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Growing Australia’s iron advantage

NOVEMBER 2024

Contents

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Note: All dollar figures are Australian dollars unless indicated otherwise.

Executive summary

1

Australia could produce 20% of global green iron by 2050…

- 53% of global steel production in 2050 is forecast to be green (30%) or lower emissions (23%) steel
- The shift away from conventional steelmaking will create new supply chains
- Australia has the renewable energy capabilities to produce green iron, particularly compared to other iron ore exporters and existing iron producers
- Australia is forecast to be a cost-competitive producer of green iron in 2030 and 2050 if the industry can get to scale
- Australia could supply 20% of global green iron in 2050 (310Mt)

2

… reducing global emissions by 1.7% and generating growth

- Steel production is highly emissions intensive, generating between 6% to 9% of global CO_2 emissions
- Ironmaking is the most emissions intensive part of the steel value chain, responsible for up to 90% of emissions
- Australia's green iron potential is equivalent to reducing global steel emissions by 1.7%, surpassing Australia's current emissions (1.2% of global emissions)
- Australia's green iron potential could add $103 billion to the economy and support 27,500 direct jobs in 2050

3

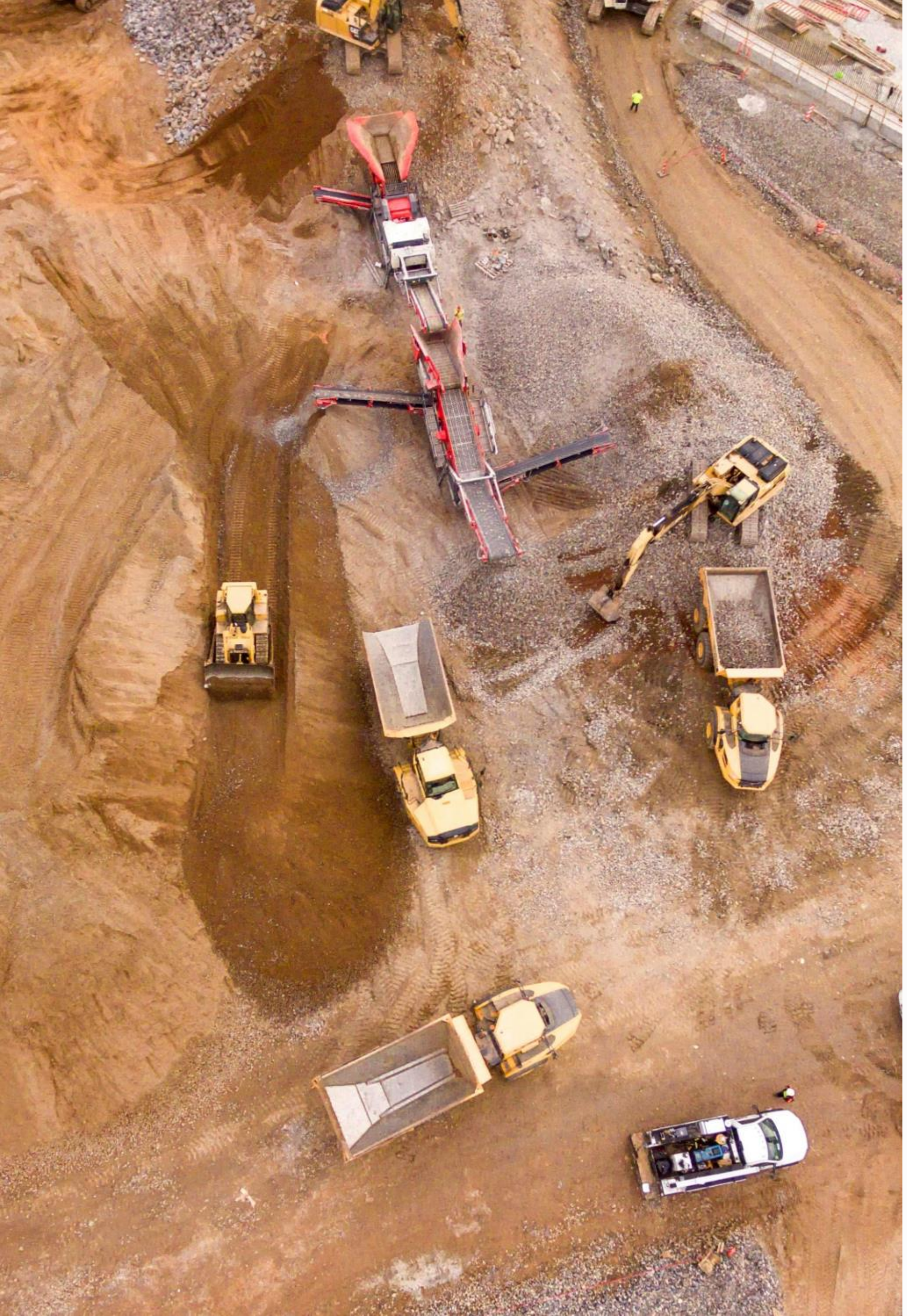
The industry faces short-term feasibility and scale challenges

- Australia's green iron potential requires 16TWh of additional renewable energy generation by 2030 and 775TWh by 2050 (nearly 2.4 times the National Renewable Energy Target for 2030)
- >90% of this electricity is used to make green hydrogen
- $28.8 billion of investment could be required by 2030 to kick-start green iron production, including a production plant, hydrogen facility and renewable energy and battery systems
- Approvals processes and the risk of new technologies continue to be barriers to investment

4

Policy solutions should prioritise these immediate issues

- In the short term, key barriers are the feasibility of early-stage technologies, scale of infrastructure required and availability of capital
- Policy initiatives should urgently address these barriers to enable large-scale investment and drive industry growth
- As the industry moves towards a 'scale-up' phase, additional support will be required to maintain Australia's forecast cost competitiveness, connect Australian supply to demand, and develop a skilled workforce



53% of global steel production in 2050 is forecast to be green or lower emissions

