at home and in our region. Manufacturing green iron, a preferred import product for green steel manufacturing, is an optimal industry to develop to evolve and future-proof the iron ore industry. An ideal green iron plant produces less than 3 per cent of the emissions of a conventional blast furnace.[5] Australia realising its green iron industry potential is critical to reducing the emissions of the iron and steel industry in our region and offers a clear emission reduction solution to our iron ore trading partners. This option also allows Asian steel producers to maintain their economic competitiveness in steel production, and steel industry jobs, by importing more suitable Australian green iron.

Asian steel producers are beginning to pursue Australian trade and investment. But successful partnerships are not guaranteed. Major Asian steel producers are pursuing green iron and steel value chains involving Australia, but they are also looking elsewhere. Australia's ore challenges, and other industry headwinds, add to the need for a more active and unified national pursuit of green iron opportunities.

Australia must enhance domestic support to succeed in a green steel world. Australia's green iron and steel success is not assured. Enabling priorities for this new industry include accelerating supply of renewable energy; new magnetite mining and developing new hematite processing technologies; developing a renewable hydrogen industry; and building renewable hydrogen-ready green iron plants. Co-locating assets would maximise efficiency. To deliver these, the government must provide a well-coordinated policy mix of carrots—that is, industry policy containing improved fiscal and regulatory support—and sticks, primarily clear and stronger real emissions reductions requirements on industry.

Australia and Asia's success depends on effective cross-border cooperation. Australia's iron ore and Asia's steel industry have vast potential to collectively reduce emissions. To do this efficiently, partner countries must closely coordinate plans and policies to ensure success. The Australian Government and industry members must work closely alongside one another and with their Asian counterparts. Priorities include coordinating and expediting trade and investment plans, establishing industry standards, and enhancing research and development. Australian diplomats should also encourage Asian partners to take what could be market-transforming decisions, such as altering investment pipelines in favour of green steel-making capacity and making major public and private green steel purchase commitments.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INFORMATION BOX 1

DEFINING GREEN IRON AND STEEL

Steel-making is a two-step process: first removing oxygen from raw materials (reduction) to make iron in liquid or solid form, then turning this crude (pig) iron into a liquid suitable for casting into steel products. High CO_2 emissions result from conventional processes primarily due to the use of fossil coal and fossil gas for heating, structural stability and reduction in blast furnaces. Green iron is iron produced without the use of fossil fuels. Instead, renewable energy is used for powering the process, and renewable hydrogen (hydrogen[ii] made from water by electrolysis) is used for reduction. Green steel is made by processes using only renewable energy and by substituting the small residual amount of required carbon for non-fossil carbon.

While it is still necessary to know the carbon intensity of the entire value chain to ensure processes are 'low-emission', 'green' is used in this report to acknowledge that in addition to low-emission production technologies, low-emission industries should also prioritise avoidance of other adverse environmental, biodiversity and community impacts.

As yet, there is no globally accepted definition of green steel or related terms such as near-zero-emissions steel and low-emissions steel. There is also no common global approach and methodology for assessing lifecycle GHG emissions embedded in steel products. The World Trade Organisation notes both as prospective barriers to the emerging low-emission iron and steel trade. Several efforts to develop common understandings are under way. An International Energy Agency (IEA) communique issued ahead of the G7 Climate, Energy and Environment Ministers Meeting in May 2022 defined 'near-zero-emission steel' as a 'steel product produced by generating less than 400 kilograms of CO_2 equivalent (total GHG emissions) per tonne, including the procurement of raw materials'.[6] By comparison, steel made using the conventional blast furnace plus basic oxygen furnace route generates more than 2 tonnes of emissions per tonne of crude steel on average. Industry members and other stakeholders agreed to support the IEA's approach when adopting a broader set of Steel Standards Principles at the COP28 UN Climate Change Conference in December 2023.[7]

i As defined in Information box 1.

ii In this report, if 'renewable hydrogen' is not specified, 'hydrogen' may refer in part or wholly to fossil hydrogen production methods.

POLICY RECOMMENDATIONS FOR FORGING AUSTRALIA'S GREEN IRON KEY

Developing a green iron and steel industry has the following key requirements: an adequate renewable energy supply and sufficient other renewable consumables, including renewable hydrogen; the right iron ore available at a globally competitive price and location; suitable infrastructure for heavy industry and export; governance that creates certainty of future industry regulation; financial and non-financial enablers that preferentially seed and protect emerging low-emissions industries; and, most important of all, the political courage and policy foresight to deliver a new Australian trading identity at a time of revolutionary industrial change, investment and opportunity.[iii] Federal[iv] and state governments must coordinate to:

A Establish an at least $10 billion domestic support package to decarbonise the existing iron ore and steel industry and prioritise the development of export-focused green iron projects.

- Align government programs such as Powering the Regions, the National Reconstruction Fund, Hydrogen Headstart and new initiatives with meeting the industry's significant need for affordable renewable power and renewable hydrogen. Policies should also create demand for renewable energy.
- Australia's emissions reduction targets must align with global leadership in this space if we are to be the low-emission investment destination of choice. This provides investors with clarity, certainty and confidence. Investors already know that Australia must raise the bar on emission reduction timelines, community consultation, biodiversity protection and managing other environmental impacts, and seek clarity on these issues to aid their investment decisions. Attracting new green iron and steel investments is also far more likely with clear and future-proof climate and environmental protection regulations, not less regulation.
- Create and follow clear sector-specific emissions reduction pathways with measurable timelines, science-based targets and auditable, consistent and transparent data disclosure requirements. These must include clear deadlines for phasing out transition consumables, including fossil gas and fossil gas-hydrogen (fossil or renewable) gas blends.[v] Emission-tracking schemes, such as the Guarantee of Origin, must be expanded to all industries.
- Facilitate development of common user infrastructure in renewable energy industrial precincts in appropriate locations to ensure that the vast scale of investment required is efficiently delivered and used by all industries.
- Develop a skilled workforce and technological capabilities via continued technological research, development and training.
- Task agencies such as the Clean Energy Finance Corporation, the Australian Renewable Energy Agency and Northern Australia Infrastructure Facility with de-risking industry investments by making renewable energy and consumables competitive with fossil fuels.
- Redistribute current financial support and subsidies for the fossil fuel industry to fund renewable energy and renewable hydrogen infrastructure that, unlike investments in fossil gas, will future-proof our economy.
- Respond to significant carbon market instruments like the Carbon Border Adjustment Mechanism (CBAM of the European Union) that will be a reality of the green economy. Australia should develop equivalent measures if deemed necessary to protect domestic decarbonisation.

B Revitalise and expand Australia's Asian green iron and steel international strategic partnerships.

- Agreements should identify and expedite the creation of value chains involving Australia as a green iron maker, and countries like Japan and Korea as green steel producers. For example, the Australia–Japan Partnership on Decarbonisation through Technology and the Australia–Republic of Korea Low and Zero Emissions Technology Partnership could be aligned with national green iron and steel ambitions and strategies.
- Elevate ties with emerging steel-making giant India to position Australia as a key partner in its low-emissions steel-making future.
- Investigate options for other green iron and steel international partnerships, including pragmatic ties with industry-dominating China and emerging Southeast Asian economies.

- Resource Australia's internationally engaged agencies—including Austrade; Export Finance Australia; CSIRO; Department of Foreign Affairs and Trade; and Department of Climate Change, Energy, the Environment and Water—with supporting partnerships via business facilitation, finance, research and development, standard setting and policy formation.

C Pursue international green iron and steel leadership.

- Advocate for Australia's prospective position as Asia's 'green iron key' in dedicated iron and steel decarbonisation groups, such as the Leadership Group for Industry Transition (LeadIT).
- Make iron and steel decarbonisation a focus of any revision of existing and/or negotiation of new trade deals and engagement with global and Asian institutions and minilateral groups.
- Make iron and steel decarbonisation a focus of a prospective Australia/Pacific-hosted Conference of the Parties (COP).
- Pivot international public finance towards facilitating green iron and steel trade and investment, in line with Australia's decision to end international fossil fuel finance at COP28.
- Establish a globally significant green iron and steel centre of excellence and intergovernmental dialogue to advance research and development and policy formation.

D Better coordination of domestic and international, and Commonwealth, state and territory efforts.

- Prioritise green iron and steel as a key sector in any forthcoming renewable energy superpower master plan.
- Establish dedicated responsible (federal and state) agencies with the appropriate skills, financing, and policy and fiscal implements to match the scale of the challenge and opportunities. A highly coordinated and accountable approach that does not split responsibilities across multiple ministerial portfolios will be critical for success.
- Establish a national green iron and steel strategy.[iv] Australia needs a well-designed strategy with measurable targets, delivered by bold and deliberate statecraft, to secure a leading position in the green industrial revolution this sector is experiencing. An executable strategy must coordinate and best communicate Australia's domestic and international intentions, priorities and commitments.
- Keep onshore all domestic scrap metal to integrate into Australia's value chain.

INFORMATION BOX 2

AUSTRALIA'S GREEN IRON OPPORTUNITY

A 2023 report by the Minerals Research Institute of Western Australia (MRIWA; [8]) estimated that building just one green iron plant (one 4.8 million tonnes per annum capacity direct-reduction plant producing a reduced iron product) would deliver the following benefits:

- Generate $85 billion to Australia's gross domestic product (GDP) ($3 billion per annum).
- Generate an additional $66.5 million in real income across the local, state and national economies during construction and over a 24-year operational life through to 2050 ($2.4 billion per annum).
- Create 1,540 full-time equivalent (FTE) jobs.
- Generate an estimated $31.7 billion in Commonwealth and state taxation benefits during the construction and operations through to 2050 ($1.1 billion per annum).
- Produce less than 3 per cent of the emissions that result from conventional steel production (blast furnace coupled with a basic oxygen furnace).

A plant of this size is estimated to consume only 23.5 million tonnes per annum of iron ore. In 2022–23, Australia exported more than 900 million tonnes of iron ore, earning $124 billion in exports.[9] With more green iron plants, potential earnings are far greater.

The MRIWA report[8] highlights the costs of not transitioning to this industry. The industry's decline would cause:

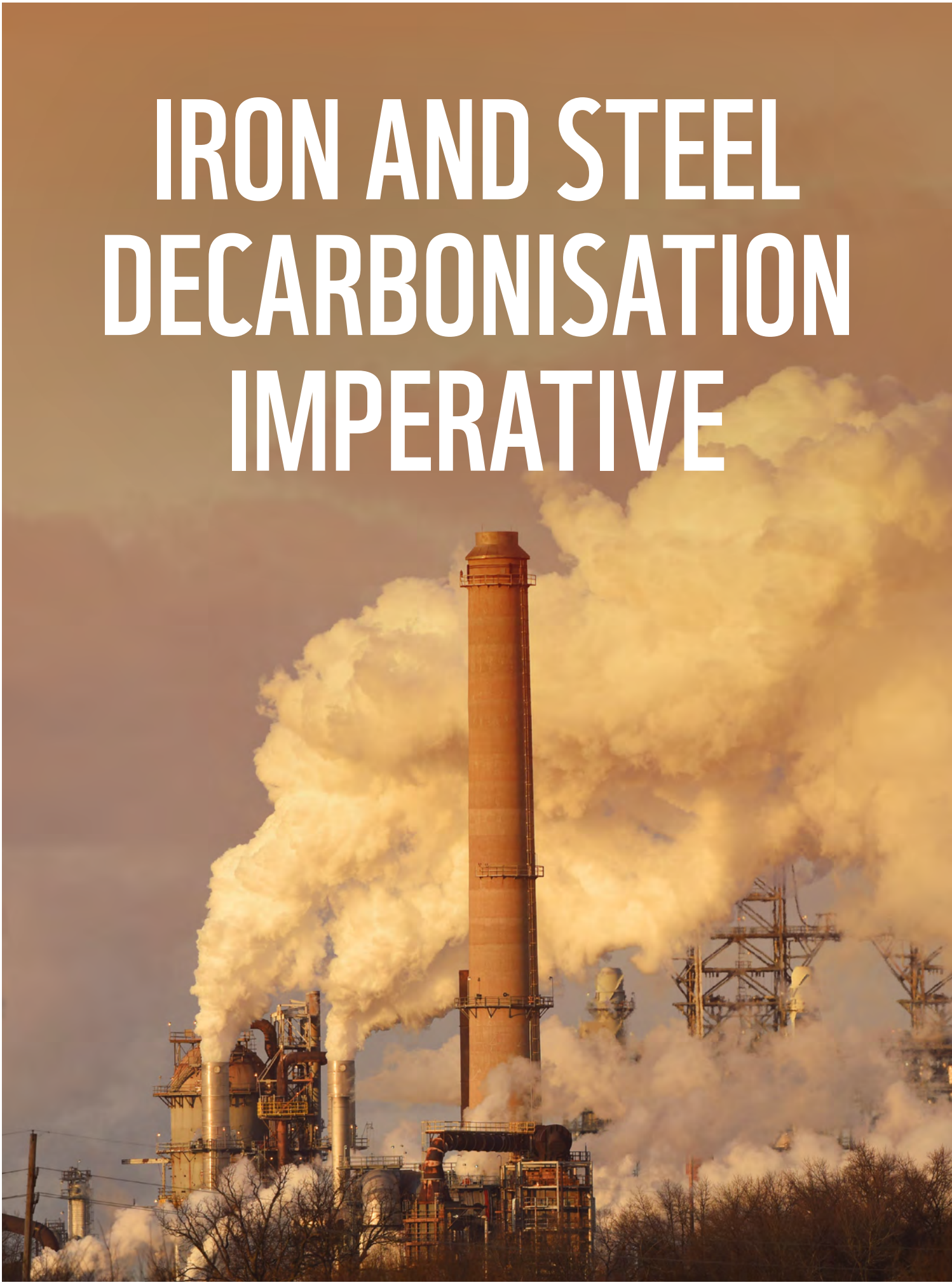
- A cumulative reduction in Australia's GDP of $313.3 billion over 25 years between 2026 and 2050, reducing the economy of the Pilbara region to one-third of its current size by 2050.
- A reduction in employment in the Pilbara region by 34,570 FTE by 2050, equivalent to more than one out of every two jobs today.
- A reduction in Western Australia's royalty income by $37.2 billion ($1.3 billion per annum).
- A reduction in Commonwealth taxes by $169.5 billion.

iii See Information box 2.

iv A federal green iron and steel strategy would also be an ideal companion strategy to the Critical Minerals Strategy released in 2023 by the Federal Department of Industry, Science and Resources Strategy at a glance | Critical Minerals Strategy 2023–2030 | Department of Industry Science and Resources.

v The need to use gas blends simply means that the inevitable use of hydrogen has been unnecessarily delayed.

IRON AND STEEL DECARBONISATION IMPERATIVE



Decarbonising iron and steel production is a global imperative. The sector generates up to 9 per cent of GHG emissions.[2] The International Energy Agency (IEA) expects steel demand to rise by more than a third through to 2050.[10] Iron and steel must simultaneously reduce emissions by 90 per cent to contribute to economy-wide net-zero emissions (NZE) by 2050.[11] This will be critical to keeping warming below the 2015 Paris climate agreement goal of 1.5°C.[11]

The sector is frequently described as 'hard to abate'.[12] This view mostly derives from the dominance of the 'integrated' steel-making route, which generates 70 per cent of current global steel output of 1.9 billion tonnes per annum.[13] In the simplest terms, integrated steel manufacturing 'reduces' iron ore by stripping its oxygen content in a blast furnace (BF), transforms the resulting 'pig iron' into crude steel in a basic oxygen furnace (BOF), and then forms this into finished products (Figure 1). Australia's largest steel works, BlueScope's Port Kembla facility in New South Wales, operates in this manner. There are limited options to adapt the inherently emission-intensive BF-BOF process to a net-zero future. BFs generate about 70 per cent of integrated steel-making's emissions.[14] There are numerous technical barriers to providing low-emissions substitutes for coal, or fossil gas, in this process and for abating the emissions that result from their use.[vi] Replacing this route with alternative production pathways is essential.

Electric arc furnaces (EAFs) are a key current enabling technology for green steel (Figure 1). EAFs use electricity to heat differing combinations of high-grade iron ore, 'direct reduced iron' (DRI) products and scrap steel to produce liquid metal, which is then cast into steel products. EAFs can be powered by 100 per cent renewable electricity, which can alone reduce their emissions by up to 75 per cent compared with fossil fuel usage.[17] Providing EAF facilities with renewable energy is a substantial decarbonisation win for Australian EAF-based steel producers like InfraBuild.[vii] EAFs are also used for steel recycling, with this 'secondary' steel expected to meet about 45 per cent of global demand by 2050, up from a quarter at present.[14] An expected scrap deficit is the major factor limiting greater deployment of EAFs, as alternative green iron feedstock is not yet widely available.

Most DRI currently utilised in EAFs is made with fossil carbon and/or hydrogen-containing gases instead of a coal-based reductant, but DRI products can also be reduced using renewable (green) hydrogen, produced by electrolysis of water using renewable energy. Analysts at leading Australian iron ore miner BHP describes the renewable hydrogen-based DRI-EAF steel production route as currently 'the only plausible pathway to carbon-free steel-making that is deployable at scale'.[18] However, EAFs require high-grade scrap, or iron ore of at least 67 per cent iron content.[18] This requirement excludes use of the hematite 'direct shipping ore' (DSO) that underpins Australian iron ore mining (see Information box 3).

Figure 1

Iron ore to steel-making process:

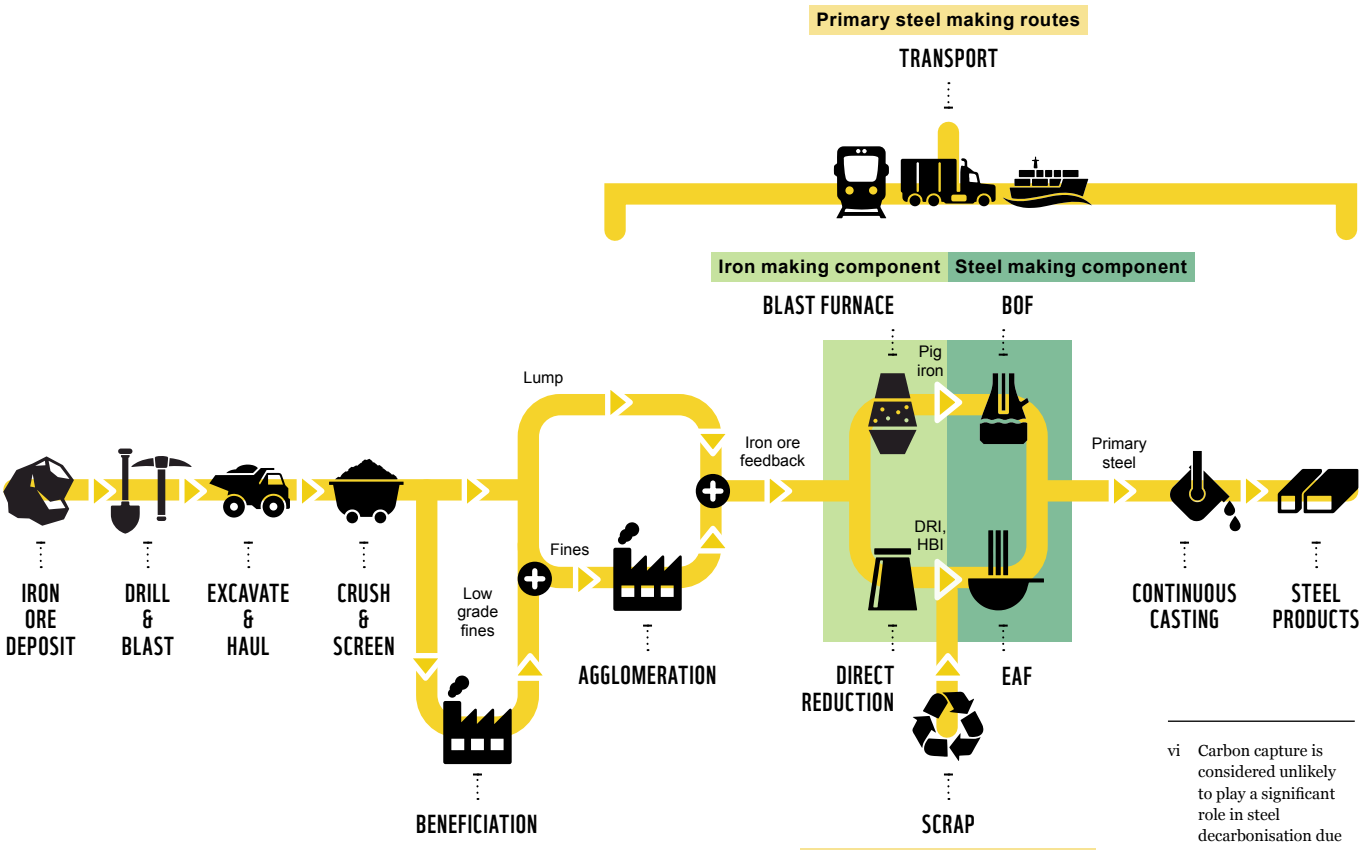
Simplified illustration (modified after reference 8) of three current steel manufacturing routes.