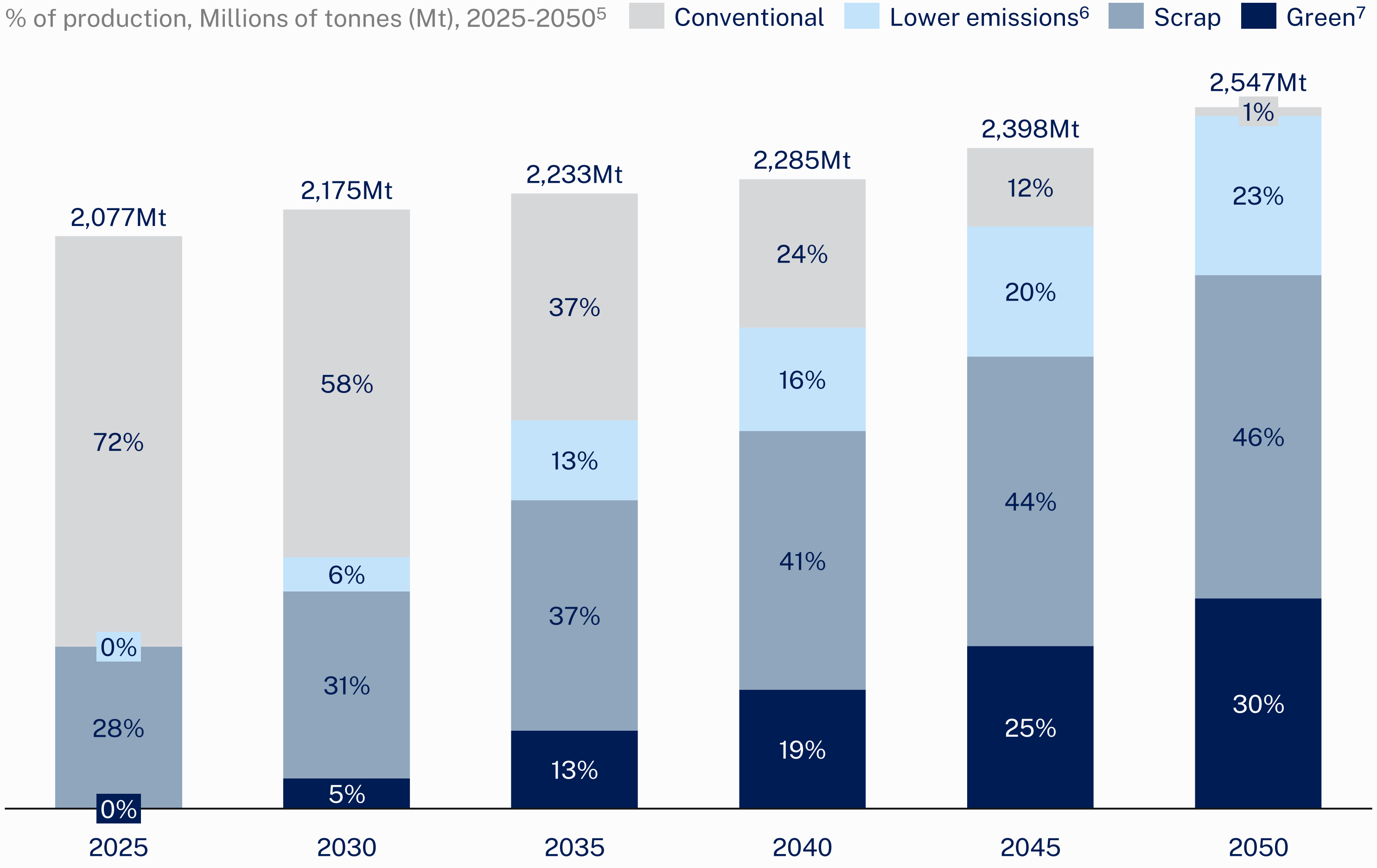
Steel is a major input across the global supply chain – from construction to manufacturing – and plays a fundamental role in economic growth and development. Without competitive substitutes, steel production is forecast to continue growing, reaching a total of 2,547Mt per year in 2050.[1]

Steel production is the result of two production methods. Primary production transforms iron ore into steel and is forecast to reach 1,373Mt in 2050 (approximately 54% of all steel production).[1] Australia supplies 56% of global iron ore demand with the majority processed into steel.[2]

However, primary steel production is highly emissions intensive, with steel generating 6-9% of global emissions (2,600Mt out of 37,400Mt in 2023).[3] As a result, green steel pathways are being developed worldwide to decarbonise the steel value chain. Commercial-scale green steel technologies are expected to become increasingly viable alternatives to conventional steel production over the next 30 years – with 30% of steel production in 2050 forecast to be green steel and a further 23% potentially made using lower emission technologies.[5]

Source: 1 IEA (2023) *Steel and aluminium*; Mission Possible Partnership (2022) *Pathways to Net Zero*; Net Zero Industry (2024) *Net-Zero Steel Pathways;* Wood Mackenzie (2023) *Steel decarbonisation to redefine supply chains by 2050*; Mandala analysis. 2 Department of Industry, Science and Resources (2024) *Resources and energy quarterly: June 2024.* 3 IEA (2020) *Iron and Steel Technology Roadmap;* McKinsey (2020) *Decarbonization challenge for steel.* 4 This share of production depends on the availability of lower emissions production facilities. If no such facilities are available, conventional methods of production may be used.

Global steel production forecast



5 These forecasts combine forecasts from IEA (2023), the 'Tech Moratorium' scenario in Mission Possible Partnership (2022), Net Zero Industry (2024) and Wood Mackenzie (2023). 6 Refers to steel production that could be made with lower emissions methods (including DRI pathways) depending on technology commercialisation, compared to near-zero emissions pathways ("green"). 7 Green iron technologies are in early phases of development with the most advanced technologies in pilot production. There are many technologies under development; however, the most prospective option is to use shaft furnaces powered by green hydrogen: Minerals Research Institute of WA (2023) *WA's Green Steel* Opportunity.

The shift away from conventional steelmaking will create new supply chains

The economics of conventional steelmaking are driven by the cost of two key inputs: coal and labour. Coal is used as a reducing agent for the iron ore and as a source of energy (electricity and heat) in the ironmaking and steelmaking phases. Steel production is also relatively labour-intensive, particularly compared to iron production.

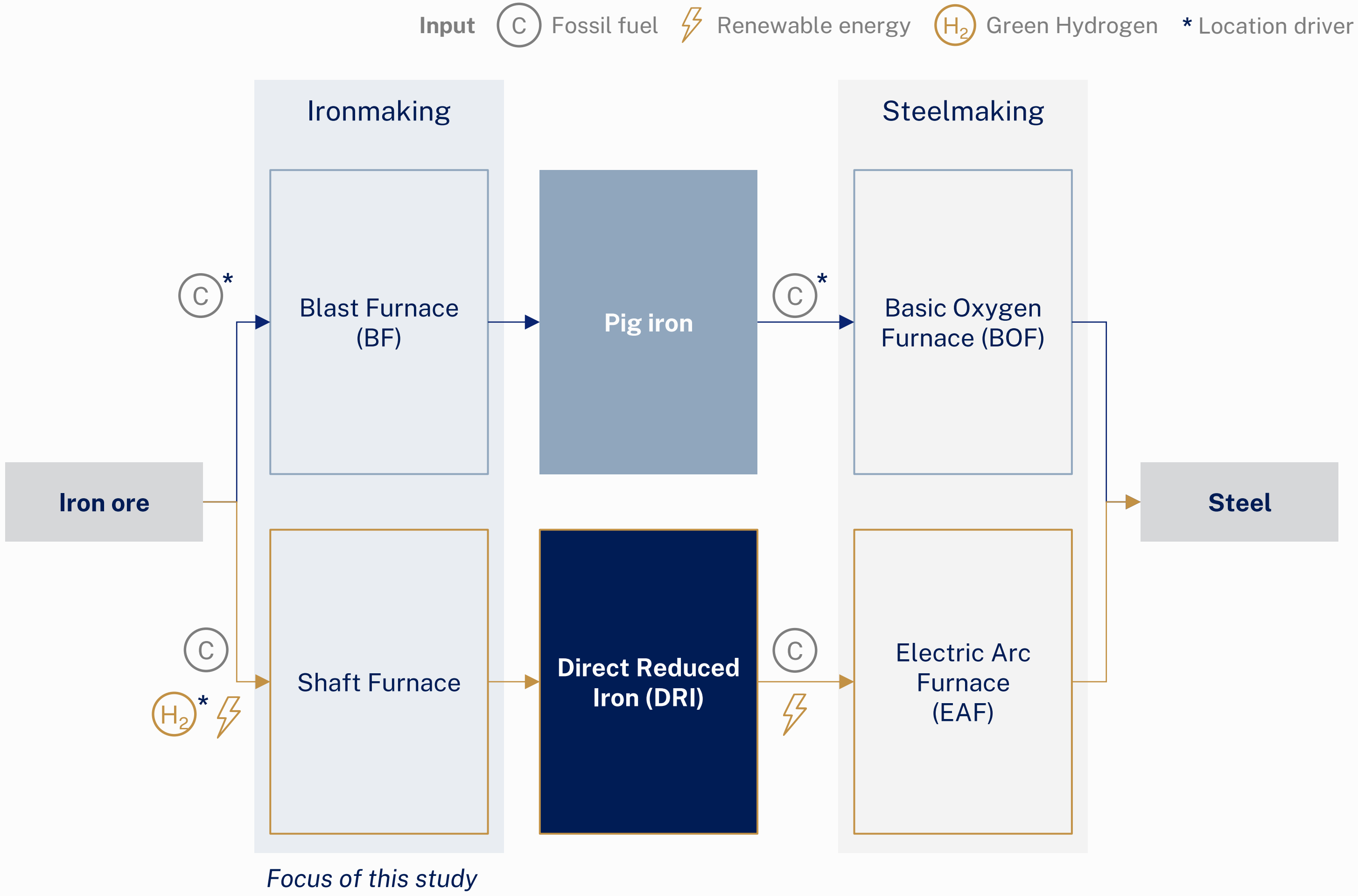
Ironmaking and steelmaking have historically been co-located in jurisdictions with access to low-cost coal and low-cost labour. This co-location has enabled further economies of scale across the process.