1. Producing iron in a BF and steel using a BOF. Feedstock for BFs also includes carbon-intense coal and limestone. Coal preparation (coking) not shown.

2. Producing iron in solid (unmelted) form in a reduction vessel—a shaft furnace, fluidised bed or similar, followed by melting in an EAF or another furnace type.

3. Secondary steel made by melting recycled scrap +/- new iron ore or DRI in an EAF.

For products made from low iron content ores (see Information box 3), another melting process step must be added to routes two and three prior to casting.



vi Carbon capture is considered unlikely to play a significant role in steel decarbonisation due its long history of underperformance (15, 16).

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INFORMATION BOX 3

WHY IRON ORE TYPES MATTER

The most common iron ore types in natural deposits of iron ore are hematite (Fe_2O_3) and magnetite (Fe_3O_4) iron ores. The hematite designation used in this report may also include amounts of hematite, goethite, siderite and other non-magnetic ores. Australia is heavily reliant on income from hematite/goethite DSO. Around 96 per cent of iron ore exported from Australia is Pilbara hematite DSO.[19] These ores have high natural iron content (52–62 per cent iron; [19]), but also high amounts of impurities that limit use of this ore type in iron-making technologies other than BFs. Although the iron content of these deposits is high, it is generally not high enough for current green iron and steel technology. In addition, there is at present no commercial technology available for beneficiating (removing impurities) these ore types to increase their iron content enough for use in green iron and steel technologies.

Magnetite ores have not been popular for mining in Australia because they typically occur as deposits with low iron content (20–30 per cent iron) and have a much higher level of impurities than DSO ores. Magnetite ores require processing before use, adding costs. However, unlike hematite DSO ores, technology exists that can convert these ores to a high iron content feed (65–70 per cent iron) suitable for green iron and steel.[19] Because magnetite is a ferromagnetic iron oxide (Fe_3O_4), and associated impurity minerals in deposits are not magnetic, impurities can be removed using magnetic separation. As demand for green iron and steel increases, magnetite will become an in-demand commodity.[19]

The challenge of producing steel from DRI made with low-grade hematite ores is yet to be conquered but is being actively researched and tested. Two options are considered leading candidates for a solution. The first employs a 'fluidised bed' reduction process (gasification of fines to reduce fine iron ore in a fluid-like state). Korea's leading steel-maker—and one leading foreign investor in Australia—POSCO uses this method in its HyREX technology.[20] The second proposed solution is to combine the DRI-EAF process with an additional electric melting/smelting furnace to remove impurities from the DRI iron products before steel-making. The total (whole of value chain) emissions intensity of these methods is still unknown.

Iron ore major Rio Tinto is also actively researching microwave technology combined with biomass reductants[22] as an alternate way to beneficiate hematite ores for use. Other near-zero technologies under development include producing iron by direct electrification-based methods such as molten oxide electrolysis (MOE) or low-temperature alkaline electrolysis.

Electrolysis methods are still being researched on a small scale, but if proven are thought to have potential to be the cheapest green steel production methods as renewable hydrogen is not needed.[23] Electrolysis-based methods also have the potential to produce no CO_2 emissions if 100 per cent renewable energy is used. Australian iron ore miner Fortescue announced in February 2023 that it had produced a world-first 150 kilograms of green iron by electrolysis in a lab.[24]

Meanwhile, several renewable hydrogen-based DRI-EAF projects using magnetite ores are already in development (Figure 3). Swedish proponents are behind the most advanced of these: HYBRIT (a partnership of steel-maker SSAB, water energy utility Vattenfall and iron ore miner LKAB) and H2 Green Steel. HYBRIT delivered the world's first renewable hydrogen-based green steel to truck maker Volvo AB in August 2021 and is targeting commercial-scale production by 2026.[27] H2 Green Steel expects to reach its first commercial production a year earlier, in 2025 ([28]; see Information box 4).

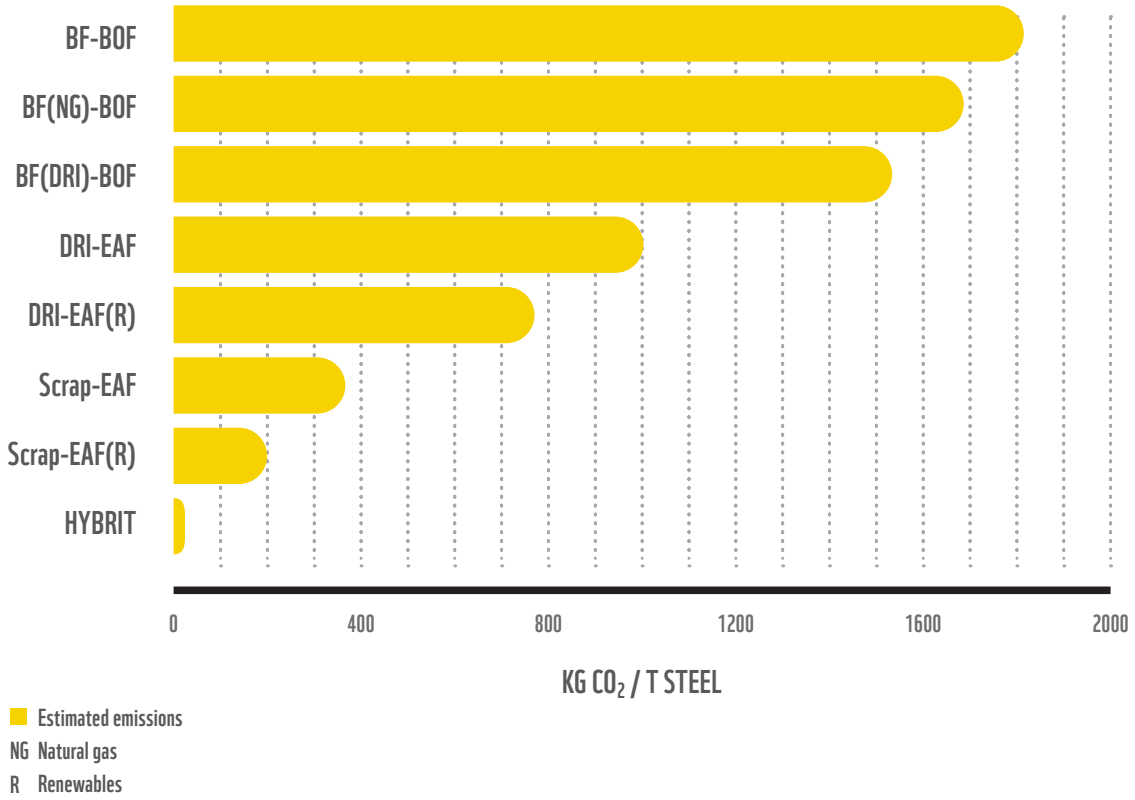


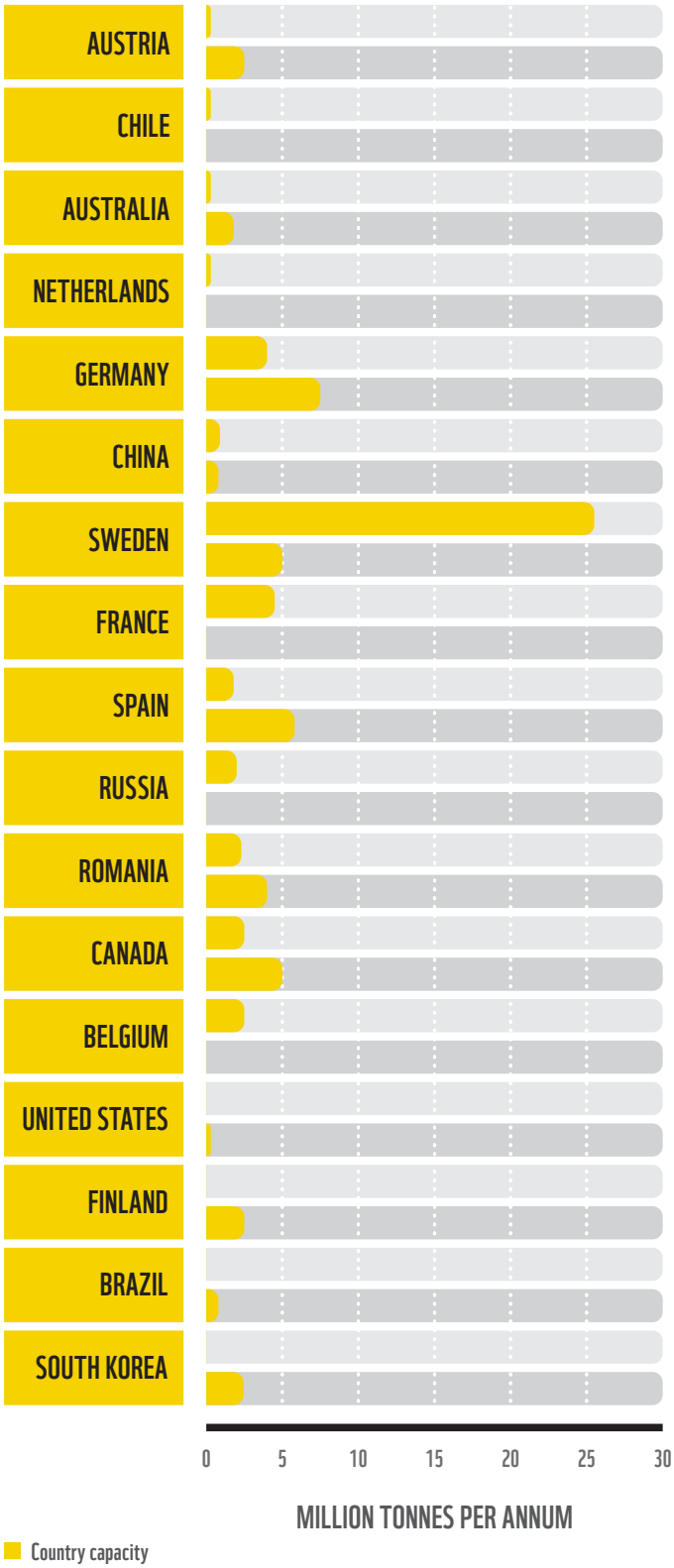
Figure 2

Estimated emissions generated by available steel technologies

Processing technologies top to bottom are: BF-BOF—conventional integrated steel-making; BF-BOF—with fossil gas substitution for some coal use; BF(DRI)-BOF—BF-BOF with a DRI component; DRI-EAF—using DRI to produce an iron product with steel manufacturing in an EAF; DRI-EAF(R)—previous process powered only by renewable energy; Scrap-EAF—secondary steel production from scrap in an EAF; Scrap-EAF(R)—previous process powered only by renewable energy; HYBRIT—DRI-EAF process using only renewable energy and renewable hydrogen (see Information box 4). Note that the emission values do not include those relating to other BF feedstocks (coal and limestone), which increase emissions from BF routes. Source: 21.

Figure 3

Announced green iron and steel projects by production capacity (February 2024). Source: 29

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RENEWABLE HYDROGEN

It is unlikely that Asian steel producers will be able to either produce or economically import sufficient volumes of renewable hydrogen. This has already resulted in a search for more optimal renewable hydrogen production locations for the emerging renewable hydrogen industry. A 2022 International Renewable Energy Agency report found renewable hydrogen production for domestic consumption would at best cost US$2.50–$3/kg in Korea and Japan by 2050, compared with US$0.75 in more optimal locations, Australia included.[25] Trading renewable hydrogen is also beset by handling and storage challenges and, to use the Australian context, likely to add far more than the 10 per cent extra cost of shipping coking coal to Asia.[26]

Countries able to produce both sufficient volumes of iron ore and inexpensive renewable hydrogen will be in a prime position to benefit (Figure 4) from this problem. Instead of renewable hydrogen export, the logical approach is to embed the emissions reduction capability of renewable hydrogen in new export products, including green iron. Australia can compete for this position with the right investment, but so can other regions (Figure 4).

Figure 4

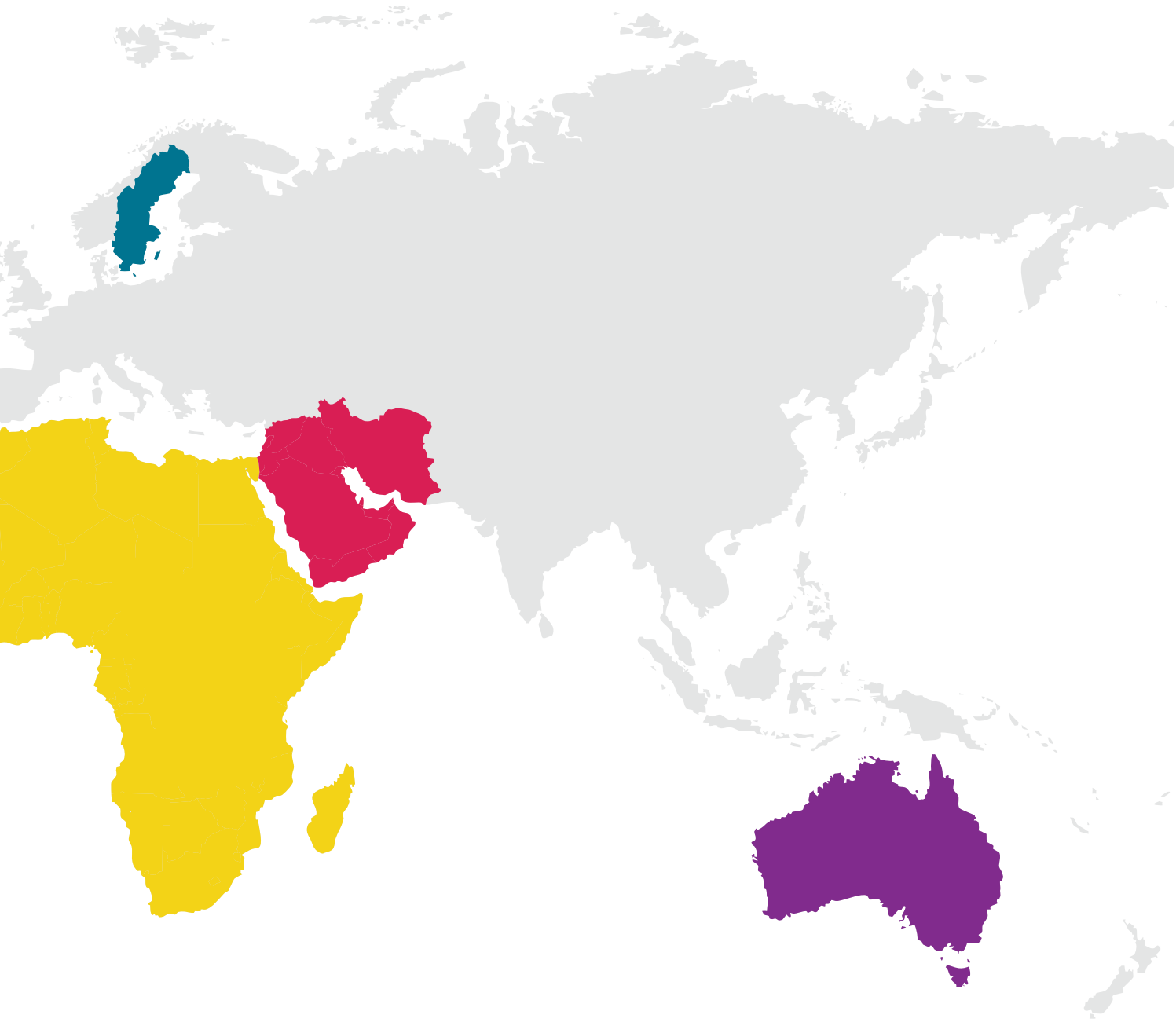
Favourably positioned regions for green iron production based on renewable energy potential (wind and/or solar) and factors like existing infrastructure, iron ore resources, and current potentially green investments. Modified after reference 15.

BRAZIL

- Largest producer of DRI grade iron ore
- High potential for renewable energy generation
- Potential renewable hydrogen exporter

AFRICA

- DRI grade iron ore production likely to expand
- Renewable hydrogen plans
- Plans to export renewable hydrogen
- Significant infrastructure needs



MIDDLE EAST

- Existing DRI production hub
- New DRI and HBI export projects under development
- High potential for renewable energy generation
- Plans to export renewable hydrogen

SWEDEN

- Low-emission steel plants under construction
- DRI-grade iron ore supply
- Stable investment environment
- Renewable energy resources (hydro), progressive policy and investment

AUSTRALIA

- Iron ore and renewable energy resources
- Stable investment environment
- Plans to export renewable hydrogen
- Pilbara hematite not suited to current DRI technology

INFORMATION BOX 4

HOW SWEDEN BECAME A GREEN STEEL LEADER

This Information box (modified after 28, 29, 30, 31) gives examples of the interventions and decisions that enabled Sweden's two green steel projects: the HYBRIT collaboration and start-up H2 Green Steel. Both projects use renewable hydrogen for direct reduction of iron ore and are powered by renewable energy. By changing from exporting iron ore to green steel, the benefit to the EU region is a reduction of annual GHG emissions by 40–50 million tonnes, an amount equivalent to Sweden's total territorial emissions.

- HYBRIT, a joint venture between Swedish power utility Vattenfall, miner LKAB and steel producer SSAB, will produce 1.2 million tonnes of crude steel annually, enabling the replacement of two BFs with one EAF. This project alone is estimated to remove 8 million tonnes of annual CO_2 emissions by 2030 (10 per cent of Sweden's emissions and 7 per cent of Finland's)
- H2 Green Steel plans to produce 2.5mtpa of green steel by 2025 and 5mtpa by 2030.

Analysis and interviews with industry experts identified four key policy factors:

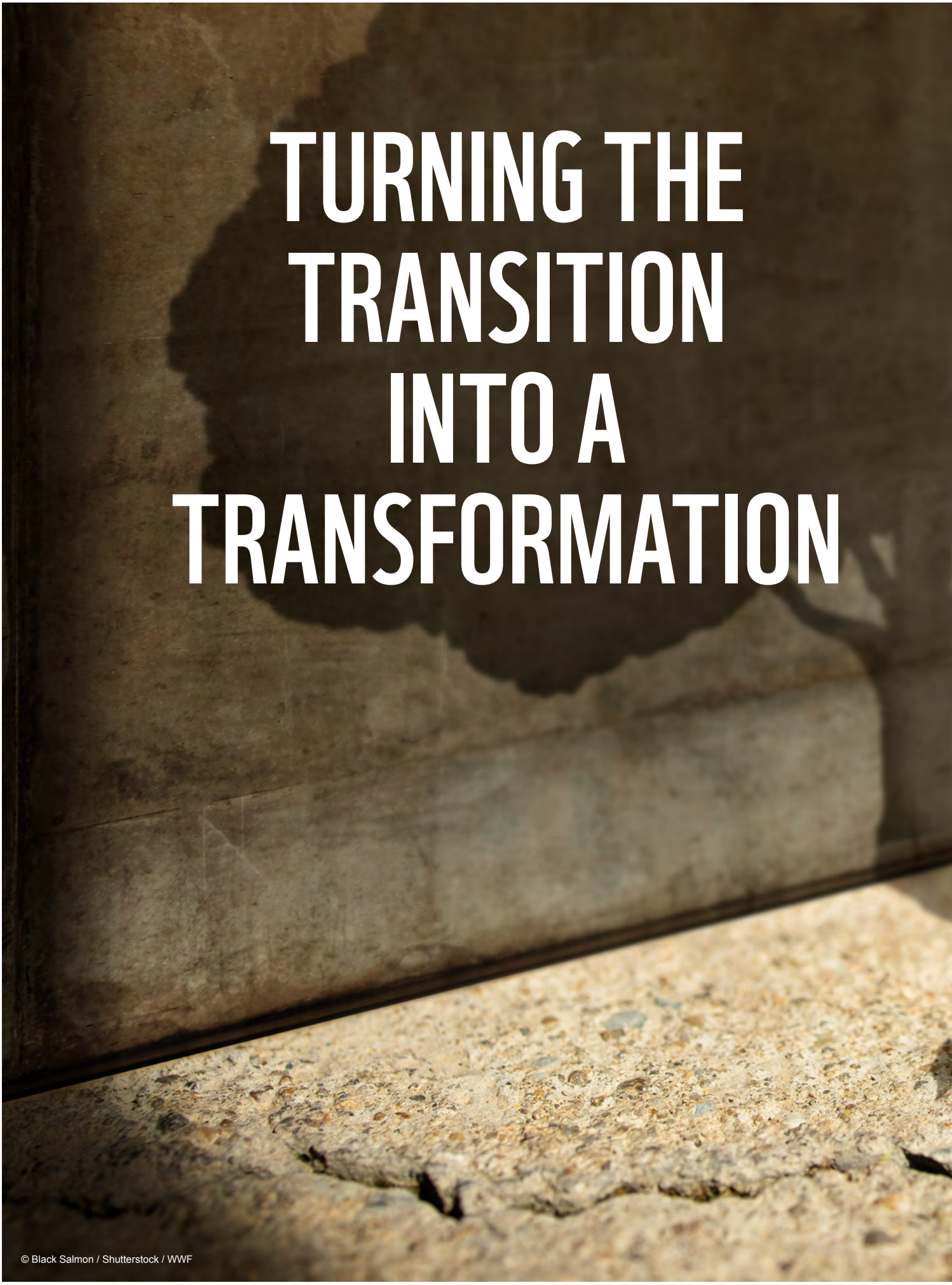
- Clear direction with broad bipartisan political backing on where iron and steel-making should be heading (the state does not pick the how but embraces the direction of the change to enable experimentation and learning by industry)
- Risk-taking is shared by the state to enable innovation, lower capital costs, create new markets and break fossil fuel dependency (be a 'de-risking' state)
- Government's ability and willingness to influence innovation and long-term orientation
- Competition bringing speed and diversity to the transition.

INTERVENTION	TYPE OF INTERVENTION	BACKING ORGANISATION	DETAILS
Government commitment to genuine reduction targets	Policy	Swedish Government	Following the Paris Agreement, Sweden introduced a Climate Policy Framework with targets that are binding for all political parties, which focuses on deep decarbonisation (net-negative emissions). This signalled a clear requirement to industry that businesses needed to embrace zero emissions.
Fossil Free Sweden decarbonisation program launched	Policy	Swedish Government	Program coordinating business initiatives by sectors by which businesses communicate policy needs to achieve the government's targets.
Refusal to continue to permit polluting coking coal plants beyond 2027	Regulation	Swedish Government	This decision was a key lever for steel-maker SSAB to seek greener production methods.
Recognition that carbon capture and storage would be insufficient to achieve emission reduction targets	Proven technology choice	Listed steel-maker SSAB	Hydrogen-based steel-making recognised as a feasible alternative to BF-BOF production. SSAB decides to create this new value chain.
Available renewable energy	Situational advantage	SSAB	Abundant hydro and wind power in the region makes renewable energy costs competitive.

Currency conversions as at 04/07/2024

INTERVENTION	TYPE OF INTERVENTION	BACKING ORGANISATION	DETAILS
Public-private partnership	Value chain cooperation	SSAB, LKAB, Vattenfall	SSAB partnering with 100 per cent state-owned entities iron ore miner LKAB (producing 80 per cent of the EU's iron ore supply and majority shareholder of SSAB) and power utility Vattenfall. The three organisations launched HYBRIT initially as a research platform for value chain decarbonisation. Vattenfall has a stated strategic intent of 'enabling customers to reach their climate targets'. The partnership allowed the companies significant influence to innovate.
Private partnerships and offtake agreements	Private partnerships and offtake agreements used to de-risk debt financing		For H2 Green Steel, offtake agreements are a major funding source, raising orders of more than SEK 100 billion (as of 4 July A$14.1 billion). Hydrogen-DRI furnace manufacturer MIDREX (Kobe Steel) and Hitachi Energy also purchased equity. This demand demonstration enabled significant financing to be raised, currently totalling €4.2 billion (as of 4 July A$6.74 billion) in debt financing and €2.1 billion (as of 4 July A$3.37 billion) in equity funding. H2 Green Steel created a record in 2023 for Europe's largest private placement funding round.
Industrial Leap program and EU exemptions for state aid	Subsidies	Swedish Energy Authority	The Industrial Leap program provided investment for green technology and research for heavy industry decarbonisation like that leading to HYBRIT's evolution, including: • SEK 3.1 billion (as of 4 July A$440.1 million) for HYBRIT, funding an industrial-scale demonstration plant producing fossil-free iron. • SEK 3.8 billion (as of A$539.3 million) for H2 Green Steel. • The EU also lifted bans on state aid for project development if projects support the EU's decarbonisation goal.
Green credit guarantees	Credit guarantee	Swedish National Debt Office (SNDO)	SNDO was given a mandate to issue green credit guarantees to absorb investment risk and lower capital costs. Guaranteed 80 per cent of a €1.2 billion (as of 4 July A$1.92 billion) loan to H2 Green Steel.
Export bank support	Loan and import guarantee	Swedish Export Credit Agency (SECA) and private banks	Undisclosed amounts. SECA also has established a Scientific Climate Council to support and advise its operations to align export finance with climate targets and set a target of 50 per cent green loans by 2030.
Revised financial targets for LKAB	Reduced dividends	Swedish Government and LKAB	The government lowering financial targets for LKAB during the transition as an alternative to increasing subsidies.
European Investment Bank (EIB) loan	Loan	EIB	The EIB, as part of the Green Deal Industrial Plan, is mandated to be the 'EU climate bank', giving preference to low-carbon projects. Provided €750 million (as of 4 July A$1.20 billion) in debt funding for H2 Green Steel.
European Union Innovation Fund	Subsidies	European Union Innovation Fund	This scheme is funded by the EU's Emissions Trading Scheme. It deploys funds from emitters to green technologies, including: • €143 million (as of 4 July $229.7 million) to support HYBRIT. • €250 million (as of 4 July €250 million = A$401.7 million) to support for H2 Green Steel.

TURNING THE TRANSITION INTO A TRANSFORMATION



As the example from Sweden demonstrates, increasing the speed and scale of iron and steel decarbonisation requires a large, deliberate and coordinated investment from government and the private sector. While the cost of transitioning the industry is difficult to estimate, industry analyst Wood Mackenzie estimates up to US$1.4 trillion (A$2.1 trillion) globally is needed to align the sector with Paris Agreement goals.[32] This total includes up to US$400 billion (A$608 billion) on developing renewable hydrogen and DRI plants, and US$500 billion (A$770 billion) for new and greened steel-making facilities.[32]

Lowering renewable hydrogen production costs is a particular priority. The MRIWA (Minerals Research Institute of Western Australia) report found Western Australian renewable hydrogen costs must reach $4/kg to make DRI cost-competitive with coal-based iron.[8] A cost below $1.50/kg is estimated to make renewable hydrogen-produced DRI competitive with fossil gas-based DRI.[8]

The MRIWA study also estimated the renewable power needs of producing renewable hydrogen and achieving broader value chain decarbonisation. It estimated that exporting 1 million tonnes per annum (mtpa) of green iron from Western Australia would require 477–500 megawatts of continuously operating new renewable capacity at capital expenditure of $4.2–$4.3 billion.[8] Producing 1mtpa of fully green steel would require 638 megawatts of new capacity and $5.6 billion spending.[8] These figures made up more than half of all assessed capital expenditures (Table 1).

Policy interventions have proven their ability to accelerate green steel progress. Europe's industry lead is testament to this. EU commitments, led by a progressively tightening emissions trading scheme and increasing carbon cost—rising from €10 per tonne in 2017 to €80 in 2023—have incentivised commercialisation by minimising the 'green premium' low-emissions steel consumers must pay.[33, 34] European companies, such as car makers, dominate demand-creation initiatives such as SteelZero, whose members commit to procure, specify or stock 100 per cent green steel by 2050.[35] A big factor motivating this progress is that European emission reduction instruments require consideration of 'whole of product life' emissions.[36]

INTERNATIONAL DECARBONISATION INITIATIVES AND INDUSTRY POLICY

International climate diplomacy is also increasingly focused on turning hard-to-abate industrial applications into priorities to abate.[37] The Leadership Group for Industry Transition (LeadIT;[5]) and SteelZero.[35] are key examples of green steel-focused cross-border cooperation involving public and private interests. The United Nations Industrial Development Organisation's Industrial Deep Decarbonisation Initiative (IDDI; [38]) is another. The Science-Based Targets initiative (SBTi)—a non-government organisation-led initiative involving WWF and other partners—has also issued steel-specific guidance to help industry set and meet Paris-aligned emissions reductions targets.[39]

Global trade and industry policy trends also encourage decarbonisation. The US Inflation Reduction Act of 2022 (IRA;[40]) is the largest

Table 1

Indicative capital expenditure to produce and export 1 million tonnes per annum of 100 per cent green iron (as HBI) and steel from Western Australia. Values AU million. Estimate does not include water use cost or mining and land use expenses; modified after 8.

	GREEN IRON		GREEN STEEL	
Asset	**Hematite ore**	**Magnetite ore**	**Hematite ore**	**Magnetite ore**
POWER GENERATION (50/50 MIXED SOLAR/WIND + BATTERIES)	$4,200	$4,300	$5,600	$5,600
PALLETISATION FACILITY	$145	$198	$162	$216
EAF FACILITY	N/A	N/A	$240	$240
SHAFT FURNACE	$1,400	$1,400	$1,500	$1,500
RENEWABLE HYDROGEN FACILITY	$783	$779	$895	$864
AMMONIA FACILITY	$0.8	$0.4	$0.8	$0.4
RENEWABLE HYDROGEN RAIL TRAINS	$14	$14	$14	$14
AMMONIA-POWERED VESSELS	$60	$60	$60	$60
Total	**$6,602.80**	**$6,751.40**	**$8,471.80**	**$8,585.40**

Values AU million. Estimate does not include water use cost or mining and land use expenses; modified after 7.

clean-energy spending package in United States history. It contains numerous subsidies for consumers and producers of low-emissions products, including a Clean Hydrogen Production Tax Credit covering US$3/kg of the cost of lowest-emissions intensity hydrogen production.[41] The IRA has also sparked a 'race to the top' in green industry policy. The EU's Green Deal Industrial Plan and Japan's Green Transformation Plan (GX;[42]) are among the responses thus far. Australian policymakers are considering some form of IRA-like master plan for delivering the current Labor Government's 'renewable energy superpower' vision[43] and as part of the planned Future Made in Australia Act.[44]

The EU's Carbon Border Adjustment Mechanism (CBAM;[45]) also began in 2023. It leverages tariffs on imports from jurisdictions with weaker emissions restrictions to avoid 'carbon leakage'[viii] of economic activity to these areas. Iron and steel are among the first CBAM targets. The EU and US are also jointly developing an agreement to tax carbon- and state-subsidy-intensive steel and aluminium imports.[46] These policies have again catalysed activity elsewhere. Other significantly trade-exposed industrial economies—Australia again included—have openly considered responses, including further emissions curbs and their own CBAM regimes.[47]

Steel-making countries have also announced significant fiscal support for decarbonisation. In 2024, the US Department of Energy announced a US$6 billion industrial decarbonisation investment for energy-intensive industries including steel.[48] In the same year, Japan added a US$11 billion Climate Transition Bond certified under the Climate Bonds Initiative to its GX plan to promote public and private investment of US$1 trillion.[42, 49]

SPEED OF TECHNOLOGY CHANGE

Some industry members, including Australia's BHP, cite factors such as the young age of most coal-based assets (BFs—three years on average, compared with their typical 20–40-year investment profile;[3]) as favouring only gradual transition,[51] a view divorced from climate change mitigation needs and current industry progress. Global Energy Monitor found 57 per cent of steel-making capacity either planned or in development as of 2023 still favoured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a BF-BOF route, while 43 per cent targeted EAF production.[50] This was a substantial improvement on the 67 per cent BF-BOF to 33 per cent EAF split of just a year earlier.[50]

An increasing shift away from new BF-BOF investment in the region is possible, as is relatively quick replacement of fossil fuel-based assets with low-emission technologies. Significant evidence supports the ability of new technologies to reach 'tipping points', including steep cost reductions and performance improvements that will mean rapid replacement of current industry standard technology (BF-BOF steel production;[52]). A prominent example saw BOF technology (a revolution of its time) replace open hearth furnaces in a two-decade period beginning in the 1960s.[14] The period from BOF design conceptualisation to implementation took just five years.[53]

More agile steel producers, and national industries, have also regularly outcompeted those that fail to adapt to new trends. Protectionist US integrated steel producers, for example, lost much of their market share to more agile Japanese and European firms, and domestic EAF-based producers, from the 1950s to 1970s.[54]

viii Companies move production from a country with strong emissions reduction policies to a country with weaker policies, allowing an increase in CO_2 emissions.

ASIA'S EMERGING GREEN STEEL PIVOT

Successfully decarbonising iron and steel will depend on the decarbonisation revolution taking hold across Asia—the current and expected future centre of steel production. China alone makes 53 per cent of global steel,[3] and Japan and Korea make 4 and 5 per cent of global steel respectively. The IEA expects China's share to drop to 35 per cent by 2050, but India is tipped for a corresponding boom, rising from 6 to 17 per cent of output by 2050.[3] Southeast Asian supply is also growing.


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Asia simultaneously underpins the world's continuing BF-BOF reliance. China accounts for 59 per cent of existing BF capacity, and India and China account for 79 per cent of BF-BOF capacity under development.[50] Indonesia, Vietnam, the Philippines and other Southeast Asian economies also have significant BF-BOF plans.[50]

Asia's BF-BOF reliance is out of step with most regional countries' established NZE commitments.[ix] Policies from key governments have, however, begun to target improvements:

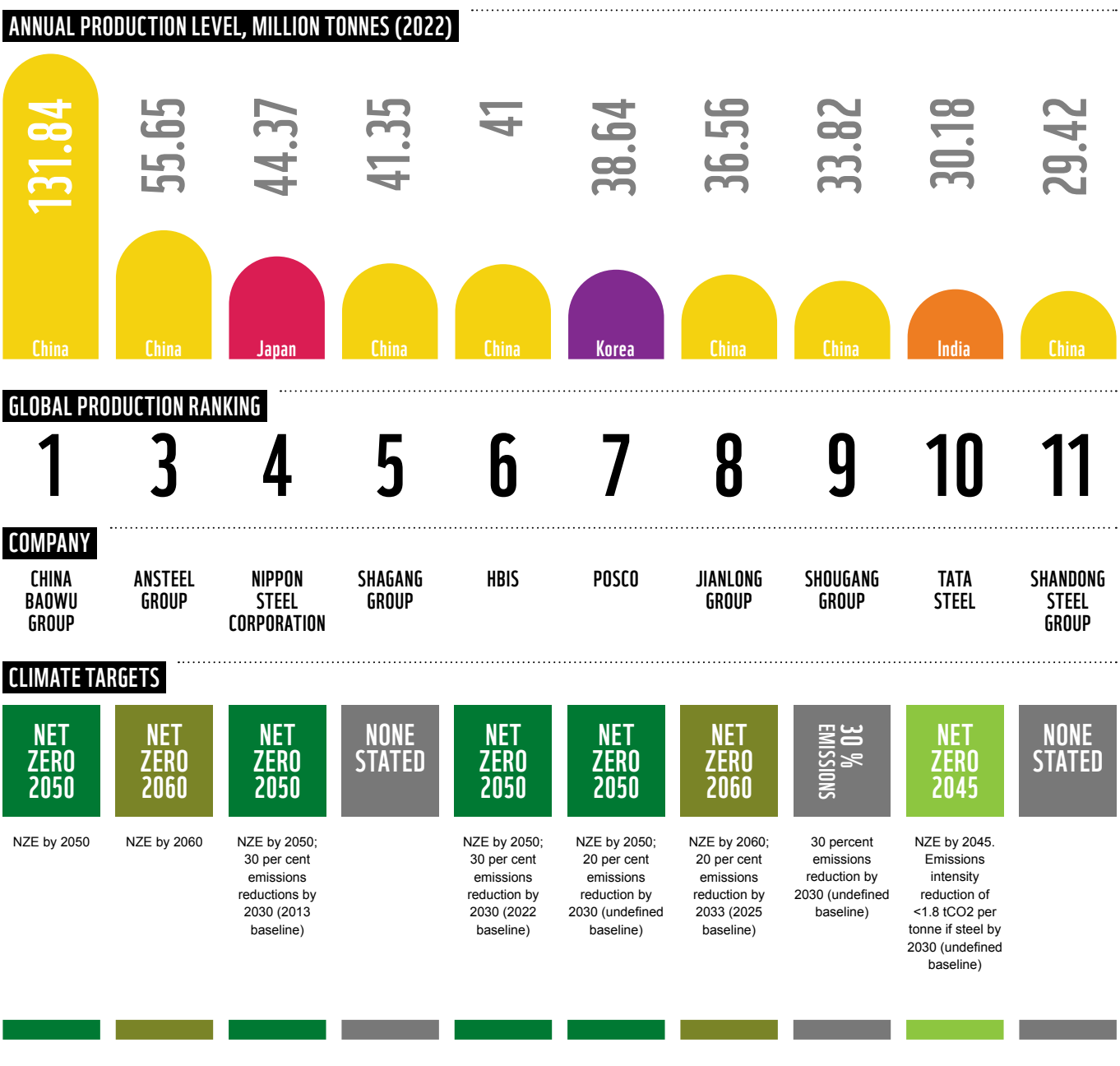
China has pursued reductions in its carbon-intensive steel-making, including through a 'capacity replacement' rule that allows new mills to only be built if existing mills with equal to 1.25 times capacity, and up to 1.5 times in some locations, are retired. EAFs can also be built to the same capacity of the retired BF-BOFs.[55]