However, the most prospective green iron production technologies are likely to replace coal with green hydrogen. Given the challenges of hydrogen transportation, green iron production is likely to be situated near green hydrogen facilities.

Cost-competitive green hydrogen production will require access to abundant, low-cost renewable energy. This will create a new steel supply chain - green iron production will gravitate toward renewable energy hubs and steel finishing will remain in areas with competitive labour costs. Other prospective green iron pathways, even if they do not require green hydrogen, are expected to require abundant, low-cost renewable energy.

Source: CSIRO (2024) *How hydrogen can help decarbonise iron making;* RMI (2024) *Green Iron Corridors: Transforming Steel Supply Chains for a Sustainable Future;* Devlin et al. (2023) *Global green hydrogen-based steel opportunities surrounding high quality renewable energy and iron ore deposits;* Devlin and Yang (2022) *Regional supply chains for decarbonising steel: Energy efficiency and green premium mitigation;* Wood and Dundas (2020) *Start with Steel;* Mandala analysis.

Illustrative steel making process and 'green' potential[1]



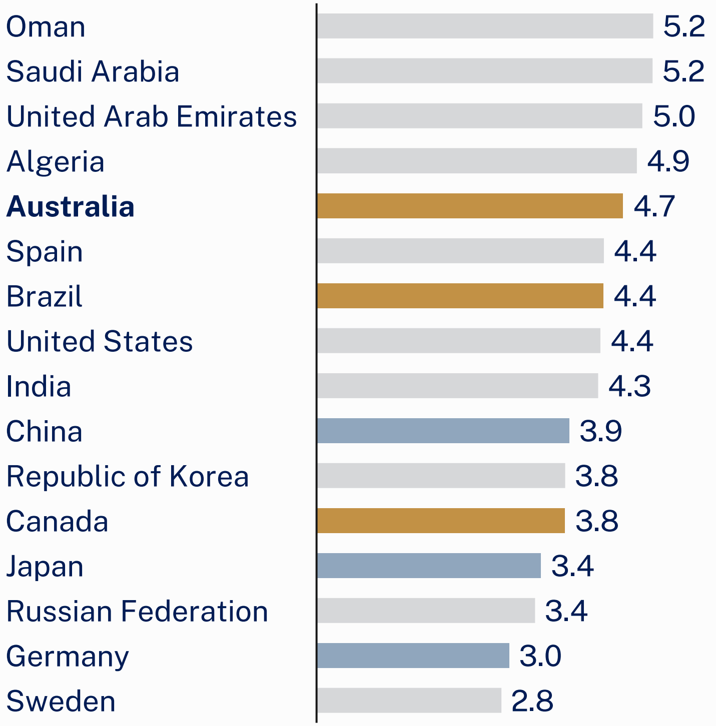
1 There are different processes that could be used to produce green steel; however, the most prospective option (presented above) is to use shaft furnaces powered by green hydrogen as discussed in Minerals Research Institute of WA (2023) *WA's Green Steel Opportunity.*
Source: Adapted from Minerals Research Institute of WA (2023) *WA's Green Steel* Opportunity and South Australia Department of Energy and Mining (2024) *Green Steel Supply Chain Analysis;* CSIRO (2024) *How hydrogen can help decarbonise iron making;* Mandala analysis.

Australia has the renewable energy capabilities to competitively produce green iron, particularly compared to other iron ore exporters and existing iron producers

Top 3 iron ore exporters[4] Top 3 iron and steel exporters[4]

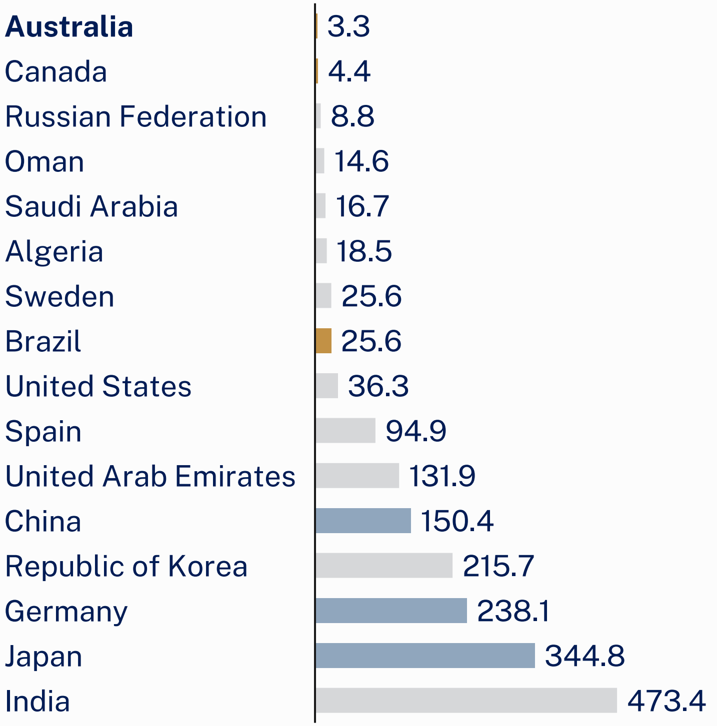
Potential power output for utility scale facility

PV power output, kWh/kWp/day, selected countries[1]



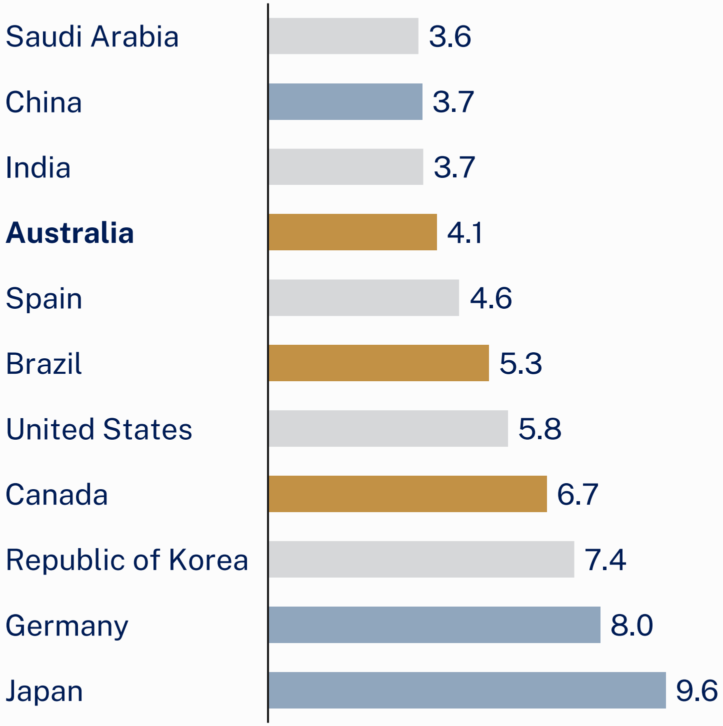
Land availability

People per square km, selected countries, 2021[2]