Chinese agencies have also set several key targets for 2025, including lifting steel recycling from 21 to 35 per cent of output, EAFs producing at least 15 per cent of crude steel and 80 per cent of existing capacity being retrofitted for 'ultra-low emissions' output.[55] China's emissions trading scheme will also include steel by 2025.[55]

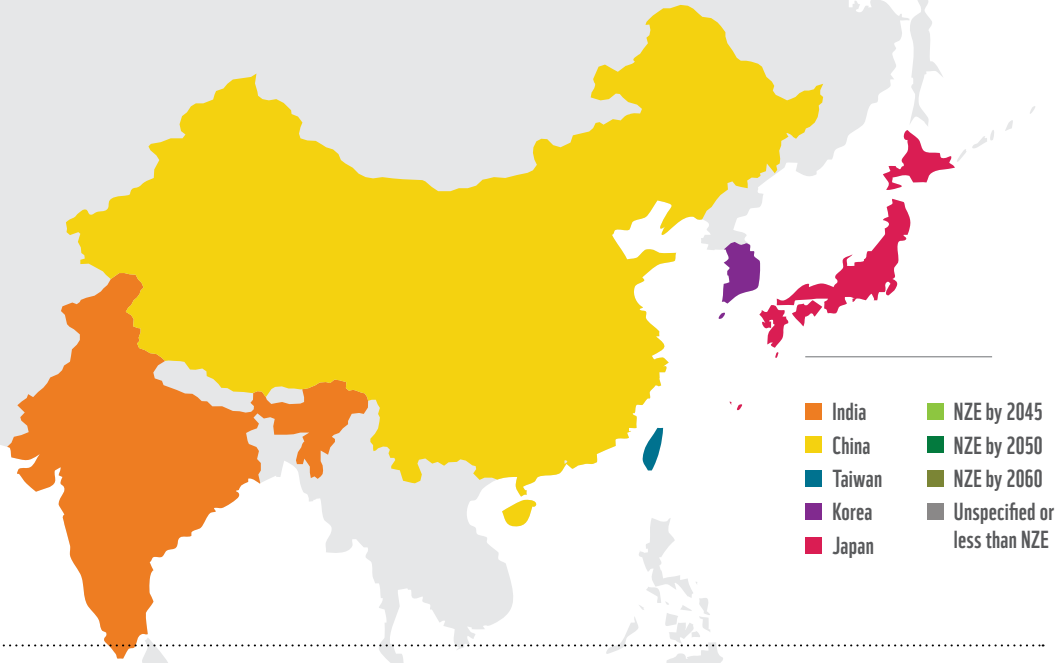
Japan unveiled new tax breaks at the end of 2023, including ¥20,000 (A$205) per tonne for producers of 'green steel made with renewable energy'.[57] Japan's Green Transformation Plan (GX) of January 2023 targeted expanding green steel production to 10 million tonnes per annum and cutting industry emissions 30 per cent from 2013 levels by 2030.[42] Tokyo has also supported industry initiatives such as the COURSE50 low-emissions technology partnership involving Nippon Steel, JFE and Kobe Steel.[58]

Figure 5

Net-zero targets of Asia's top 20 steel producers. Compiled from 4, 63.



ix Climate targets of major Asian economies (global emissions ranking in parentheses) are as follows: China (1) NZE before 2060, peaking emissions around 2030 and 'making efforts to peak earlier'; India (3) NZE by 2070 and reducing emissions intensity 45 per cent below 2005 levels by 2030; Indonesia (6) NZE by 2060 and reducing emissions by up to 43 per cent below business as usual (BAU) scenario by 2030; Japan (7) NZE by 2050 and reducing emissions 46 per cent from 2013 levels by 2030; Korea (12) NZE by 2050 and reducing emissions 40 per cent below 2018 levels by 2030; Vietnam (17) NZE by 2050 and reducing emissions 15.8 per cent below BAU scenario by 2030 and up to 43.5 per cent below BAU level, conditional on international support. Compiled from (56).



12	14	15	18	21	25	29	31	40	45
27.90	26.43	23.38	19.64	17.93	15.03	14.18	13.96	11.03	9.65
China	Japan	India	Korea	India	China	China	Taiwan	China	China
DELONG STEEL	JFE STEEL CORPORATION	JSW STEEL LIMITED	HYUNDAI STEEL	STEEL AUTHORITY OF INDIA LTD	CITIC PACIFIC	BAOWU STEEL	CHINA STEEL CORPORATION	SANMING STEEL	DONGHAI SPECIAL STEEL
NONE STATED	NET ZERO 2050	42 % EMISSIONS	NET ZERO 2050	NONE STATED	NET ZERO 2050	NET ZERO 2050	NET ZERO 2050	30 % EMISSIONS	NONE STATED
	NZE by 2050; 30 per cent emissions reduction by 2030 (2013 baseline)	42 per cent emissions reduction by 2030 (2005 baseline)	NZE by 2050		NZE by 2050	NZE by 2050; 30 per cent emissions reduction by 2030 (2023 baseline)	NZE by 2050; 22 per cent emissions reduction by 2030 (2018 baseline); 7 per cent emissions reduction by 2025 (undefined baseline)	30 per cent emissions reduction by 2035 (undefined baseline)	

Korea released its Steel Industry Development Strategy for Transition to Low-Carbon Steel Production in February 2023, along with a ₩150 billion (A$170 million) fund for low-carbon steel production. Seoul is introducing laws to improve scrap availability and finance the retirement of 11 BFs and construction of 14 hydrogen DRI plants by 2050. Additional funding will minimise BF-BOF emissions and improve EAF efficiency.[59]

India's National Steel Industry Policy of 2017 plans for EAFs (or induction furnaces) to produce 35–40 per cent of steel by 2030.[60] Delhi's Steel Scrap Policy of 2019 seeks to increase available recycling feedstock from 30 million tonnes to more than 270 million tonnes by 2030.[61] India's National Green Hydrogen Mission allocated 30 per cent, or ₩14.66 billion (A$270 million), of its pilot budget to promote renewable hydrogen in steel-making.[62]

Most major Asian steel producers also have NZE commitments and/or interim emissions reduction targets (see Figure 5). Related project announcements are growing in number. Asia hosts 15 proposals in LeadIT's Green Steel Tracker.[5] Asian companies are proposing a further six projects elsewhere in the world, including in Australia (Table 2 and Figure 6).

Asia's overall steel dominance ensures even its first steps towards decarbonisation will have outsized impact. Asia already boasts significant current and planned EAF capacity, for example. China has a world-leading 17 per cent of the EAF fleet.[50] India, Japan and Korea have 4–5 per cent each. China also leads on planned EAF capacity, with 17 per cent, while India has a third-placed 9 per cent.[50]

STRANDED ASSET RISK

Regional activity could easily increase towards potential tipping points for steel decarbonisation. Asia's overdependence on emissions-intensive BOF-BF steel-making makes it vulnerable to increasing green demand, creating potential economic liabilities. Developing all planned global BF-BOF capacity—with unabated emissions and continuation of historical industry overcapacity—is estimated to create a stranded asset risk of up to US$554 billion. Asia boasts the top eight of nine countries most sustaining this risk.[64]

Industry could seize on key pivot points if sufficiently motivated. One is a wave of approaching reinvestment decisions for carbon-intensive BF capacity. About 70 per cent of the

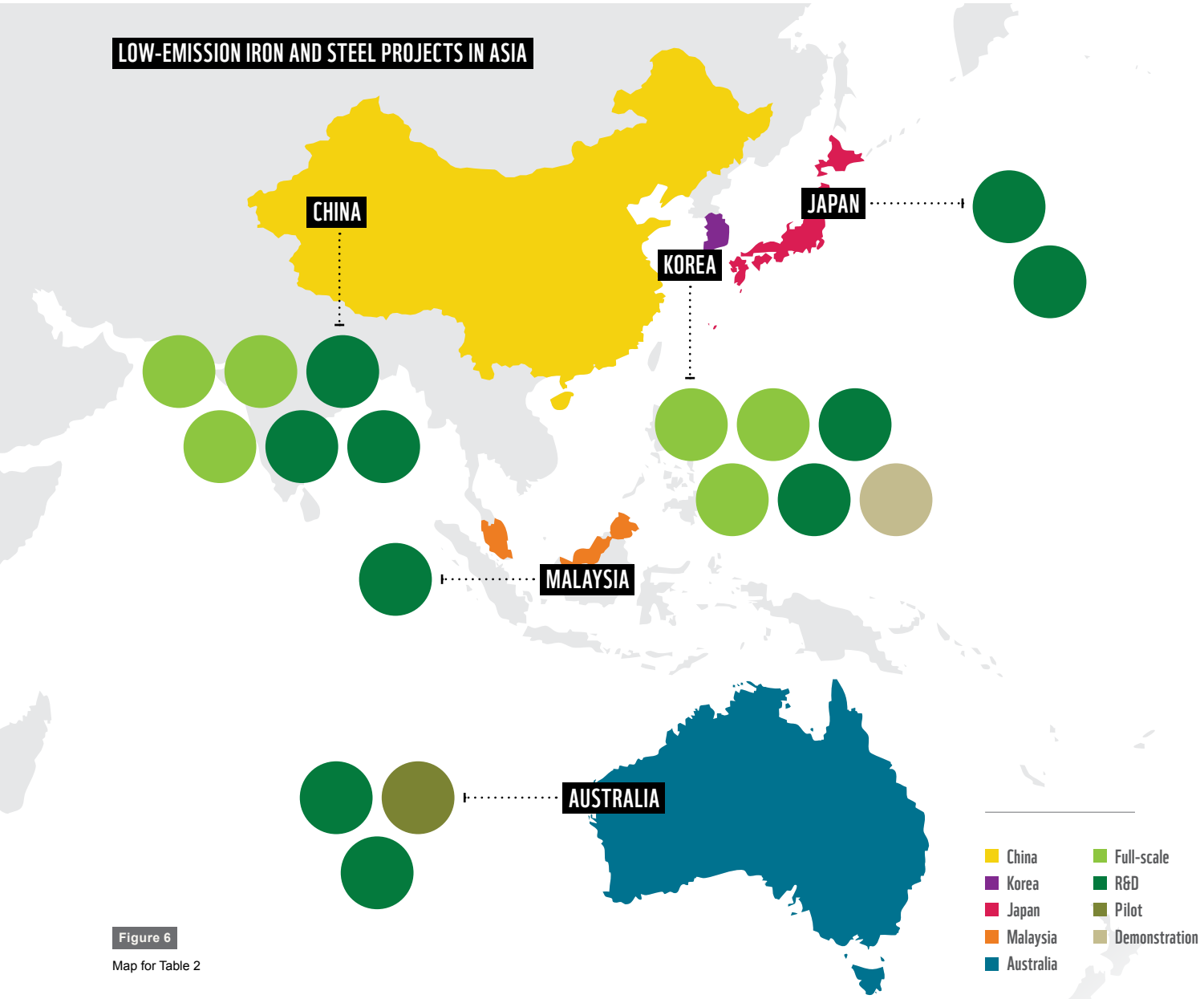


Figure 6

Map for Table 2

global BF fleet requires relining this decade. Operators thus have a clear choice between locking in carbon-based production or investing in greener capacity.[12] It is important that the sector develops clear transition pathways to avoid investing in new and existing assets like BFs that have the potential to become stranded.[65]

Addressing persistent steel-making overcapacity is another potential pivot. Subsidisation of otherwise unprofitable operations has led to industry utilisation averaging only 70–75 per cent globally.[50] China has already taken steps to reduce its leading share of this excess (as described earlier). Other Asian countries could follow suit. As the largest consumers, in addition to producers, of steel, Asian economies also have vast untapped capacity to spark the guaranteed demand that prospective green producers require to alter investment plans. The close integration of government and industry in most Asian economies, including large numbers of state-owned enterprises, could help create this demand.

Major green steel purchasing commitments from Asian companies, such as car makers and construction firms, or government agencies could best kickstart market creation on a global level. New legislated curbs on the amount of embodied carbon permitted in steel and related products could also contribute.

External parties are already playing an important role in sparking Asian steel decarbonisation. In particular, compliance requirements for the EU's CBAM regime that include EU importers beginning to report on embodied carbon levels in iron and steel imports in January 2024, and needing to purchase carbon certificates for goods produced in higher-emissions jurisdictions from 2026,[45] have coincided with stronger steel decarbonisation commitments in many Asian countries.

COMPANY	COMPANY LOCATION	INVESTMENT LOCATION	PROJECT TYPE	PROJECT PARTNERS	PROJECT FOCUS	YEAR ONLINE
BAOSTEEL	China	Zhanjiang, China	Full-scale	Tenova, Energiron, Sinosteel Engineering & Technology Co Ltd	Iron and steel—hydrogen direct reduced	Not stated
BAOTOU STEEL	China	Gucheng, China	Full-scale	Ping An Bank	Carbon capture, storage and utilisation	Not stated
CHINA BAOWU GROUP	China	China	R&D	BHP	Iron and steel	Not stated
CHINA BAOWU GROUP	China	Tsinghua University, China	R&D	Rio Tinto, Tsinghua University	Iron and steel	Not stated
HBIS GROUP	China	Hebei province, China	Full-scale	Tenova	Iron and steel—hydrogen-enriched fossil gas direct reduced	2021
HBIS GROUP	China	China	R&D	BHP	Iron and steel—hydrogen direct reduced	Not stated
JFE STEEL CORPORATION	Japan	Japan	R&D	BHP	Steel	Not stated
NIPPON STEEL CORPORATION	Japan	Japan	R&D	Rio Tinto	Steel	Not stated
POSCO	Korea	Australia	R&D	Origin Energy	Renewable hydrogen—production and export	Not stated
POSCO	Korea	Pilbara, Australia	Pilot	Engie	Renewable hydrogen—production	2028

Table 2

Examples of low-emission iron and steel projects in development by companies based in the Indo-Pacific.

Data shown spatially in Figure 6. Compiled from 5, 63.

Table 2 continued

POSCO	Korea	Pilbara, Australia	R&D	Hancock Prospecting	Iron and steel—hydrogen direct reduced	
POSCO	Korea	Korea	Full-scale	Not stated	Renewable hydrogen—production	Not stated
POSCO	Korea	Korea	Full-scale	Hyundai Motor, SK Group, Hanwha and Hyosung	Iron and steel	Not stated
POSCO	Korea	Korea	R&D	Rio Tinto	Iron and steel—hydrogen direct reduced	Not stated
POSCO	Korea	Korea	R&D	BHP	Iron and steel—cross-value chain technology	Not stated
POSCO	Korea	Pohang, Korea	Demonstration	Primetals Technologies	Iron and steel—hydrogen direct reduced, biomass	2030
POSCO	Korea	Gwangyang, Korea	Full-scale	N/A	Steel—hydrogen direct reduced and electric arc furnace	2026
POSCO	Korea	Sarawak, Malaysia	R&D	Petroleum Sarawak	Carbon capture and storage	Not stated
POSCO	Korea	Duqm, Oman	Full-scale	Samsung Engineering Co, Korea Southern Power Co, Korea West-East Power Co, Engie, PTT Exploration	Renewable hydrogen—production	2030
TATA STEEL	India	Ijmuiden, Netherlands	Full-scale	McDermott, Danieli, Hatch	Iron and steel—hydrogen direct reduced	2030
TATA STEEL	India	Ijmuiden, Netherlands	Full-scale	HyCC, Port of Amsterdam	Renewable hydrogen—production	2025
TATA STEEL	India	Ijmuiden, Netherlands	Pilot	HyCC, Port of Amsterdam	Iron and steel—smelting reduction	2017

REGIONAL STEEL VALUE CHAIN TRANSFORMATION

Decarbonising Asian iron and steel is a critical step towards the global steel supply chain achieving its net-zero ambitions and lessening emissions-related climate breakdown. Producing green steel requires eliminating emissions at all stages (Figure 1, end uses, and product recycling), beginning at the mine site. MRIWA's report found that 'green iron ore mining' from renewables is already economical and a rising competitive advantage in jurisdictions such as Western Australia with high renewables deployment potential.[8]


O_2

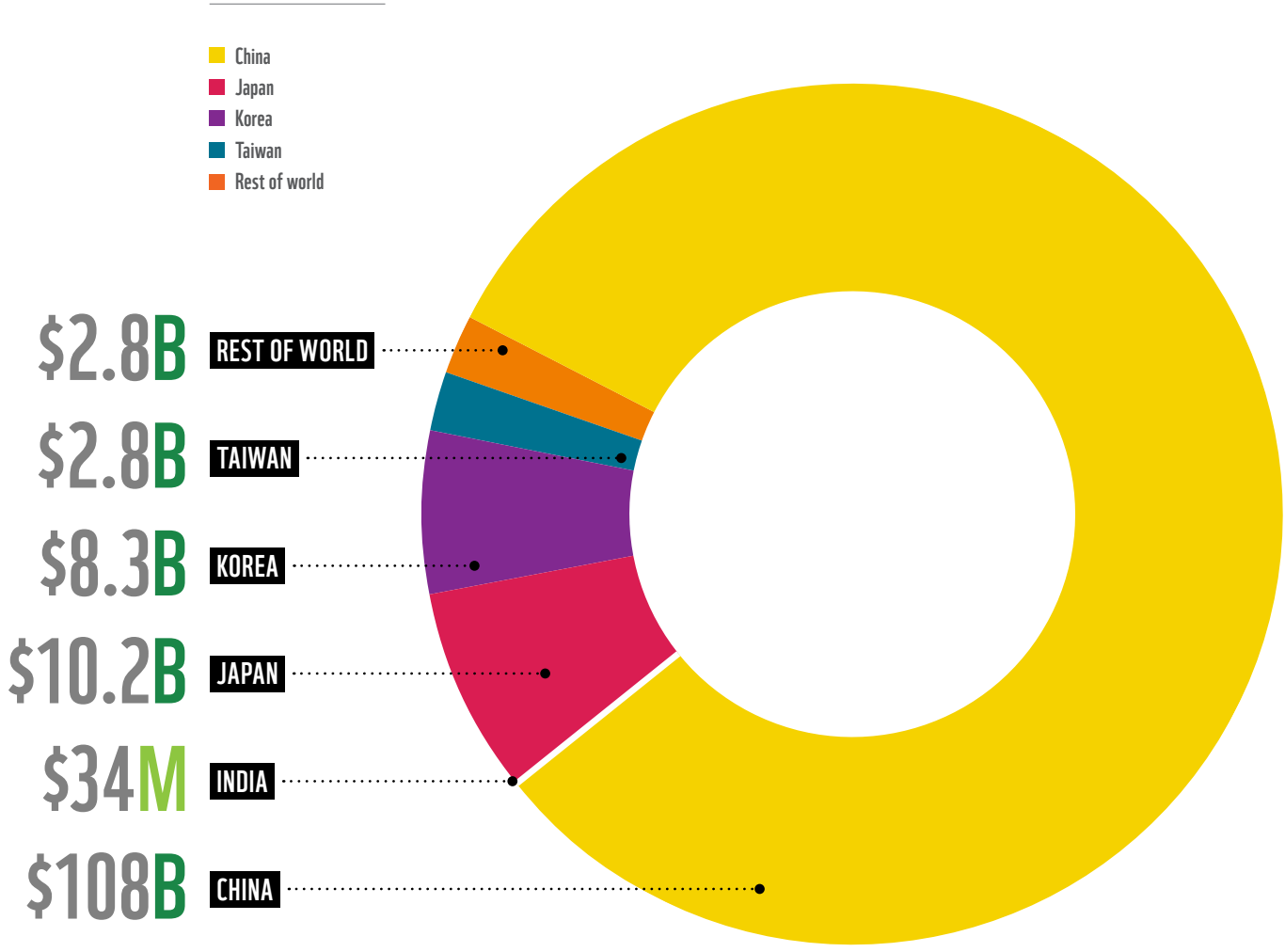
A more complicated change concerns the resources miners must develop. The most advanced green steel technology route currently available favours (in general) magnetite over hematite deposits. This shift is important for Australia, and Western Australia and South Australia in particular as the main ore-hosting states. Decarbonisation is just one of several headwinds facing Australian iron ore. Others include structural shifts in China's economy, which are slowing its materials use intensity, and Beijing's longstanding desire to diversify iron ore imports away from Australia. The latter challenge was central to Chinese companies helping greenlight Guinea's long-delayed Simandou mine–considered the world's largest untapped high-grade iron ore mine—in late 2023.[66]

Iron ore challenges will reverberate across the broader Australian economy. Iron ore is Australia's most valuable export, earning $133 billion in 2021–22.[67] This trade predominantly services Asia, and China in particular (Figure 7). Market analyst Wood Mackenzie notes that rival mining jurisdictions, led by Brazil and Africa, are better positioned for green steel due to their existing higher-grade iron ores.[32] Some analysts have suggested that the Australian iron ore trade will begin to experience losses as early as 2024 as buyers source more suitable ore types elsewhere.[68] The rise of green steel also creates a bleak future for Australian coal mining. Coal is Australia's second-largest export, returning $114 billion in sales in 2021–22.[67] About 60 per cent is metallurgical coal bound for Asia's BFs.[32] To tackle climate change Australia must choose to replace these industries with green iron.