Levelised cost of energy for utility-scale solar

US cents/kWh, selected countries, 2022[3]



Australia has leading renewable potential

Australia has high land availability

Australia offers competitive energy costs

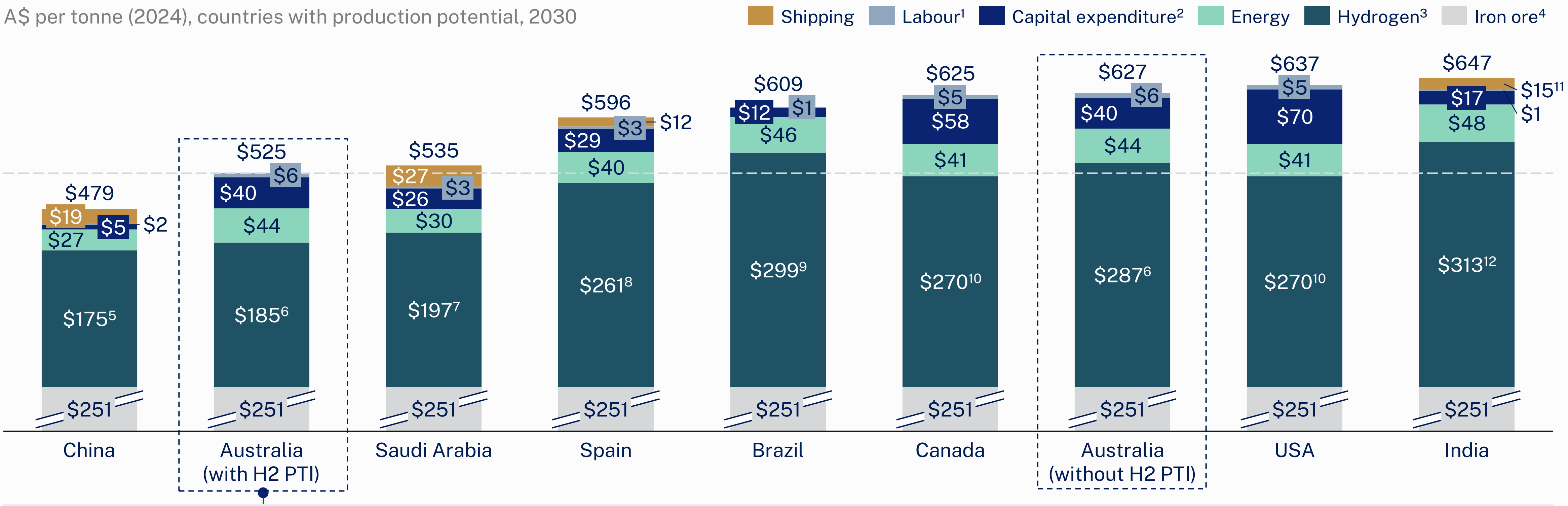
Note: Countries are selected for comparison if it has a domestic iron ore supply, is an existing iron producer or has public commitments to developing a domestic green iron industry. Country not shown if data not available. Sweden does not have LCOE data available for a utility-scale solar comparison, but has achieved an LCOE for commissioned onshore wind projects of 3.7 US cents / kWh: IRENA (2023) *Renewable Power Generation Costs in 2022.*

1 World Bank and Solargis (2020) *Global Photovoltaic Power Potential Study*: Practical PV Potential Level 1 - Photovoltaic power output of a PV system (specific yield); in this case, the long-term power output produced by a utility-scale installation of monofacial modules fixed mounted at an optimum tilt, measured in kWh/kWp/day (excluding land with identifiable physical obstacles to utility scale plants). 2 World Bank (2024) *World Development Indicators*. 3 IRENA (2023) *Renewable Power Generation Costs in 2022*. 4 Observatory of Economic Complexity (2023) *Product data*.

The proposed hydrogen production tax incentive (PTI) is forecast to make Australian green iron cost-competitive in 2030

Production cost per tonne of green iron by component

A$ per tonne (2024), countries with production potential, 2030



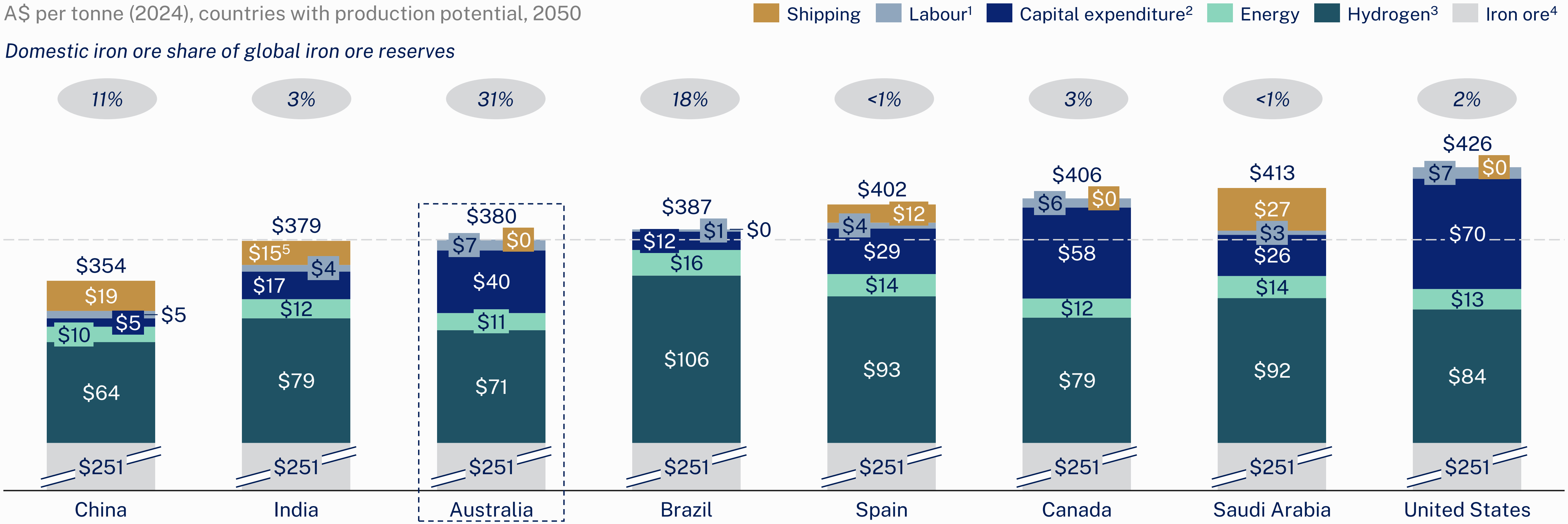
The hydrogen PTI is forecast to be an effective incentive for supporting Australia's cost competitiveness in clean export industries, however, this is not guaranteed and can change due to factors including speed of market entry and the scale up of renewable energy generation in Australia and other countries

Note: Countries with production potential were chosen based on long-term hydrogen costs (and renewable energy potential), the availability of iron ore, and whether the country has an existing iron/steel industry; 1 Based on wage for steel worker: Economic Research Institute (2024); 2 Based on capital expenditure for a green iron production facility in Australia: Wang, C. and Walsh, S. (2024), and cost of an advanced manufacturing facility: Turner and Townsend (2024). Numbers do not include capital expenditure on renewable energy; 3 Assumes adequate renewable energy to produce green hydrogen; 4 Based on average price of iron ore in the year to September 2024; 5 Transition Asia (2024); 6 Wang, C. and Walsh, S. (2024). PTI using a $2 incentive per kilogram of renewable hydrogen produced, between 1 July 2027 and 30 June 2040: Australian Tax Office (2024) *Hydrogen Production and Critical Minerals Tax Incentives;* 7 Alvarez & Marsal (2024); 8 Aurora Energy Research (2023); 9 Agora Energiewende (2024); 10 ICCT (2024); 11 While India has iron ore reserves, it is only sufficient to satisfy forecast domestic demand; 12 Wood Mackenzie (2024).
Source: Australian Tax Office (2024) *Hydrogen Production and Critical Minerals Tax Incentives*; Wang, C. and Walsh, S. (2024) *South Australian Green Iron Supply Chain Study;* Mandala analysis.