Australia's iron ore sector can, however, adapt to changing circumstances in a way that coal cannot. To begin with, Australia has significant magnetite iron ore. Magnetite represents 38 per cent of Australia's demonstrated iron ore resources, with 80 per cent of this found in Western Australia.[69] Australia's third-largest iron ore miner, Fortescue Metals Group (FMG), opened a new magnetite mine in 2023 (Iron Bridge) with initial capacity of 22mtpa and is considering further magnetite

Figure 7

Value of Australian iron ore exports by destination (B = A$ billion; M = A$ million). Source: Author's calculations from DISER (2024; 9).



IRON ORE MINER	PARTNER	PROJECT
RIO TINTO	BlueScope Steel	A RioTinto-BlueScope memorandum of understanding (MoU) prioritises investigating using hydrogen to directly reduce iron ore into a product that can be processed in an electric arc melter, to produce metallic iron suitable to make finished steel[72]
	China Baowu	Rio Tinto and China Baowu have an MoU to explore a range of projects, including a pilot-scale electric melter at one of Baowu's steel mills in China, using DRI from low and medium-grade iron ore, and jointly studying opportunities for low-carbon iron in Western Australia[73]
BHP	HBIS	BHP and Chinese steel producer HBIS are trialling using BHP's Pilbara ores in blends in HBIS's DRI plant and evaluating the performance in downstream steel-making[74]
	Hatch	BHP and engineering services firm Hatch has an agreement to design and construct a pilot electric smelting furnace plant in Australia to trial the use of Pilbara ores[75]
FMG	China Baowu	FMG and China Baowu have an MoU to collaborate on 'exploring lower emissions in iron-making technology at one of China Baowu's operations in China using Fortescue iron ore and hydrogen, iron ore beneficiation research and development, and collaboration opportunities in renewable energy and renewable hydrogen'[76]
	Mitsubishi, Voestalpine, Primetals	FMG, Mitsubishi and Voestalpine have an agreement to develop an industrial-scale pilot iron-making plant based on Primetals Technologies' HYFOR direct reduction and smelter solutions in Austria. Primetals reports that a HYFOR pilot plant in operation since 2021 has already run successful trials using FMG's Pilbara ores[77]


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Table 3

Selected Australian R&D partnerships targeting Pilbara hematite ores

In addition to individual partnerships, in 2024 Rio Tinto and BHP partnered with steel-maker BlueScope to jointly explore the use of electric smelting furnace technology with Pilbara hematite ores (71).

investments, complementing FMG's generally strong decarbonisation commitments, including targeting real zero (offset-free) Australian emissions by 2030 and net-zero Scope 3 emissions by 2040.[70] The South Australian Government has also established a strategy to make the state a leading magnetite supplier, with a 50mtpa production target.[69]

Technological breakthroughs could also ensure Australia's hematite projects succeed in a green steel future. Australia's three largest iron ore miners—BHP, Rio Tinto and FMG—are all exploring options to either make their Pilbara ores suitable to a DRI-EAF route or, more prominently, develop alternative iron and steel-making that can utilise lower-grade hematite ores.[15] Most of these investigations are occurring in conjunction with steel-making customers and/or technology partners (see Table 3).

Green steel is likely to trigger a geographic redistribution of steel-making. Integrated steel-making currently co-locates most iron and steel-making, with major industrial economies (most often also major steel consumers) dominating steel production. It has been correspondingly difficult for resource-rich countries such as Australia to move beyond exporting raw materials. However, green iron and steel has different technological, resource and associated economic considerations that offer the opportunity to create new industries for Australia.

BENEFITS FOR AUSTRALIA

Australia could derive significant economic returns from moving further down the steel value chain. Knowing the exact value of these exports is difficult without the existence of a long-established market, but estimates are being made. One example by the Western Australian Government (MRIWA) is included in Information box 2. Additional modelling released in 2023 by Sunshot, an alliance of business, union and conservation interests including WWF-Australia,[78] identified five growth opportunities for clean energy exports from Australia that could generate an estimated $314 billion per annum by 2040. This includes a potential $96 billion for green iron and steel revenue. Sunshot estimated that $38 billion of public investment was needed to stimulate a further $109 billion of private investment required to activate all five opportunities: critical minerals, battery production, green iron, green steel, and renewable hydrogen production.[78]

Numerous other investigations have placed green iron and steel at or near the top of Australia's green export priorities and advocated for significantly increased governmental support. The consortium proposing the Australian Renewable Industry Package[x]

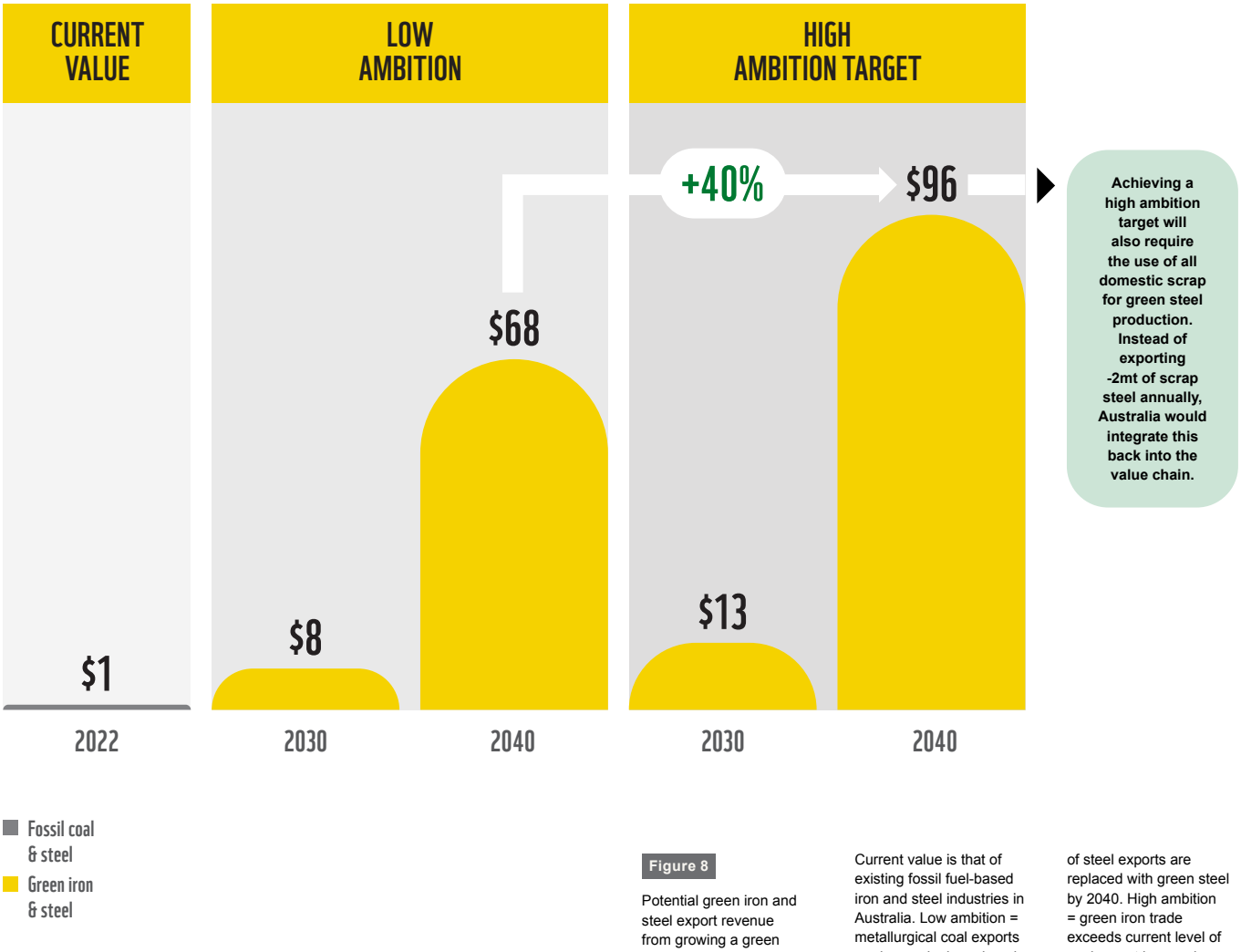


Figure 8

Potential green iron and steel export revenue from growing a green iron and steel export industry in Australia

Current value is that of existing fossil fuel-based iron and steel industries in Australia. Low ambition = metallurgical coal exports are increasingly replaced with green iron exports, achieving 100 per cent by 2040, and 1 million tonnes of steel exports are replaced with green steel by 2040. High ambition = green iron trade exceeds current level of coal export income by 2040, and green steel exports exceed 19 million tonnes. Source: 78

has, for example, advocated for 'a minimum of $100 billion in federal government spending over 10 years—in addition to other policies—to support green iron and steel, among other green export and domestic decarbonisation priorities'.[80](x)

Australia must also ensure that domestic primary steel-making (about 0.3 per cent of global supplies) and secondary (recycled) steel-making industries,[8] and any capacity additions to these, transition to a greener pathway. New renewable energy-powered EAF capacity could also be added to join the country's two existing secondary steel facilities—InfraBuild's Laverton (Victoria) and Rooty Hill (New South Wales) facilities. All should run on 100 per cent renewable power. Provision of appropriate feedstock will also be key. Securing scrap steel for secondary production through export controls will eventually be necessary. A domestic scrap industry could also efficiently utilise material from Australia's growing oil and gas and mining decommissioning sector.

Promising green steel-making developments are proposed in South Australia and Western Australia (see Information box 5). Improved policy support might help Australia capture a larger share of steel-making in a decarbonising world. But a more achievable and globally significant target lies in making and exporting large amounts of green iron, specifically the easily shipped hot-briquetted form of DRI. Lower-wage major economies, principally in Asia, remain better-placed producers of final green steel and have additional advantages in customer integration.[36]

x This consortium consists of the Australian Council of Trade Unions, Climate Action Network Australia, Smart Energy Council, Australian Conservation Foundation, Rewiring Australia, First Nations Clean Energy Network, New Energy Nexus and Climate Energy Finance.

INFORMATION BOX 5

MAJOR AUSTRALIAN GREEN STEEL PROJECTS

Liberty Steel (via GFG Alliance) proposes to phase out out coal-based BF-BOF steel-making at its Whyalla steelworks in South Australia. It has purchased a 160-tonne electric arc furnace (EAF) and is engaging suppliers for a 1.8 million tonne per annum (mtpa) direction reduced iron (DRI) plant to process locally mined magnetite. The DRI plant will initially run on fossil gas, before transitioning to hydrogen and potentially renewable hydrogen. The new investments are expected to lift steel production capacity at Whyalla from 1mtpa to more than 1.5mtpa and reduce emissions by 90 per cent by 2025.[81]

The Government of South Australia has additionally launched an expression of interest for partners to investigate the development of a hydrogen-based DRI plant to produce hot briquetted iron (HBI) in South Australia before 2031.[82] The South Australian Government will also release a green iron and steel strategy in 2024.

Green Steel WA is proposing a scrap-based EAF in Collie, Western Australia, which would be Western Australia's first steel plant. It would have a 400,000 tonnes per annum capacity. Construction is expected to begin in late 2024 and operation in 2026.[83] Green Steel WA is also proposing a 2.5mtpa hydrogen DRI plant in Western Australia's Mid West region, converting locally sourced iron ore to green DRI for export. A final investment decision is due in late 2025, with operations scheduled for 2028.[84]

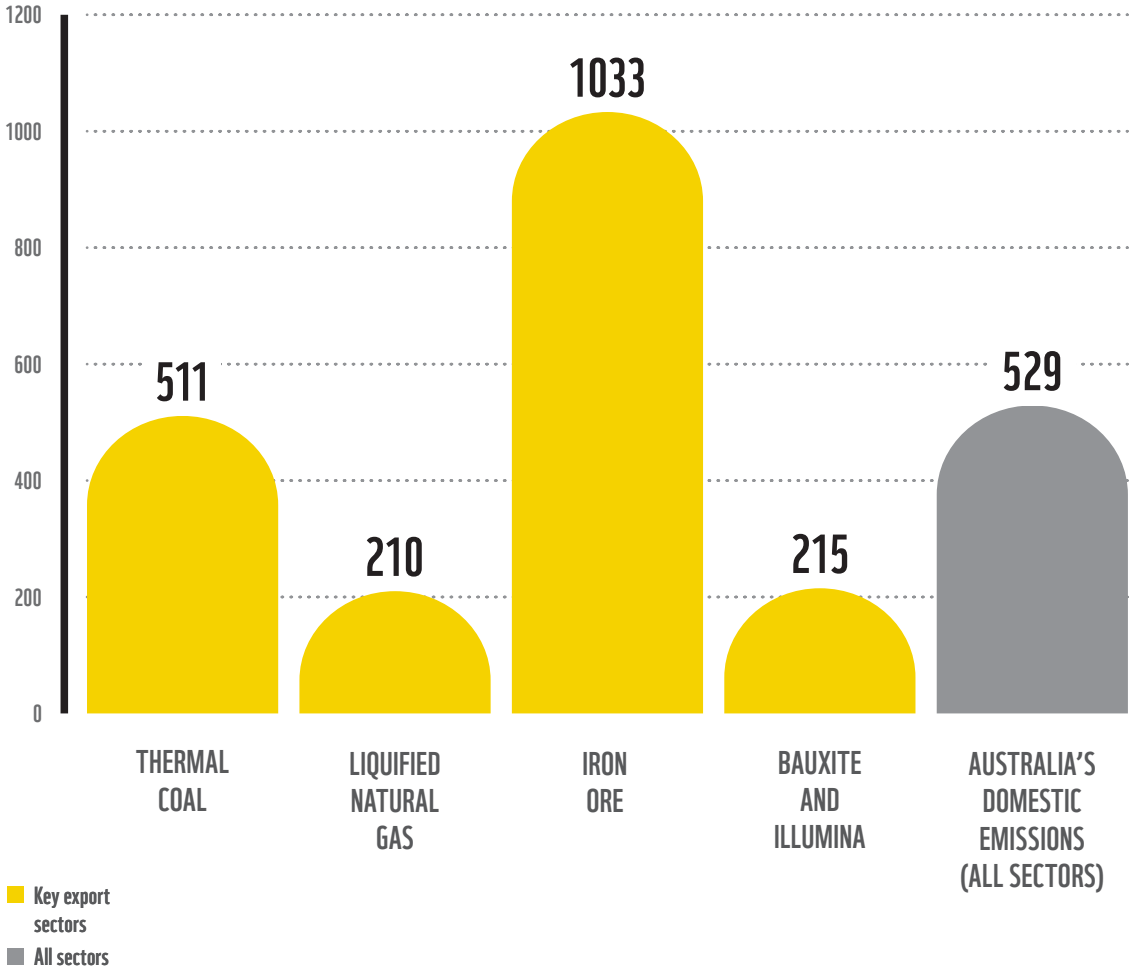
BENEFITS FOR AUSTRALIA'S TRADING PARTNERS

Reshoring significant iron-making capacity to Australia could deliver a significant climate and economic benefit. Australia should lift its domestic emissions reduction targets of 43 per cent on 2015 levels by 2030 and net-zero by 2050.[xi] It could, however, make an even bigger climate contribution by helping its trading partners to decarbonise.[xii] An estimated 98 per cent of emissions from four key Australian export sectors—thermal coal, fossil gas, iron ore, and bauxite and alumina—are Scope 3 emissions generated offshore. The estimated Scope 3 emissions from Australia's iron ore alone exports are close to double Australia's domestically generated emissions from all sectors (Figure 9).

Reducing Scope 3 emissions generated by Asian steel producers would advance the current Labor Government's vision of Australia as a 'renewable energy superpower'. This has both domestic and international resonance. In his 2023 annual climate change statement, Australian Climate

Figure 9

Scope 3 emissions from key Australian export sectors versus total domestic emissions (million tonnes CO2-e). Source: 3



Change and Energy Minister Chris Bowen noted that developing industries such as green metals domestically could 'boost Australian resilience, help diversify global clean energy supply chains and support the strategic objectives of our global partners'.(86) The Australian Federal Government has also promoted its improved clean energy and climate ambition in ties with existentially threatened Pacific neighbours.(87)

If properly calibrated, Australia realising its green iron potential could have surprisingly small economic impact on its Asian trading partners, particularly in the politically important employment realm. Germany's Agora Industry and Wuppertal Institute estimate that steel producers that import more cost-competitive green iron over domestically produced DRI—with either domestic or imported renewable hydrogen—could safeguard more than 90 per cent of jobs in their iron and steel value chains.(12) Employment numbers in the sector are heavily weighted towards steel-making and finishing.(12)

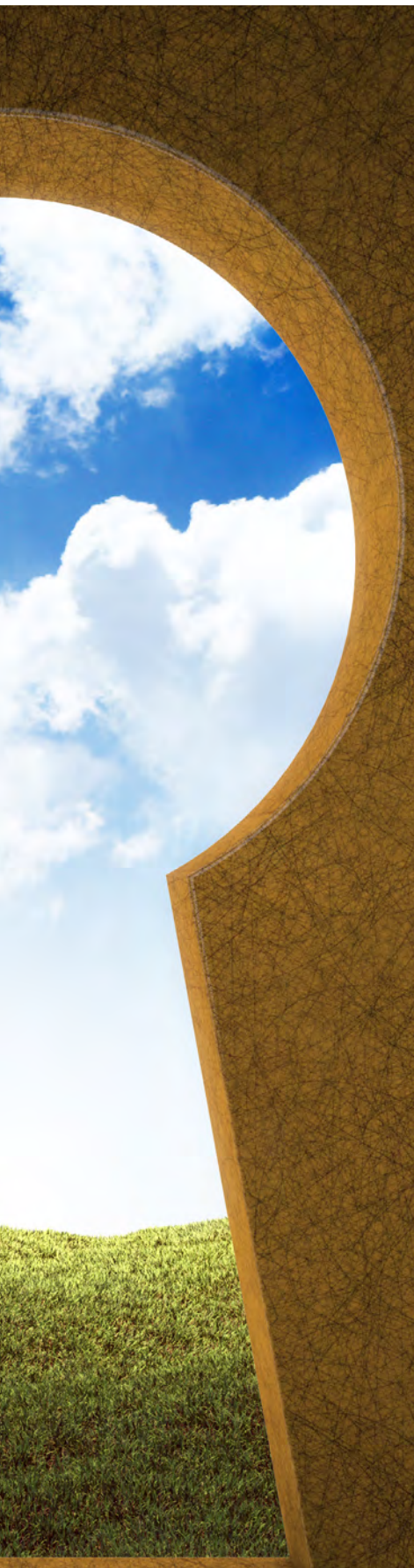
Importing green iron imports from Australia could instead be critical to many Asian countries maintaining their economic competitiveness as global steel-making decarbonises. One reason for the relatively slow pace of Asia's steel decarbonisation thus far, particularly in northeast Asia, has undoubtedly been the challenge of achieving cost-competitive renewable hydrogen production. Related policy regimes, including Japan and Korea's national hydrogen strategies, envision their countries as significant renewable hydrogen producers and importers, including for industrial use. Yet both countries would be better served importing more affordable/easily transported green iron from countries such as Australia. Japan's Renewable Energy Institute notes Japan sourcing green iron imports could also 'avoid the excessive infrastructure investment required to import large amounts of hydrogen'.(88)

Asian steel manufacturers are increasingly aware of their need to adapt. The largest producers in Korea, Japan and China have each explored green steel-linked investments in Australia. Korea's POSCO boasts the most advanced of these. It is considering a $40 billion investment in the Pilbara region, including $28 billion for renewable hydrogen and $12 billion for green HBI production and export. Japan's Nippon Steel and China's Baowu Group are also investigating Australia for the offshore components of their emerging low-carbon value chains.(15)

xi Analysis suggests a fair contribution to a 1.5°C warming trajectory means domestic emissions targets 67 per cent below 2005 levels by 2030, 90 per cent below 2015 levels by 2035 and reaching net-zero by 2038 (85).

xii The journey towards fully decarbonising international iron and steel value chains could, however, involve complicated international carbon accounting results and necessary domestic compromises. MRIWA's modelling, for example, noted that Western Australia could employ a phased approach to iron and steel decarbonisation. This could start with building out fossil gas-produced DRI production capacity, which could be repurposed for renewable hydrogen DRI once it becomes cost-competitive. MRIWA estimated gas DRI in Western Australia would produce an estimated 0.86–0.89 tonnes of CO_2 per tonne of steel, compared with 2.0–2.11 tonnes of CO_2 per tonne of steel for coal-based pig iron. This would also mean that steel-linked emissions generated in Western Australia would rise sharply, from 0.03 to 0.16 tonnes of CO_2 to 0.54 tonnes of CO_2 per tonne of steel—a fivefold increase to realise a net reduction in global steel-making emissions of around 56–59 per cent. This would require Australia to find greater emissions savings elsewhere in its economy to maintain its international climate commitments (8). This modelling also does not take into account of lifecycle emissions for gas.

HOW TO FORGE AUSTRALIA'S GREEN IRON KEY



Australia's iron ore and Asia's steel sector have enjoyed a highly complementary relationship over several decades. Green steel threatens to disrupt these mutually beneficial ties. But moving beyond the carbon-intensive status quo is inevitable and must be expedited if the world is to avert the most serious climate harm. Doing so is increasingly feasible and most progress depends on overcoming economic and socio-political challenges. Australian observers who discount Asia's ability to quickly transition to green steel underplay the degree to which Australia could help overcome these obstacles. National ties with Asia could move green steel towards a tipping point of mass adoption.

Australia has a particular opportunity and, indeed, an imperative, to become a significant green iron producer and exporter. It could forge a 'green iron key' to unlock Asia's globally significant green steel transition, by providing cost-effective inputs to emerging value chains. Doing so would pass a significant milestone in Australia's 'renewable energy superpower' journey.

Australia will, however, need to actively pursue this outcome. A passive approach risks opening the door to international rivals who could quickly establish strong and not easily dislodged positions in emerging value chains. The fact that Australia's currently exploited ore bodies are mostly ill-suited to EAF steelmaking—and that Australia's leading iron ore customer, China, is already looking for opportunities to diversify its imports—exacerbates the challenge. Middle Eastern, African and South American iron ore miners are already well-motivated to reduce Australia's Asian market dominance. Most are already in discussions with the same Asian steel giants considering Australia as a destination for their necessary offshore investments.[15]

DOMESTIC PRIORITIES

Australia's major domestic priorities for realising its green iron and steel potential are:

- Quickly transitioning iron ore mining and EAF facilities to operate on renewable energy
- Ensuring new, or upgrades to existing, domestic steel-making facilities target a green steel conducive pathway
- Developing new magnetite iron ore resources and/or technology pathways to make Pilbara hematite ores suitable for green iron and steel-making
- Developing substantial new renewable hydrogen supplies (enough to signal we are serious about meeting future demand) (Figure 10) and dramatically lowering costs
- Building new renewable hydrogen-ready DRI plants
- Supporting the expansion of Australia's domestic steel recycling industry, including retaining scrap metals within Australia to support the needs of the domestic steel industry
- Developing a supportive industrial ecosystem, including common user infrastructure and an appropriately skilled workforce.

Some industry members are actively advancing these outcomes, though new Commonwealth and state and territory government commitments are required to ensure greater consistency of effort. An ideal strategy would include a mix of carrots—that is, industry policy consisting of improved fiscal and regulatory support—and sticks, primarily stronger emissions curbs.

Table 4

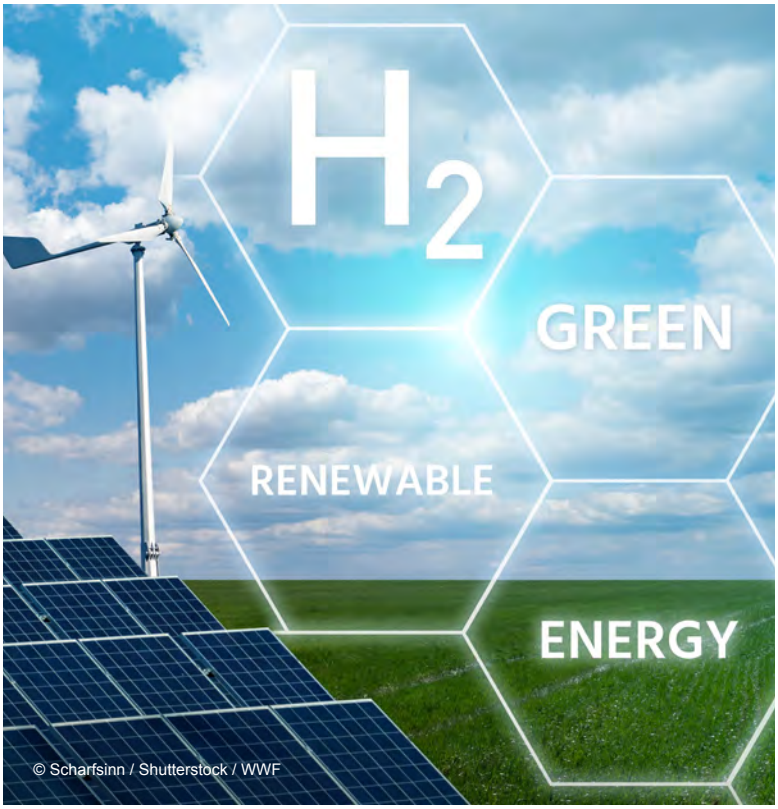
Indicators of commitment to developing a renewable hydrogen economy

Bloomberg New Energy Finance estimates that by 2050, hydrogen could make up to 10 per cent of the world's primary energy consumption and identifies seven indicators of hydrogen industry development (89, 90).

DRIVER	EFFECT
Net-zero climate targets are legislated	Makes it clear that all sectors will need to decarbonise
Standards governing hydrogen use are harmonised and regulatory barriers removed	Clears or minimises obstructions to hydrogen projects
Production targets with investment mechanisms are introduced	Provides a revenue stream for producers, increases competition, builds capacity and experience, and gives equipment manufacturers confidence to invest
Stringent heavy transport emissions standards are set	Provides an incentive for manufacturers to produce, and users to buy, fuel cell trucks and ammonia-powered ships
Mandates and markets for low-emissions products are formed	Provides an incentive for manufacturers to produce low-emission goods (like steel and cement) that will require the use of hydrogen
Industrial decarbonisation policies and incentives are put in place	Helps to coordinate infrastructure investment and scale efficient use of hydrogen. Provides incentives for hydrogen use
Hydrogen-ready equipment becomes commonplace	Enables and reduces the cost of fuel switching to hydrogen

The Commonwealth's upgraded Capacity Investment Scheme, which is scheduled to underwrite investment in 32 gigawatts of new clean energy generation and storage—equivalent to about half the capacity of the east coast's National Electricity Market (NEM)—offers a strong platform for new activity.[91] Working alongside state and territory commitments, it could help provide the supply of new renewable power essential to decarbonising all stages of the iron and steel value chain. A potential shortcoming, however, is that it applies only to Australia's NEM and not smaller-scale networks and off-grid applications or to Western Australia yet.

Various government funding agencies and programs—including the Clean Energy Finance Corporation, Australian Renewable Energy Agency, National Reconstruction Fund, Powering the Regions Fund and Northern Australia Infrastructure Facility—could also play prominent roles in de-risking new green iron and steel investments. Removing approval bottlenecks to new developments should also be approached with the aim of giving regulation clarity, not compromising the management of environmental and biodiversity impacts, and delivering much-needed improvement to community consultation practices.



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Cost-competitive renewable hydrogen production would be a particularly strong advantage for Australia. Building out low-cost renewable energy, which contributes 50–70 per cent of renewable hydrogen production costs,[92] is the major priority. Investing in new electrolyser capacity is another. Alkaline electrolyser technology that can operate at the required scale is available now and has proven renewable hydrogen-producing viability at a lower cost than proton exchange membrane alternatives.[93] Providing sufficient volumes of suitable water (desalinated and demineralised) is a further priority and reliant on best-practice public resource management.

Australia already provides significant support to its hydrogen sector, including through a dedicated national strategy in place since 2019. This includes the development of a Guarantee of Origin certification,[94] but this needs to be fast-tracked. Many competitor countries are pursuing renewable hydrogen production, with far greater fiscal support such as the Inflation Reduction Act. Australia's existing hydrogen strategy is also too widely targeted and tied to redundant assumptions, including the desirability of directly exporting molecules over hydrogen-embodied goods. Recent expert assessments correctly call for a more strategic approach, including prioritising renewable hydrogen production for decarbonising the most viable Australian green exports, green iron included.[36, 95, 96, 97] Commitments such as the Commonwealth's $2 billion Hydrogen Headstart[98] subsidies should be better tailored to this outcome. A Grattan Institute [36] proposal to replace Hydrogen Headstart's production credits with 'contracts for difference'[xiii] also has merit.

There is a strong need to coordinate and co-locate industry investments to accelerate activity and maximise efficiency. Establishing green iron and steel-centric industry clusters, or 'renewable energy industrial precincts',[99] could best advance this. Western Australia's Pilbara region would be a logical destination for one of these. Commonwealth, state and local governments have a vital role to play in corralling and coordinating various value chain partners and activities, and providing support such as common user infrastructure, appropriately skilled workers, and research and development.

xiii Contracts for difference begin by establishing a 'strike price' for a commodity trade. Under the proposed model, the government would pay producers the difference if the market price of the contracted commodity falls below the strike price. If the market price rises above the strike price, the producer would pay the government the difference. This would minimise risk to the government and incentivise more competitive industry activity compared with production credits, which have no price exposure mechanism.

Australia should also have stronger climate legislation. National and key state (for example, Western Australian) emissions reductions and carbon neutrality targets are unaligned with a 1.5°C future and should be improved. The Commonwealth's Safeguard Mechanism should also be tightened or replaced with a stronger tool for pricing carbon and reducing green premiums. Australia is already investigating its own CBAM regime, which could help protect the bolder action that would be incentivised by other improvements.

INTERNATIONAL PRIORITIES

Domestic commitments will, however, count for nothing if not accompanied by strong international cooperation. Strong integration with Asia has been critical to Australia's past resources industry successes, including attracting the equity investments and offtake agreements that underpinned development of new sectors. Effective collaboration between Australian public and private interests and Asian counterparts could again enhance mutual economic competitiveness and decarbonisation.

Authors Thurbon, Hynd and Tan[100, 101] argue that the green statecraft required for the energy transition is more complex than simply changing exported commodities to renewables and requires a deep understanding of the national objectives (security, economic and geopolitical) of each of our trading partners. They highlight that the value chains of renewable energy technologies are typically more complex and globally interconnected than those of fossil fuels. Consequently, more proactive, sophisticated and geopolitically cognisant strategies are required to drive progress towards renewable energy superpower status. Australia must show by communication and targeted actions that we understand the future needs of our trading partners.

INFORMATION BOX 6

FOSSIL FUEL VERSUS GREEN ENERGY SUPERPOWER STATECRAFT

	FOSSIL FUEL SUPERPOWERS	GREEN ENERGY SUPERPOWERS
Key attributes	Based on a nation's natural endowment of commodities (fossil oil, fossil gas, coal)	• Based on a nation's technical and manufacturing capabilities in renewable energy technologies
Enabling statecraft style	Externally oriented weaponisation of natural energy resources for political purposes	• Externally oriented weaponisation of renewable technologies and equipment for political purposes • Externally oriented focus on international leadership in combatting climate change • Domestic fostering of technological and manufacturing capabilities • Coordination of external and domestically oriented statecraft between states - State and industry activism beyond foreign investment and trade, such as technology transfers, outsourcing and alliances - Awareness and ability to navigate the statecraft of others
Political-economic legacies	• Exacerbated global climate crisis • Limited secondary economic benefits in job creation/ value-adding	• Contributes to climate change mitigation • Demonstrated international leadership in addressing the global climate crisis • Major secondary economic benefits in job creation/value-adding • Sophisticated techno-industrial base

Modified after 100, 101

The main priorities for Australia working with its international partners are:

- Aligning national green iron and steel strategies—including in related sectors such as renewable hydrogen—to maximise decarbonisation and economic competitiveness and manage any tensions arising from domestic policy interventions.
- Coordinating expedited development of cross-border value chains, including through joint publicly financed de-risking of Australian green iron-making and related projects and securing Asian equity investments and/or offtake agreements in Australian operations.
- Establishing new trade-facilitating standards and policies, including agreed definitions and measurement regimes for green steel and pricing mechanisms for increasingly important products such as DRI, making necessary modifications to current or future bilateral and multilateral trade agreements, and cooperating on potential CBAMs.
- Developing new technological pathways for green iron and steel-making best suited to Australian and Asian capacities.
- Establishing transformational policies for market creation, including Asian BF-BOF capacity retirements and replacement, and major green steel purchasing commitments.

Australia took tentative steps towards improved international climate action under its previous Scott Morrison-led government, mainly through the formation of intergovernmental clean energy partnerships. These targeted the joint development of low-emissions technologies and cross-border value chains. The Australia–Japan Partnership on Decarbonisation through Technology and Australia–Republic of Korea Low and Zero Emissions Technology Partnership both extend to low-emissions iron and steel.[102] Australia also has a renewable hydrogen-focused partnership with India and a lower level, CSIRO-administered, Australia-India green steel research and development agreement.[103]

Continued commitment to existing green iron and steel partnerships is warranted and should even be increased. Ties with Japan, Korea and even India would ideally already be producing the sort of breakthroughs that have resulted from Asia–Australian cooperation in other clean energy sectors. On hydrogen, for example, Australian and Japanese public and private interests have developed one of the world's most advanced cross-border pilot programs—albeit based on brown coal—through Victoria's Hydrogen

Energy Supply Chain project.[104] In critical minerals, Japanese and Korean government agencies and businesses have for many years worked with their Australian counterparts to de-risk investment in Australian mines, to secure materials for their domestic manufacturers.[105]

A revival of Australia's Japan and Korean green iron and steel partnerships could reflect greater clarity around the optimal value chain role for all countries and help align national strategies. Elevated ties with India could best position Australia to tap future growth in its market. Australia could also pursue green iron and steel partnerships with other countries. China is a notable option here. China's desire to reduce its dependence on Australian iron ore imports reflects significant bilateral geopolitical tensions. Yet effective iron and steel decarbonisation will be difficult without effective political guidance surrounding Australia and China's unrivalled iron and steel relationship. Southeast Asian countries are also potential future partnership targets.

Australia's internationally engaged agencies have key roles to play in bolstering green iron and steel cooperation. These include Austrade on business facilitation; Export Finance Australia on financing; CSIRO on research and development; and the Department of Foreign Affairs and Trade (DFAT) and Department of Climate Change, Energy, Environment and Water (DCEEW) on standard setting, trade negotiations and broader policy formation. All agencies will need to work closely with counterparts in Asian steel-making countries, many of which have stronger economic policy levers to pull.

From being a valuable partner, Australia could aim to become a green iron and steel leader. It could use its membership of existing groups, such as LeadIT[5]—in which Japan, Korea and India already participate—to promote itself as Asia's green iron key. It could also promote its green iron and steel priorities in revising existing, or developing new, bilateral and multilateral trade deals, moving beyond its traditional market access pursuits towards the facilitation of mutual decarbonisation. It could extend this leadership to a range of groups and dialogues, including global organisations such as the United Nations, G20 and World Trade Organisation, regional forums such as the Asia–Pacific Economic Cooperation, and geopolitically influenced 'minilaterals' such as the Quad and Indo–Pacific Economic Framework for Prosperity.

Several of the Albanese government's international commitments are already conducive to this leadership project. Australia's reinstated position of Ambassador for Climate Change could help intermediate with Asian iron and steel partners. Australia could make green iron and steel a significant thematic focus of the COP climate negotiations it is looking to host with Pacific partners. Canberra could also increase financial assistance to the sector in the wake of its late 2023 decision, at the COP28 negotiations, to end public funding for international fossil fuel projects.[106]

Australia could even create wholly new green iron and steel institutions. A globally significant centre of excellence and/or international dialogue is one option. This could play a particularly important role in advancing research and development around new pathways for green iron and steel-making that is best suited to Australia and its Asian trading partners' capacities. It could also provide a worthy platform for conferring with these same Asian partners on other priorities, including greening steel-making investment plans and making major green steel purchasing commitments.

COORDINATING RESPONSES

There is, finally, an obvious need for Australia to tie its various domestic and international green iron and steel commitments together in a coherent manner, to best inform and guide decisions by government, industry and the broader community at home and abroad. Various state and territory commitments should also be harmonised with Commonwealth decisions. Establishment of a national green iron and steel strategy, akin to those Australia has in place for sectors, such as hydrogen and critical minerals, could help achieve this. This could establish a formal volumetric target, or set targets, for Australian green iron production—starting with a 2030 date—to spark domestic activity and simultaneously signal intentions to international partners seeking imports. An alternative would be to make green iron and steel a priority sector in any forthcoming 'renewable energy superpower' master plan that Australia might develop.