If renewable energy generation scales over the medium term, and costs decrease, Australia is forecast to continue to be cost-competitive in 2050

Production cost per tonne of green iron by component

A$ per tonne (2024), countries with production potential, 2050



Note: Countries with production potential were chosen based on long-term hydrogen costs (and renewable energy potential), the availability of iron ore, and whether the country has an existing iron/steel industry. Hydrogen PTI no longer in operation in Australia (ends 2040): Australian Tax Office (2024) *Hydrogen Production and Critical Minerals Tax Incentives.*
1 Based on estimated wage for a steel worker: Economic Research Institute (2024); 2 Based on estimated capital expenditure for a green iron production facility in Australia: Wang, C. and Walsh, S. (2024), augmented by cost of constructing advanced manufacturing facility: Turner and Townsend (2024). Numbers do not include capital expenditure on renewable energy; 3 Based on midpoint between 'optimistic' and 'pessimistic' cost scenarios for 2050: IRENA (2022). Assumes adequate availability of renewables to produce green hydrogen; 4 Based on the average price of iron ore in the year to September 2024; 5 While India has iron ore reserves, it is only sufficient to satisfy forecast domestic demand.
Source: IRENA (2022) *Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green hydrogen cost and potential;* USGS (2024) *Iron Ore*; Wang, C. and Walsh, S. (2024) *South Australian Green Iron Supply Chain Study;* Mandala analysis.

Australia is forecast to produce 20% of global green iron supply in 2050

Green iron is not currently available at a commercial scale, although announced production is 47Mt by 2030. Sweden has the most capacity announced to date, followed by Australia at 6Mt.[1] While these early investments will be critical to commercialising green iron technologies, demand will be determined by cost over the medium term. First mover countries who achieve the lowest cost of production will capture the majority of global demand.

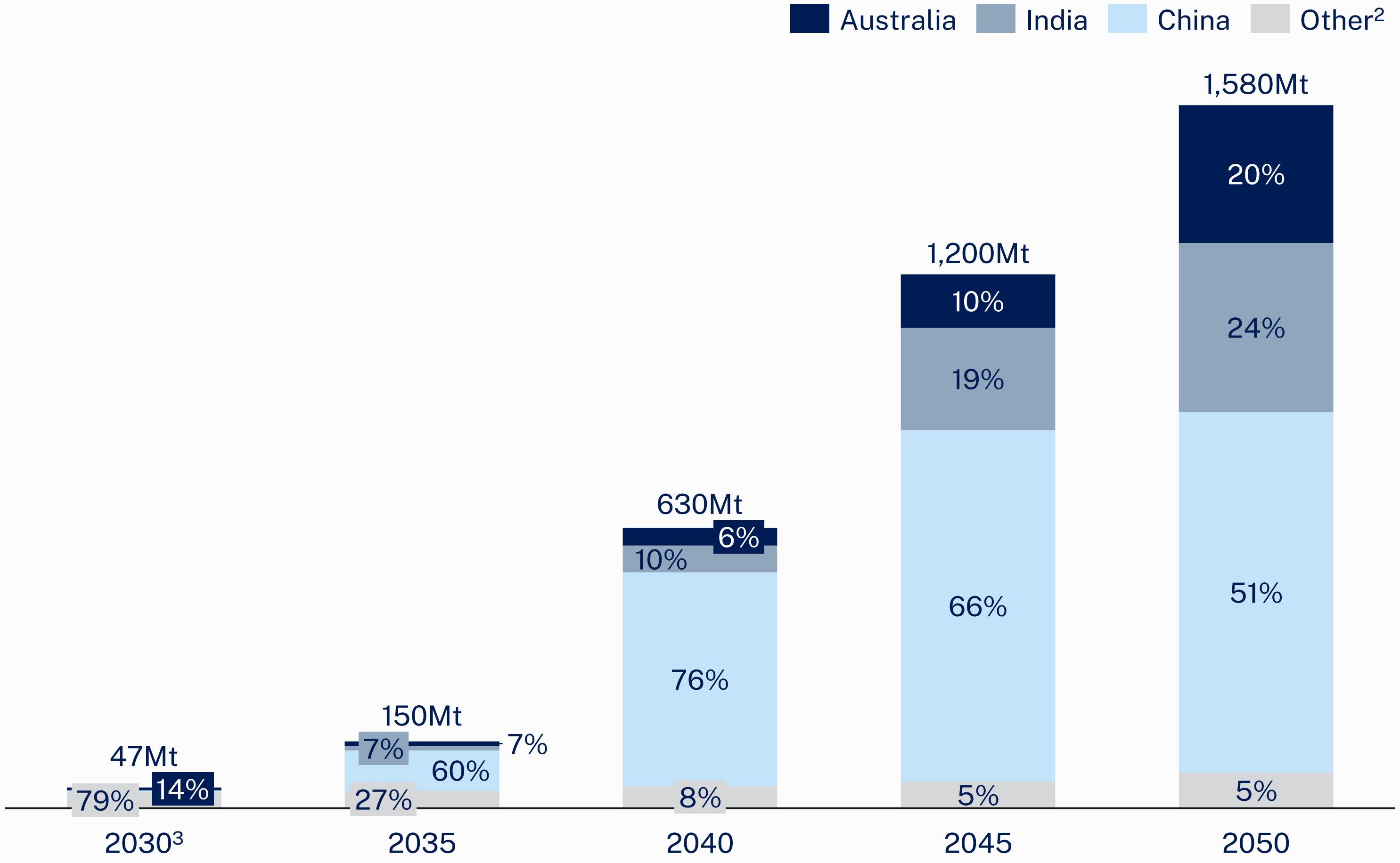
China is forecast to be the lowest cost producer. This is the result of China's ability to rapidly scale industrial outputs, including renewable energy generation. If China produces up to its maximum productive capacity, it is estimated to supply 810Mt of green iron in 2050, equivalent to 52% of global production.[2]

India and Australia have similar cost profiles in 2050. In this scenario, it is estimated that India will utilise domestic ore to produce green iron for its domestic steel industry but is unlikely to export. In this case, India would produce 380Mt of green iron in 2050 (24% of global production). If Australia can scale its renewable energy and green iron capacity to maintain forecast cost-competitiveness, Australia could capture 310Mt of global green iron production in 2050 (20% of global production).[3]

1 Agora Industry (2023) *Global Steel Transformation Tracker.* 2 As China's current steel production is plateauing, it is assumed China's current production capacity is the limit of China's industrial productive capacity. 3 Assumes importing countries do not place import restrictions on Australian green iron and other producers do not implement policies that reduce their per-unit cost of production.

Forecast green iron production by most cost-competitive countries[1]

Millions of tonnes (Mt), 2030-2050



1 Only most cost-competitive producers are shown. 2 Production assumed to be driven by domestic policy instead of competitiveness. 3 Based on announced projects: Agora Industry (2023) *Global Steel Transformation Tracker*. Source: Agora Industry (2023) *Global Steel Transformation Tracker;* Global Energy Monitor (2024) *Global Steel Plant Tracker, April 2024 (v1) release;* IEA (2023) *Steel and aluminium*; Mission Possible Partnership (2022) *Pathways to Net Zero*; Net Zero Industry (2024) *Net-Zero Steel Pathways;* Wood Mackenzie (2023) *Steel decarbonisation to redefine supply chains by 2050*; Zhou, T., Gosens, J., Xu, H. and Jotzo, F. (2022) *China's green steel plans*; Mandala analysis.