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GLOSSARY

Alkaline electrolysis	Producing iron using direct-current electrolysis with a low-temperature alkaline solution.
Asia-Pacific Economic Cooperation	An Asia-Pacific economic forum aiming to support sustainable economic growth in the Asia-Pacific. https://www.apec.org/
Austrade	Australian Trade and Investment Commission (Austrade) is an Australian Government agency promoting trade, investment, tourism and education. https://www.austrade.gov.au/en/about-austrade
Australia–Japan Partnership on Decarbonisation through Technology	A partnership between the governments of Australia and Japan to work on technology enabling collaboration on decarbonisation and meeting the goals of the Paris Agreement. Other agreements include the Hydrogen Energy Supply Chain (HESC), the Japan–Australia Energy and Resources Dialogue and the Australia–Japan Joint Statement of Cooperation on Hydrogen and Fuel Cells. https://www.minister.industry.gov.au/ministers/taylor/media-releases/japan-australia-partnership-decarbonisation-through-technology
Australian Renewable Energy Agency (ARENA)	ARENA is an Australian Government agency that seeks to support the transition to net-zero by encouraging pre-commercial innovation via funding and knowledge support. www.arena.gov.au
Australia–Republic of Korea Low and Zero Emissions Technology Partnership	Partnership between the governments of Australia and the Republic of Korea to collaborate across existing and emerging low and zero-emissions technologies including hydrogen, low-emissions steel and iron ore. https://www.dcceew.gov.au/about/news/new-low-emissions-technology-partnership-with-the-republic-of-korea
Basic oxygen furnace (BOF)	A furnace for converting molten pig/crude iron and scrap steel to new liquid steel to produce steel products.
BF-BOF	Most common steel production route where raw materials (iron ore and fluxes) are first reduced (oxygen is removed from the iron) and melted in a blast furnace to produce crude iron. The crude iron is then further heated to remove unwanted materials (slag) from the crude iron in a basic oxygen furnace to produce steel. Both processes happen in the same 'integrated' steel-making facility.
Blast furnace (BF)	A furnace used to melt and remove oxygen (reduce) from iron ore to produce liquid crude iron (pig iron). The blast refers to pressurised air supplied to catalyse the chemical reaction between the iron ore, coal and limestone flux. The use of coal and limestone make this a high CO2-emitting process.
Capacity Investment Scheme (CIS)	The CIS is an Australian Government framework to encourage new investment in renewable capacity, such as wind and solar, as well as clean dispatchable capacity, such as battery storage. https://www.dcceew.gov.au/energy/renewable/capacity-investment-scheme

Carbon Border Adjustment Mechanism (CBAM)	The CBAM is the EU's tool to put a fair price on the carbon emitted during the production of carbon-intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries. https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en
Carbon-intensive	Processes that emit high amounts of carbon dioxide resulting from the use of carbon-bearing materials like fossil fuels.
Clean Energy Finance Corporation (CEFC)	CEFC is an Australian Government agency investing government funds to facilitate increased flows of finance into the clean energy sector to achieve Australia's emissions reduction targets. https://www.cefc.com.au/
Clean Hydrogen Production Tax Credit (US)	The United States Inflation Reduction Act (IRA) of 2022 provides a production credit for each kilogram of qualified clean hydrogen produced by a taxpayer at a qualified clean hydrogen production facility. The credit amount is dependent on the emissions intensity of the hydrogen. https://www.irs.gov/newsroom/treasury-irs-issue-guidance-on-the-tax-credit-for-the-production-of-clean-hydrogen
Climate diplomacy	Joining climate policy and foreign policy to achieve sustainable progress on climate goals.
Climate Transition Bond (Japan)	A US$11 billion Climate Transition Bond, with proceeds being used to fund Japan's ambitious Green Transformation (GX) program. The bond is certified by the Climate Bonds Initiative. https://www.climatebonds.net/resources/press-releases/2024/02/japan-will-issue-11billion-climate-transition-bond-certified-under
Climate Bonds Initiative	International organisation working to mobilise global capital for climate action via a bonds certification scheme. https://www.climatebonds.net/
Carbon dioxide (CO_2) equivalent	Unit of measurement for the impact of different greenhouse gases on global warming by referring to a calculated equivalent amount of CO2.
Carbon leakage	Where companies move production from a country with strong emissions reduction policies to a country with weaker policies, allowing an increase in CO2 emissions.
Conference of the Parties (COP)	Conference of the Parties to the United Nations Framework Convention on Climate Change, the peak decision-making body for the world's climate change commitments. (https://unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop)
COURSE50	Japanese project aiming to reduce CO2 emissions from the blast furnace by combining this hydrogen reduction technology and the separation and recovery technology for CO2 emitted from the blast furnace. https://www.course50.com/en/message/
CSIRO	Commonwealth Scientific and Industrial Research Organisation—Australia's national science agency. https://www.csiro.au/en/about
Decarbonisation	Reducing and removing carbon dioxide and other greenhouse gas emissions from the atmosphere.

Department of Climate Change, Energy, the Environment and Water (DCCEEW)	An Australian Government department responsible for climate change, energy, the environment and water monitoring and regulation. https://www.dcceew.gov.au/
Department of Foreign Affairs and Trade (DFAT)	An Australian Government department responsible for promoting and protecting national interest, security and trade. https://www.dfat.gov.au/
De-risking	Reducing the chance of future financial loss and negative impacts.
Direct reduced iron (DRI)	DRI (or sponge iron) is iron produced from iron ore without melting using a reducing gas.
Direct-shipping ore (DSO)	Iron ores that have an iron content that is high enough (typically above 60 per cent iron) that they can be used directly in blast furnaces.
DRI-EAF	Steel production process that couples direct reduction of iron ore with steel-making using an electric arc furnace.
Electric melter/smelter	Electric melters are an under-development type of furnace needed to remove impurity material from iron produced by DRI processes before producing steel. Electric smelters also perform reduction of iron ores.
Electric arc furnace (EAF)	Electric furnace used to melt crude iron, scrap and DRI products to produce liquid steel.
Emissions	Greenhouse gases released to the atmosphere.
Export Finance Australia	An Australian Government agency providing financial support for export trade and international infrastructure development. https://www.exportfinance.gov.au
Fluidised bed	Gas-based iron ore reduction process producing DRI from fine iron ore particles.
Fossil fuels	Carbon-based fuels including coal, fossil oil and fossil gas.
Gas blends	Blending carbon-based fossil gas with hydrogen (either fossil or renewable) to produce a reductant gas.
Green	See Information box 1.
Renewable hydrogen	Hydrogen produced from water using electrolysis methods powered by renewable energy.
Green Deal Industrial Plan (EU)	The Green Industrial Plan is a European Union program to increase the competitiveness of Europe's net-zero industry by creating a more supportive environment for scaling up the EU's manufacturing capacity for the net-zero technologies and products required to meet Europe's ambitious climate targets. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en
Green iron	See Information box 1.

Green iron key	The title of this report was chosen because, given the huge emissions associated with steel-making, developing green iron manufacturing capability in Australia is key to our region's decarbonisation. By replacing conventional steel-making with onshore green iron production and (largely) offshore steel-making, overall steel value chain emissions will be greatly decreased if renewable energy and renewable hydrogen are used.
Green steel	See Information box 1.
Green Transformation Plan (GX)	Japan's Green Transformation Plan. https://www.meti.go.jp/english/press/2023/pdf/0210_003b.pdf
Greenhouse gas (GHG)	Any gas released to the atmosphere that contributes to the greenhouse effect (atmospheric heating), of which carbon dioxide is the most significant.
Group of 20 (G20)	Intergovernmental forum for economic cooperation. The G20 is made up of 19 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Saudi Arabia, South Africa, Russia, Türkiye, the United Kingdom and United States) and two regional bodies: the African Union and European Union (https://www.g20.org/en/about-the-g20)
Guarantee of Origin scheme	An Australian Government scheme that provides a mechanism to track and verify emissions associated with hydrogen and other products made in Australia, and for renewable electricity certification. https://www.dcceew.gov.au/energy/renewable/guarantee-of-origin-scheme
Hematite iron ore	See Information box 3.
HYBRIT	See Information box 4.
Hydrogen Energy Supply Chain project (HESC)	The HESC project achieved a world first by demonstrating that clean liquid hydrogen could be extracted from Victoria (Australia) and shipped to Kobe in Japan. The hydrogen was extracted using coal-based processes but may provide useful lessons for future renewable hydrogen applications. https://www.hydrogenenergysupplychain.com/about-the-pilot/
Hydrogen Headstart	An Australian Government program to provide revenue support for large-scale renewable hydrogen projects through competitive hydrogen production contracts. To date, the scheme has invested $2 billion. https://www.dcceew.gov.au/energy/hydrogen/hydrogen-headstart-program
Indo–Pacific Economic Framework for Prosperity (IPEF)	IPEF is a United States government diplomatic collaboration framework with 14 member countries, including Australia, Japan and the Republic of Korea. https://www.commerce.gov/ipef
Industrial Deep Decarbonisation Initiative (IDDI)	IDDI is a United Nations Industrial Development Organisation Clean Energy Ministerial initiative to stimulate demand for low carbon industrial materials by standardising carbon assessments, establishing ambitious public and private sector procurement targets, incentivising investment into low-carbon product development and designing industry guidelines. https://www.unido.org/IDDI

Industrial Leap Program	Project of the Swedish Energy Agency for providing fundings to achieve emission reduction targets. Part of the European Union Recovery and Resilience Facility and Next Generation EU. https://www.energimyndigheten.se/en/innovations-r--d/energyintensive-industry/the-industrial-leap/
Inflation Reduction Act (IRA)	The IRA is a series of funding initiatives by the United States government for clean energy, climate mitigation and resilience, agriculture and conservation-related investment programs. https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/
International Energy Agency (IEA)	IEA is an industry agency providing data, analysis and policy recommendations on energy issues. https://www.iea.org/about/mission
Leadership Group for Industry Transition (LeadIT)	LeadIT is a collective of countries and companies committed to action to achieve the Paris Agreement. Launched by the governments of Sweden and India at the UN Climate Action Summit in September 2019 and supported by the World Economic Forum. Australia, Japan and the Republic of Korea are members. https://www.industrytransition.org/who-we-are/
Magnetite iron ore	See Information box 3.
Molten oxide electrolysis (MOE)	Reduction of iron ore using direct current electrolysis. Iron ore is dissolved in a high-temperature (1,600°C) solution of silicon dioxide, and the iron and oxygen are separated using electrolysis.
Minerals Research Institute of Western Australia (MRIWA)	MRIWA is a research organisation of the Government of Western Australia specialising in mining and minerals research. https://www.mriwa.wa.gov.au/
Mtpa	Million tonnes per annum.
National Electricity Market (NEM)	An Australian electricity network connecting all states and territories except Western Australia and the Northern Territory. https://www.aemc.gov.au/energy-system/electricity/electricity-system/NEM
National Green Hydrogen Mission	A Government of India initiative that aims to make India the global hub for production, usage and export of renewable hydrogen and its derivatives. https://mnre.gov.in/national-green-hydrogen-mission/
National Reconstruction Fund Corporation (NRFC)	An Australian Government entity for the purpose of the Public Governance, Performance and Accountability Act 2013. The NRFC was established to diversify and transform Australia's industry and economy to secure future prosperity and drive sustainable economic growth. https://www.finance.gov.au/government/specialist-investment-vehicles/national-reconstruction-fund-corporation
National Steel Industry Policy	A policy of the Government of India to develop the domestic steel industry. The policy envisages to domestically meet the entire demand of steel and high-grade automotive steel, electrical steel, special steel and alloys for strategic applications. https://steel.gov.in/en/national-steel-policy-nsp-2017

Natural gas	Hydrocarbon gas combination (primarily methane) used as a carbon-based fuel. Sourced from fossil carbon deposits.
Net-zero emissions (NZE)	Net-zero means that the amount of greenhouse gas removed from the atmosphere is equal to the amount of greenhouse gas released to the atmosphere.
Northern Australia Infrastructure Facility (NAIF)	NAIF is an Australian Government entity offering loans for the development of infrastructure projects in northern Australia and the Australian Indian Ocean Territories. https://www.naif.gov.au/
Paris-aligned	An emission reduction plan that will achieve the climate goals of the Paris Agreement.
Pelletisation	The process of mixing finely ground iron ore with additives to make a pellet. Pellets are then fired at a high temperature (indurated) to allow the pellet to be handled and transported. Pelletisation allows fine iron ore material to be used for iron-making.
Powering the Regions	An Australian Government fund for decarbonising regions and renewable energy infrastructure development. The fund has an Industrial Transformation Stream intended to support the reduction of greenhouse gas emissions related to industrial activity. https://arena.gov.au/funding/powering-the-regions-industrial-transformation-stream/
Quad	A diplomatic partnership between Australia, India, Japan and the United States.
Regenerative economy	A regenerative economy is climate resilient, electrified, and uses only clean and renewable energy. It is nature positive by design, socially inclusive and enhances well-being. WWF's vision is that, by 2030, Australia is an active leader in the transition to a productive and resilient economy that lives within planetary boundaries and restores both natural and social capital. This requires moving from linear to circular business models that eliminate waste and pollution, keeping materials and products in use for longer, while also regenerating damaged ecosystems and halting species loss.
Relining	Replacing the refractory lining of a blast furnace (made of carbon and graphite bricks) that protects the furnace and extends its use.
Renewable	Made from fossil-free energy sources like solar and wind.
Safeguard Mechanism	An Australian Government policy for reducing emissions at Australia's largest industrial facilities. It sets legislated baseline limits on the greenhouse gas emissions of industrial facilities and the amount to which these must fall each year to contribute to national emission reduction targets. It involves a credit trading scheme. https://www.dcceew.gov.au/climate-change/emissions-reporting/national-greenhouse-energy-reporting-scheme/safeguard-mechanism

Science Based Targets initiative (SBTi)	SBTi is a corporate climate action organisation that enables companies and financial institutions worldwide to play their part in combating the climate crisis by developing standards and guidance for companies to plan their transition to net-zero. Partners include CDP, the United Nations Global Compact, the We Mean Business Coalition, the World Resources Institute and WWF. https://sciencebasedtargets.org/
Shaft furnace	Any upright furnace using gas (fossil gas or hydrogen) to achieve reduction of iron ore without melting.
Steel Industry Development Strategy for Transition to Low-Carbon Steel Production	A ₩150 billion (A$170 million) fund to support low-carbon steel production. https://www.seaisi.org/details/22417?type=news-rooms
SteelZero	A demand-based initiative for green steel where members make a public commitment to procure 50 per cent of their steel by 2030 from producers on the pathway to net-zero and to procure 100 per cent net-zero steel by 2050. Hosted by the Climate Group in partnership with Responsible Steel. https://www.theclimategroup.org/about-steelzero-
Stranded asset	Investment in a physical asset that may become obsolete as green production methods emerge.
Sunshot	A report by a consortium including the Business Council of Australia, Australian Council of Trade Unions, World Wide Fund for Nature-Australia and the Australian Conservation Foundation prepared as a joint federal government submission on Australia's renewable export opportunities. https://www.acf.org.au/federal-budget-2023-24-could-shape-australia-future-in-global-energy-transition
The Paris Agreement	The Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016. Its overarching goal is to hold 'the increase in the global average temperature to well below 2°C above pre-industrial levels' and pursue efforts 'to limit the temperature increase to 1.5°C above pre-industrial levels'. However, in recent years, world leaders have stressed the need to limit global warming to 1.5°C by the end of this century. https://unfccc.int/process-and-meetings/the-paris-agreement#What%20Is%20The%20Paris%20Agreement
World Trade Organisation (WTO)	The WTO is an organisation that sets global rules for trade. https://www.wto.org

Hot Briquetted Iron - HBI / © N-sky / Shutterstock / WWF

REFERENCES

1. The Transition Away from Oil & Gas: A WWF Network Policy Position, May 2021. WWF International.
   https://wwfint.awsassets.panda.org/downloads/wwf_policy_position___the_transition_away_from_oil___gas.pdf

2. Climate change and the production of iron and steel. (2021). World Steel Association.
   https://worldsteel.org/publications/policy-papers/climate-change-policy-paper/

3. Burke, P. et al. (2022). Contributing to regional decarbonisation: Australia's potential to supply zero-carbon commodities to the Asia-Pacific. Energy, Vol. 248.
   https://researchprofiles.anu.edu.au/en/publications/contributing-to-regional-decarbonization-australias-potential-to-

4. Witecka, W. K., von Eitzen Toni, O., Scott, J., Burmeister, H., Wang, L. (I.), Lechtenböhmer, S., Schneider, C., Zelt, O. & Åhman, M. (2021). Global steel at a crossroads: Why the global steel sector needs to invest in climate-neutral technologies in the 2020s. Agora Industry, Wuppertal Institute and Lund University.
   https://www.agora-energiewende.org/publications/global-steel-at-a-crossroads

5. Green Steel Tracker. (2024). Leadership Group for Industry Transition. Accessed 22 January 2024
   https://www.industrytransition.org/green-steel-tracker/

6. Achieving Net-Zero Heavy Industry Sectors in G7 Members. (2022). International Energy Agency.
   https://www.iea.org/reports/achieving-net-zero-heavy-industry-sectors-in-g7-members

7. Steel Standard Principles: Common emissions measurement methodologies to accelerate the transition to near zero. (2024). World Trade Organisation.
   https://www.wto.org/english/tratop_e/envir_e/steel_standards_principles_e.pdf

8. Western Australia's Green Steel Opportunity. (2023). Minerals Research Institute of Western Australia.
   https://www.mriwa.wa.gov.au/minerals-research-advancing-western-australia/focus-areas/green-steel/green-steel-resources/

9. Resources and Energy Quarterly: December 2023. (2024). Australian Government Department of Industry, Science and Resources.
   https://www.industry.gov.au/publications/resources-and-energy-quarterly-december-2023.

10. Iron and Steel Technology Roadmap: Towards more sustainable steelmaking. (2020). International Energy Agency.
    https://www.iea.org/reports/iron-and-steel-technology-roadmap

11. Net-Zero by 2050: A Roadmap for the Global Energy Sector. (2021). International Energy Agency.
    https://www.iea.org/events/net-zero-by-2050-a-roadmap-for-the-global-energy-system

12. Witecka, W. K., von Eitzen Toni, O., Somers, J. & Reimann, K. (2021). 15 insights on the global steel transformation. Agora Industry and Wuppertal Institute.
    https://www.agora-industry.org/publications/15-insights-on-the-global-steel-transformation

13. Fact sheet: Steel and raw materials. (2023). World Steel Association.
    https://www.steel.org.au/getattachment/458fa31b-2586-47bb-a645-9411140863dd/WSA_fact_raw_materials_2018.pdf#:~:text=Key%20raw%20materials%20needed%20in%20steelmaking%20include%20iron,including%20iron%20ore%2C%20coal%2C%20limestone%20and%20recycled%20steel.

14. Peplow, M. (2021). Can industry decarbonise steelmaking? Chemical and Engineering News, Vol. 99, Issue 22.
    https://cen.acs.org/environment/green-chemistry/steel-hydrogen-low-co2-startups/99/i22

15. Nicholas, S. & Basirat, S. (2023). Australia faces growing green iron competition from overseas. Institute for Energy Economics and Financial Analysis.
    https://ieefa.org/resources/australia-faces-growing-green-iron-competition-overseas

16. Nicholas, S. & Basirat, S. (2024). Carbon capture for steel? Institute for Energy Economics and Financial Analysis.
    https://ieefa.org/resources/carbon-capture-steel

17. Shahabuddin, M. S. et al. (2023). Substitution of natural gas with hydrogen: A case study for electric arc furnace-based steel-making in terms of mass, energy and lifecycle emission analysis. Journal of Sustainable Metallurgy (under review).

18. Ellis, B. & Bao, W. (2020). Pathways to decarbonisation episode two: steelmaking technology. BHP podcast, 5 November 2020.
    https://www.bhp.com/news/bhp-insights/2020/11/pathways-to-decarbonisation-episode-two-steelmaking-technology

19. Iron Ore. (2018). GeoScience Australia. https://www.ga.gov.au/scientific-topics/minerals/mineral-resources-and-advice/australian-resource-reviews/iron-ore

20. Carbon Neutral HyREX: Breakthrough hydrogen reduction iron-making technology with near-zero emission. POSCO. Accessed 22 January 2024. https://www.posco.co.kr/homepage/docs/eng7/jsp/hyrex/

21. Hornby, S. & Brooks, G. (2021). Impacts of hydrogen DRI on EAF sSteelmaking. Technical article, MIDREX. https://www.midrex.com/tech-article/impact-of-hydrogen-dri-on-eaf-steelmaking/

22. Rio Tinto's BioIron™ proves successful for low-carbon iron-making. (2022). Rio Tinto. https://www.riotinto.com/en/news/releases/2022/rio-tintos-bioiron-proves-successful-for-low-carbon-iron-making

23. Fact sheet: Electrolysis in iron-making. (2021). World Steel Association. https://worldsteel.org/wp-content/uploads/Fact-sheet-Electrolysis-in-ironmaking.pdf

24. Half-year results to 31 December 2022. Fortescue Future Industries/ Fortescue Metals Group ASX release, 15 February 2023. https://cdn.fortescue.com/docs/default-source/announcements-and-reports/2512248.pdf?sfvrsn=56690a34_4

25. Global Hydrogen Trade to Meet the 1.5°C Climate Goal: Part III—Green Hydrogen Cost and Potential. (2022). International Renewable Energy Agency. https://www.irena.org/publications/2022/May/Global-hydrogen-trade-Cost

26. Liebreich, M. (2022). Liebreich: The Unbearable Lightness of Hydrogen. Bloomberg New Energy Finance. https://about.bnef.com/blog/liebreich-the-unbearable-lightness-of-hydrogen/

27. Green steel: Swedish company ships first batch made without using coal. (2021). The Guardian/Reuters in Stockholm, 19 August 2021. https://www.theguardian.com/science/2021/aug/19/green-steel-swedish-company-ships-first-batch-made-without-using-coal?ref=satyam-studio.ghost.io

28. Jones, F. (2023). Europe's first commercial green steel plant to open in Sweden. Mining Technology. https://www.mining-technology.com/news/green-steel-hydrogen/

29. Algers, J. (2024). Leading with Industrial Policy: Lessons for Decarbonisation from Swedish Green Steel. Roosevelt Institute. https://rooseveltinstitute.org/publications/leading-with-industrial-policy/

30. HYBRIT Demonstration. HYBRIT fossil-free steel. Viewed March 2024. https://www.HYBRITdevelopment.se/en/HYBRIT-demonstration/

31. Powering a new, clean industrial revolution. H2 Green Steel. Viewed March 2024. https://www.h2greensteel.com/

32. Wu, M., Vora, M. & Chaudhary, I. (2022). Pedal to the metal: Iron and steel's US$1.4 trillion shot at decarbonisation. Wood Mackenzie. https://www.woodmac.com/horizons/pedal-to-the-metal-iron-and-steels-one-point-four-trillion-usd-shot-at-decarbonisation/

33. Carbon Price Tracker. (2023). Ember. Accessed 23 January 2024. https://ember-climate.org/data/data-tools/carbon-price-viewer/

34. Attwood, J. (2023). Green steel demand is rising faster than demand can ramp up. Bloomberg New Energy Finance. https://about.bnef.com/blog/green-steel-demand-is-rising-faster-than-production-can-ramp-up/

35. SteelZero. (2024). Climate Group. https://www.theclimategroup.org/steelzero

36. Wood, T., Reeve, A. & Yan, R. (2023). Hydrogen: Hype, hope or hard work? Grattan Institute. https://grattan.edu.au/report/hydrogen-hype-hope-or-hard-work/

37. Ghosh, A., Runge-Metzger, A., Victor, D. G. & Zou, J. (2022). The new way to fight climate change: Small-scale cooperation can succeed where global diplomacy has failed. Foreign Affairs. https://www.foreignaffairs.com/world/new-way-fight-climate-change

38. Industrial Deep Decarbonisation Initiative: An initiative of the Clean Energy Ministerial. United Nations Industrial Development Organisation. https://www.unido.org/IDDI

39. Steel Science-Based Target-Setting Guidance. (2023). Science-Based Targets. https://sciencebasedtargets.org/sectors/steel

40. Inflation Reduction Act Guidebook: Clean Energy. (2023). The White House. https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/

41. Hensley, B. & Lappetelainen, A. (2023). Race to the top on clean energy: The US and EU response to China's dominance. Report by Kaya Partners for the Inevitable Policy Response. https://www.unpri.org/download?ac=17824

42. Overview of Japan's Green Transformation (GX). (2023). GR Japan. https://grjapan.com/sites/default/files/content/articles/files/gr_japan_overview_of_gx_plans_january_2023.pdf

43. Ayres, T. (2023). Keynote address to the National Manufacturing Summit. Old Parliament House Canberra, 3 August 2023. https://www.minister.industry.gov.au/ministers/ayres/speeches/keynote-address-national-manufacturing-summit

44. Albanese, A. (2024). A future made in Australia. Speech to Queensland Media Club, 11 April 2024.

45. Carbon Border Adjustment Mechanism: Information for Importers of Iron and Steel. (2023). Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/1234d17a-9e1f-11ee-b164-01aa75ed71a1/language-en/format-PDF/source-305958842

46. Gijs, C. & Aarup, S. A. (2023). It's the EU and US against the rest of the world in new steel club. Politico. https://www.politico.eu/article/steel-aluminum-tariffs-european-union-united-states-china-imports-trade/

47. Hancock, A. & Pfeifer, S. (2024). How global trade could fragment after the EU's tax on 'dirty' imports. Financial Times. https://www.ft.com/content/ca51ebf5-fbb8-4c88-a93d-ded3d6d3bcdd

48. Biden-Harris administration announces $6 billion to transform America's industrial sector, strengthen domestic manufacturing and slash planet-warming emissions. (2024). Energy.Gov (US Department of Energy). https://www.energy.gov/articles/biden-harris-administration-announces-6-billion-transform-americas-industrial-sector

49. Japan will issue $11 billion Climate Transition Bond, Certified under the Climate Bonds Standard. (2024). Climate Bonds Initiative. https://www.climatebonds.net/resources/press-releases/2024/02/japan-will-issue-11bn-climate-transition-bond-certified-under

50. Pedal to the Metal: It's Time to Shift Steel Decarbonisation into High Gear. (2023). Global Energy Monitor. https://globalenergymonitor.org/wp-content/uploads/2023/07/GEM_SteelPlants2023.pdf

51. Ng, E. (2022). Green steel is still decades away in Asia as hydrogen struggles to replace coal-fired furnaces, says mining giant BHP. South China Morning Post. https://www.scmp.com/business/article/3201543/green-steel-still-decades-away-asia-hydrogen-struggles-replace-coal-fired-furnaces-says-mining-giant

52. The Breakthrough Effect: How to Trigger a Cascade of Tipping Points to Accelerate the Net-Zero Transition. (2023). Systemiq, University of Exeter & Bezos Earth Fund. https://www.exeter.ac.uk/media/universityofexeter/globalsystemsinstitute/documents/The_Breakthrough_Effect_Systemiq.pdf

53. Smil, V. (2006). Transforming the Twentieth Century: Volume 2: Technical Innovations and Their Consequences. Oxford University Press. https://academic.oup.com/book/25970

54. Kawabata, N. (2023). Evaluating the technology path of Japanese steel producers in green steel competition. The Japanese Political Economy, Vol. 49, Issue 2–3, pp231–252. https://www.tandfonline.com/doi/full/10.1080/2329194X.2023.2258162

55. Zhou, T., Xu, H., Gosens, J. & Jotzo, F. (2022). China's net-zero plans: Policy brief on near-term policy challenges and Australia-China links in Decarbonisation. Australian National University. https://acbc.com.au/wp-content/uploads/2022/03/ANU-policy-brief-Chinese-climate-and-energy-policy-trends.pdf

56. Countries. Climate Action Tracker. Viewed January 2024. https://climateactiontracker.org/countries/

57. Fujioka, K. (2023). Japan plans 10-year tax breaks for EV and chip production. Nikkei Asia. https://asia.nikkei.com/Politics/Japan-plans-10-year-tax-breaks-for-EV-and-chip-production

58. Low Carbon Steel Development in Japan. (2023). Transition Asia. https://transitionasia.org/low-carbon-steel-development-in-japan/

59. Korea unveils steel plan, eyes low-carbon project fund. (2023). Southeast Asia Iron and Steel Institute. https://www.seaisi.org/details/22417?type=news-rooms#:~:text=South%20Korea%20has%20announced%20a%20steel%20industry%20development,won%20%28%24115.9mn%29%20fund%20to%20support%20low-carbon%20steel%20production.

60. National Steel Policy. (2017). Ministry of Steel, Government of India. https://steel.gov.in/en/national-steel-policy-nsp-2017

61. Steel Scrap Recycling Policy. (2019). Ministry of Steel, Government of India. https://steel.gov.in/sites/default/files/Steel%20Scrap%20Recycling%20Policy%2006.11.2019.pdf

62. Garg, V., Gulia, J., Gupta, K., Shaik, N. & Srivastava, S. (2023). Steel Decarbonisation in India. Institute for Energy Economics and Financial Analysis.
https://ieefa.org/resources/steel-decarbonisation-india

63. Top steel-producing companies 2022/2021. (2024). World Steel Association.
https://worldsteel.org/steel-topics/statistics/top-producers/

64. Coal-based steelmaking capacity plans up 8 per cent in 2022, pushing stranded asset risk past half a trillion dollars. (2023). Global Energy Monitor.
https://globalenergymonitor.org/press-release/coal-based-steelmaking-capacity-plans-up-8-percent-in-2022-pushing-stranded-asset-risk-past-half-a-trillion-dollars/

65. Woods, I. & Sullivan, R. (2023). Decarbonisation Investment Solutions for Sectors: A discussion paper on Sector Transition Plans and their importance to investors. Investor Group on Climate Change.
https://igcc.org.au/wp-content/uploads/2023/10/IGCC-Sector-Pathways-Report_2023.pdf

66. Simandou iron ore project update. (2023). Rio Tinto.
https://www.riotinto.com/en/news/releases/2023/simandou-iron-ore-project-update.

67. Rocks that shape Australia. (2024). Geoscience Australia.
https://www.ga.gov.au/about/visiting-ga/public-displays/rocks-that-shape-australia

68. Seidel, J. (2024). Australia's biggest export on the brink of $30 billion loss. The Advertiser.
https://www.adelaidenow.com.au/business/companies/mining/australias-biggest-export-on-the-brink-of-30-billion-loss/news-story/3954280b4c701f53ad9da4a5d6a3bf3b

69. Horngren, T. et al. (2023). Pathways to industrial decarbonisation: Positioning Australian industry to prosper in a net-zero global economy, phase 3 report. Australian Industry Energy Transitions Initiative.
https://energytransitionsinitiative.org/wp-content/uploads/2023/08/Pathways-to-Industrial-Decarbonisation-report-Updated-August-2023-Australian-Industry-ETI.pdf

70. Thompson, B. (2023). Forrest's giant sigh of relief as Iron Bridge mine produces magnetite. Australian Financial Review.
https://www.afr.com/companies/mining/forrest-s-giant-sigh-of-relief-as-iron-bridge-mine-ships-magnetite-20230430-p5d4g0

71. Australia's leading iron ore producers partner with BlueScope on steel decarbonisation. (2024).
BHP. https://www.bhp.com/news/media-centre/releases/2024/02/australias-leading-iron-ore-producers-partner-with-bluescope-on-steel-decarbonisation

72. Rio Tinto and BlueScope to explore low-carbon-steelmaking pathways. (2021). Rio Tinto.
https://www.riotinto.com/news/releases/2021/Rio-Tinto-and-BlueScope-to-explore-low-carbon-steelmaking-pathways

73. China Baowu and Rio Tinto extend climate partnership to decarbonise the steel value chain. (2023). Rio Tinto.
https://www.riotinto.com/en/news/releases/2023/china-baowu-and-rio-tinto-extend-climate-partnership-to-decarbonise-the-steel-value-chain

74. BHP strengthens partnership with China's HBIS Group through agreement on enhanced decarbonisation trials in steelmaking. (2023). BHP.
https://www.bhp.com/news/media-centre/releases/2023/12/bhp-strengthens-partnership-with-chinas-hbis-group

75. BHP and Hatch commence design study for an electric smelting furnace pilot. (2023). BHP.
https://www.bhp.com/news/media-centre/releases/2023/03/bhp-and-hatch-commence-design-study-for-an-electric-smelting-furnace-pilot

76. Fortescue partners with world's largest steel-maker to reduce emissions across iron and steel-making. (2023). Fortescue.
https://fortescue.com/news-and-media/news/2023/07/10/fortescue-partners-with-world's-largest-steel-maker-to-reduce-emissions-across-iron-and-steel-making

77. Fortescue, Primetals Technologies and Voestalpine to jointly evaluate groundbreaking green iron-making plant. (2022). Fortescue.
https://fortescue.com/news-and-media/news/2022/12/20/fortescue-primetals-technologies-and-voestalpine-to-jointly-evaluate-groundbreaking-green-ironmaking-plant

78. Sunshot: Achieving global leadership in clean exports. (2023). Report for Australian Conservation Foundation, Australian Council of Trade Unions, Business Council of Australia and WWF-Australia. Accenture.
https://assets.nationbuilder.com/auscon/pages/22780/attachments/original/1698704413/Sunshot_-_Achieving_Global_Leadership_in_Clean_Exports_Final_Report.pdf

79. The Transition Away from Oil & Gas: A WWF Network Policy Position, May 2021. WWF International.
https://wwfint.awsassets.panda.org/downloads/wwf_policy_position___the_transition_away_from_oil___gas.pdf

80. A new $100 billion Australian Renewables Industry Package is critical for our future security and prosperity. (2023). Media release by Australian Council of Trade Unions, Climate Action Network Australia, Smart Energy Council, Australian Conservation Foundation, Rewiring Australia, First Nations Clean Energy Network, New Energy Nexus and Climate Energy Finance.
https://climateenergyfinance.org/wp-content/uploads/2023/09/110923-AUSTRALIAN-RENEWABLES-INDUSTRY-PACKAGE-media-release-1.pdf

81. Liberty Steel in Whyalla announces the phase-out of coal-based steelmaking with purchase of a low carbon emissions electric arc furnace. (2023). GFG Alliance.
https://www.gfgalliance.com/media-release/liberty-steel-in-whyalla-announces-the-phase-out-of-coal-based-steelmaking-with-purchase-of-a-low-carbon-emissions-electric-arc-furnace/

82. Global call to arms for SA's push to decarbonise iron. (2024). Government of South Australia.
https://www.premier.sa.gov.au/media-releases/news-items/global-call-to-arms-for-sas-push-to-decarbonise-iron#:~:text=The%20Government%20aims%20to%20establish,process%20by%2095%20per%20cent

83. Collie Green Steel Mill. Green Steel of WA. Viewed March 2024.
https://www.greensteelwa.com.au/collie-green-steel-mill/

84. Mid West Hydrogen DRI Plant. Green Steel of WA. Viewed March 2024.
https://www.greensteelwa.com.au/collie-green-steel-mill-copy/

85. Meinhausen, M. & Nicholls, Z. (2023). Updated assessment of Australia's emission reduction pathway targets and 1.5°C pathways. Climate Resource.
https://www.climate-resource.com/reports/wwf/20230612_WWF-Aus-Targets.pdf

86. Annual Climate Change Statement 2023. (2023). Australian Government Department of Climate Change, Energy, the Environment and Water.
https://www.dcceew.gov.au/sites/default/files/documents/annual-climate-change-statement-2023.pdf

87. Bowen, J. (2022). Re-energising the Indo-Pacific: Australia's clean energy opportunity. Climate Council & Perth USAsia Centre.
https://www.climatecouncil.org.au/resources/re-energising-the-indo-pacific-australias-clean-energy-opportunity/

88. The Path to Green Steel: Pursuing Zero-Carbon Steel-Making in Japan. (2023). Renewable Energy Institute.
https://www.renewable-ei.org/en/activities/reports/20221118.php

89. Hydrogen Economy Outlook: Key Messages. (2020). Bloomberg New Energy Finance.
https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

90. 2022 New Energy Outlook, Bloomberg New Energy Finance.
https://about.bnef.com/new-energy-outlook

91. Delivering more reliable energy for all Australians. (2023). Media release from the Hon Chris Bowen MP, Minister for Climate Change and Energy. Department of Climate Change, Energy, the Environment and Water.
https://minister.dcceew.gov.au/bowen/media-releases/delivering-more-reliable-energy-all-australians

92. Getting H2 right: Success factors for Australia's hydrogen export industry. (2021). PWC.
https://www.pwc.com.au/energy-transition/getting-h2-right-australias-competitive-hydrogen-export-industry.html

93. van Haersma Burma, B., Peretto, M., Matar, Z. M. & van de Kaa, G. (2023). Towards renewable hydrogen-based electrolysis: Alkaline vs proton exchange membrane. Heliyon, Vol. 9, Issue 7.
https://www.sciencedirect.com/science/article/pii/S2405844023052076

94. Guarantee of Origin scheme. (2023). Department of Climate Change, Energy, the Environment and Water.
https://www.dcceew.gov.au/energy/renewable/guarantee-of-origin-scheme

95. Philipps, T. (2023). Green gold: A strategy to kickstart Australia's renewable energy future. Centre for Policy Development.
https://cpd.org.au/work/green-gold-renewable-industry-future/

96. Finkel, A. (2023). Powering Up: Unleashing the Clean Energy Supply Chain. Black Inc.

97. Garnaut, R. (ed). (2022). The Superpower Transformation: Making Australia's Zero-Carbon Future. La Trobe University.

98. Hydrogen Headstart program. (2024). Department of Climate Change, Energy, the Environment and Water.
https://www.dcceew.gov.au/energy/hydrogen/hydrogen-headstart-program

99. Renewable energy industrial precincts: Briefing paper. (2020). Beyond Zero Emissions and WWF-Australia.
https://treasury.gov.au/sites/default/files/2021-05/171663_beyond_zero_emissions_supporting_document_1.pdf

100. Thurbon, E., Hynd, A.M. & Tan, H. (2022). To become a renewable energy superpower, Australia must match its strategic vision with a new green energy statecraft. Asia Society.
https://asiasociety.org/australia/become-renewable-energy-superpower-australia-must-match-its-strategic-vision-new-green-energy

101. Thurbon, E., Hynd, A. M. & Tan, H. (2023). Australia's national security mandates green energy statecraft. The Mandarin.
https://www.themandarin.com.au/229483-australias-national-security-mandates-a-new-type-of-green-energy-statecraft/

102. Australia's international clean energy partnerships. Australian Government Department of Climate Change, Energy, the Environment and Water. Accessed 24 January 2024.
https://www.dcceew.gov.au/climate-change/international-climate-action/international-partnerships.

103. India-Australia Green Steel Partnership. (2023). CSIRO Towards Net-Zero Mission.
https://research.csiro.au/tnz/india-australia-green-steel-partnership/.

104. The world-first Hydrogen Energy Supply Chain (HESC) Project. HESC. Accessed 24 January 2024.
https://www.hydrogenenergysupplychain.com/

105. Vekasi, K. (2022). Building Resilient Critical Mineral Supply Chains: Lessons from Japan and South Korea. In Burke, S. et al. (2022). Critical Minerals: Global Supply Chains and Indo-Pacific Geopolitics, pp13–22. The National Bureau of Asian Research.
https://www.nbr.org/publication/critical-minerals-global-supply-chains-and-indo-pacific-geopolitics/

106. Downie, C. & Peterson, M. (2023). COP28: Turning the tap off slowly: Why Australia's decision to end overseas fossil fuel finance matters. The Conversation.
https://theconversation.com/cop28-turning-the-tap-off-slowly-why-australias-decision-to-end-overseas-fossil-fuel-finance-matters-219318

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WWF-Australia National office

Suite 3.01, Level 3,
45 Clarence Street
Sydney NSW 2000
PO Box 528
Gadigal Country

Tel:+1800 032 551
hello@wwf.org.au
@WWF_Australia
wwf.org.au