Australia's green iron contribution could have more impact than national net zero

Australia generates 1.2% of global emissions per year (465Mt out of 37,400Mt in 2023).[1] Australia, alongside all parties to the Paris Agreement, has legislated a target of net zero greenhouse gas emissions by 2050. However, with the development of clean export industries, Australia has the opportunity to contribute to global decarbonisation beyond domestic emissions reduction activities.

For example, the steel production value chain is highly emissions intensive, with steel generating between 6 to 9% of global CO_2 emissions (2,600Mt out of 37,400Mt in 2023).[2]

Ironmaking is the most emissions intensive component of steel production. The most common iron production method, using a blast furnace and basic oxygen furnace, generates up to 90% of total steel value chain emissions.[3]

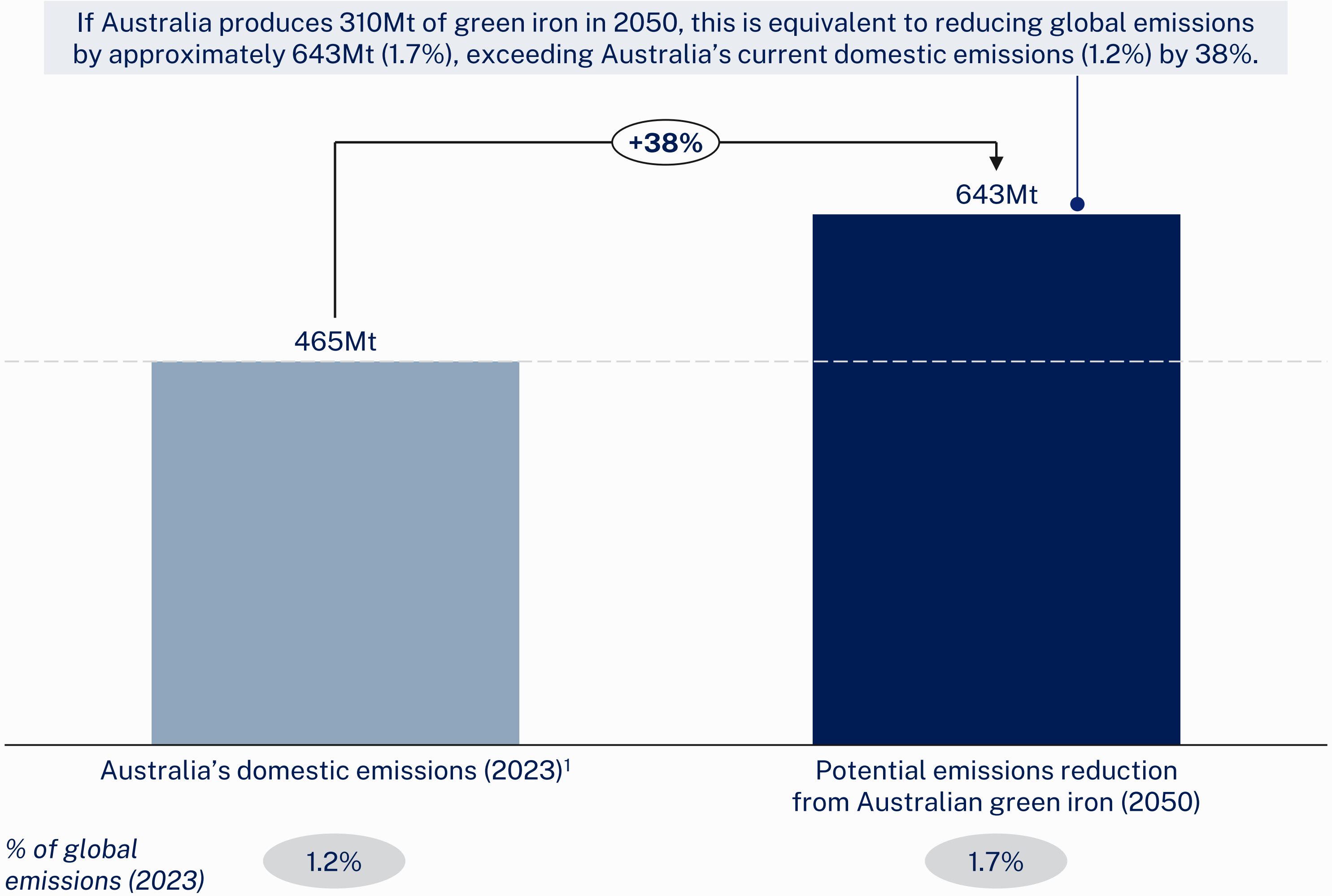
If Australia reaches its green iron potential and exports 310Mt of green iron in 2050, replacing conventional steel production, this is equivalent to reducing global steel emissions by approximately 643Mt (1.7% of global emissions in 2023).[4]

In this scenario, an Australian green iron industry would contribute more to global decarbonisation efforts than reaching national net zero by 2050.

Source: 1 Department of Climate Change, Energy, the Environment and Water (2023) *Australia's Emissions Projections: Baseline scenario for 2023*; IEA (2024) *CO2 Emissions in 2023*. 2 IEA (2020), *Iron and Steel Technology Roadmap;* McKinsey (2020) *Decarbonization challenge for steel.* 3 Minerals Research Institute of Western Australia (2023) *Western Australia's Green Steel Opportunity*. 4 World Steel Association (2023) *Sustainability indicators 2023;* Mandala analysis.

Comparison of annual emissions by source

Annual Mt CO_2 emissions in Australia and potential reduction from modelled green iron production in 2050

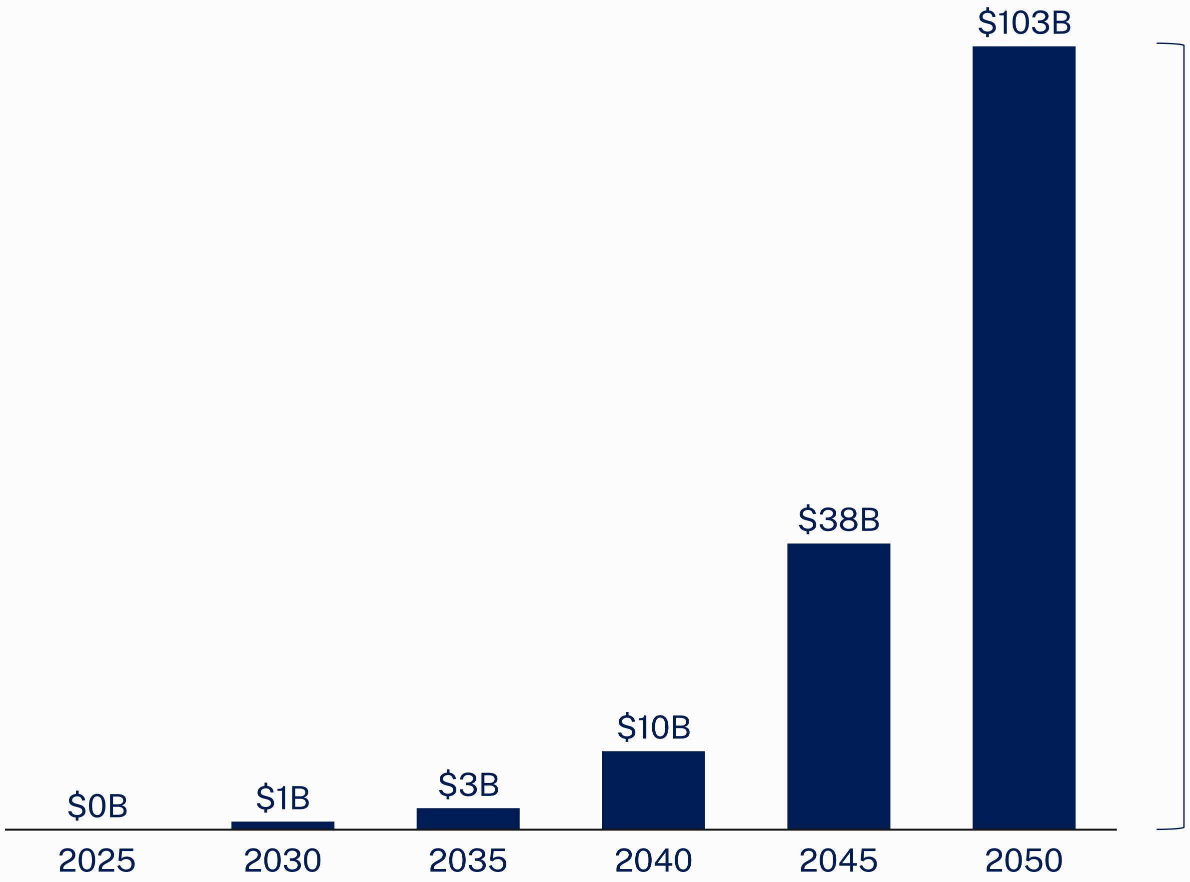


Note: Potential emissions reduction assumes Australian green iron production replaces blast furnace iron production (most common ironmaking production method).

Australia's green iron industry would add $103 billion to the economy in 2050 and support 27,500 direct jobs

Forecast economic contributions of a domestic green iron industry

Annual economic contributions, 2025 to 2050



CONTRIBUTIONS FROM GREEN IRON

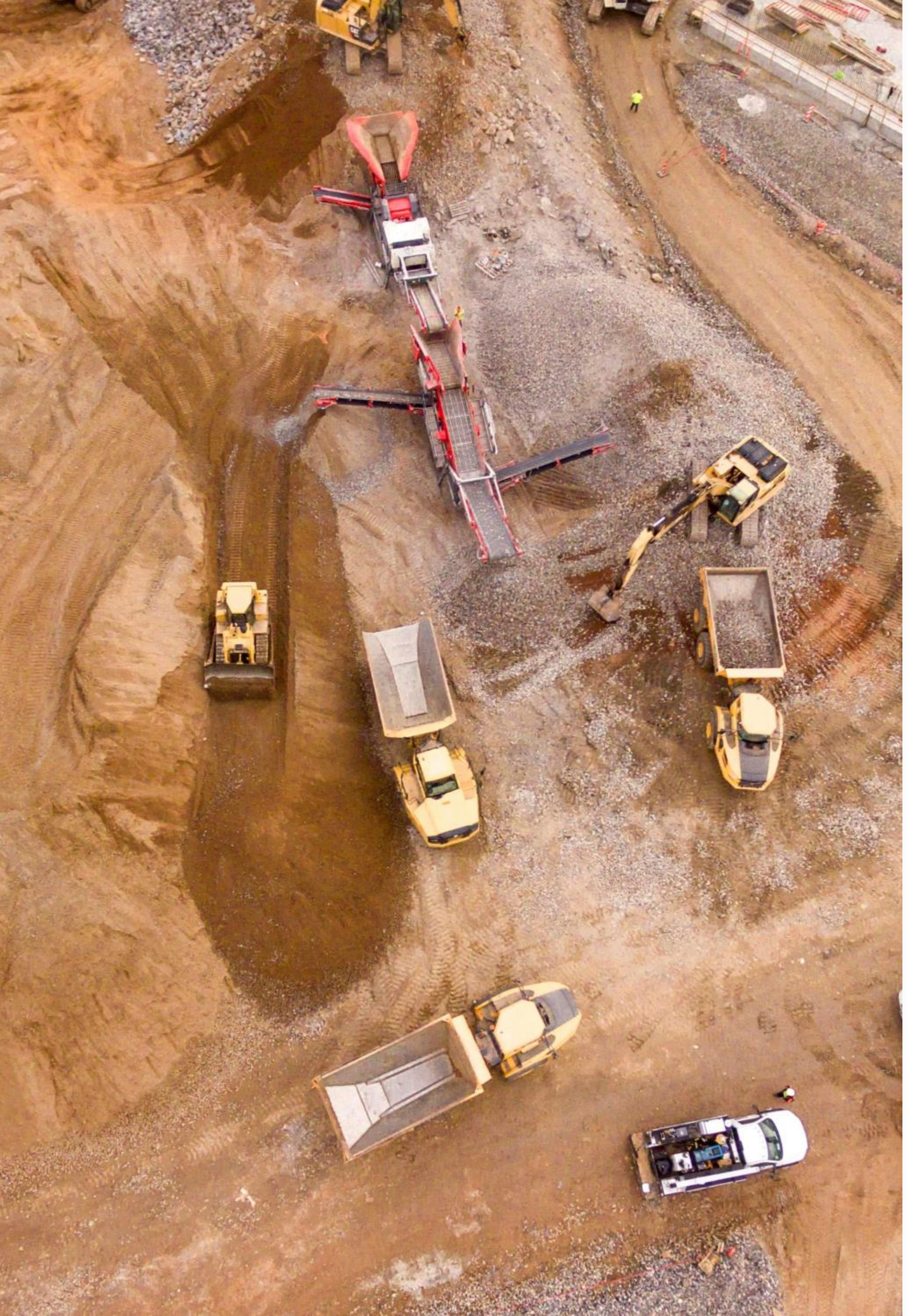
$103 billion in economic contribution in 2050 from green iron, with an average of $25.7 billion per annum from 2030 to 2050

This is 5.7 times the size of Australia's current aluminium industry ($18 billion in economic contribution)[1]

27,500 ongoing direct jobs supported in 2050, in a green industry

This is compared to 20,700 jobs supported by Australia's current aluminium industry[1]

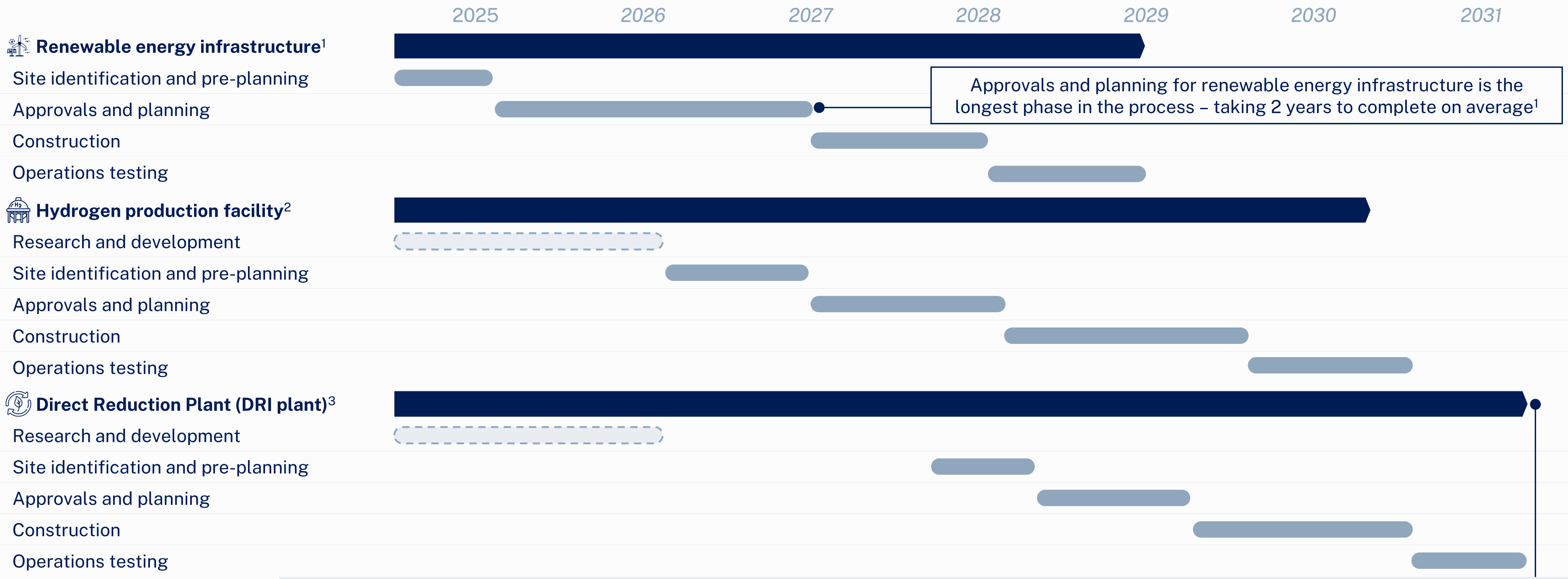
1 Includes bauxite mining, alumina refining, aluminium smelting, and aluminium extrusion.
Source: Australian Aluminium Council (2024) *Economic contribution of the Australian Aluminium Industry;* Mandala analysis.



It could take at least six years for a green iron plant to reach production in Australia based on current development timelines

Illustrative project development timeline for green iron and enabling infrastructure

Indicates new technology development (timeline uncertain)



Green iron production is reliant on renewable energy generation and, most likely, green hydrogen production. Based on current timelines, renewable energy projects commenced in 2025 will be operational in 2029 and, with concurrent infrastructure development, enable green iron production in 2031.

1 Infrastructure includes a solar and wind farm. Timeline of renewable infrastructure is informed by ANU (2024) *Renewable projects are getting built faster – but there's even more need for speed* and Clean Energy Investor Group (2022) *Delivering major clean energy projects in NSW*. 2 Timeline of hydrogen production facility is informed by Fortescue (2024) *Fortescue officially opens Gladstone Electrolyser Facility*. 3 DRI plant timeline is informed by Queensland Government (2024) *Going green in Gladstone* and Green Steel WA (2024) *About us.*
Source: Austrade (2024) *Australia forges a future made from green steel*; Mandala analysis.

The feasibility of green iron technologies and the scale of infrastructure investment are major barriers to green iron industry development in the short term

Key barriers to green iron production by industry development phase

Industry development phase (indicative timeline)

Barrier	Description	**Investment** (to 2030)	**Scale up** (to 2040)	**Operational** (to 2050+)
1 **Feasibility**	Green iron technologies, including green hydrogen and iron production, are in early development phases – from research and development (R&D) to pilot plants	✓		
2 **Scale**	Green iron production will require unprecedented investment in renewable energy generation and industrial infrastructure	✓	✓	
3 **Cost competitiveness**	Australia's green iron competitiveness is not guaranteed, and demand for green iron is unlikely to accelerate until it is cost competitive with conventional steel	✓	✓	
4 **International supply chain development**	The steel supply chain will need to adjust to accommodate new trade pathways between producers, exporters and importers		✓	✓

Urgent priority (Investment phase)

Notes: Non-exhaustive, includes major barriers only. In the current environment, Australia is forecast to be a cost competitive producer of green iron in 2030, as a result of the proposed hydrogen production tax incentive, and in 2050. If Australia's competitive position changes due to new policy developments in competitor countries, or faster scale up of renewable energy generation capabilities, Australia may lose this competitive advantage.
Source: Mandala analysis.

Green iron technologies are in early development phases – from R&D to pilot plants

Australian industry are investing in novel green iron technologies which are currently in the early R&D and pilot phases of development. These technologies include the ability to produce green hydrogen at scale, the ability to produce green iron at scale, and the ability to process Australian hematite ore to be suitable for green iron production.

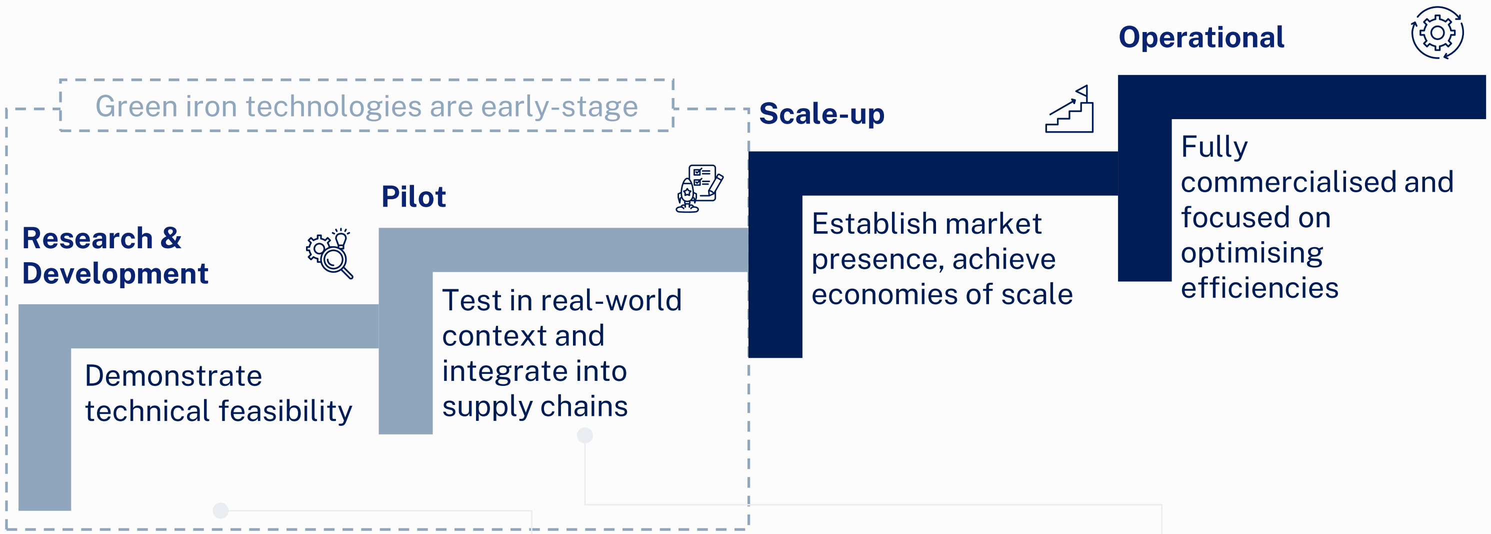
While Australia is consistently recognised for its leading research capabilities, and substantial industry investment into green iron technologies, the domestic commercialisation landscape is challenging.

Moving from R&D and pilot phases to full-scale operations presents several challenges for private companies, including the high capital requirements to scale production and the high-risk profile of novel technologies. This high-risk profile can also make it difficult to attract capital and financing for longer-term projects, given the uncertainty of investment returns and despite the medium-term opportunity for Australian green iron.

Increasing the opportunities for research institutions and industry to collaborate on new green iron technology projects is also more likely to accelerate the development of practical technologies.

Sources: Institute for Energy Economics and Financial Analysis (2023) *Australia faces growing green iron competition from overseas*; Industry Innovation and Science Australia (2023) *Barriers to collaboration and commercialisation*; Industry Innovation and Science Australia (2024) *Barriers to collaboration and commercialisation.*

Example Australian green iron technologies by technology development phase



Example project	CSIRO low temperature agglomeration process for Australian iron ores	BHP, RioTinto, BlueScope ironmaking Electric Smelting Furnace
Phase	R&D	Pilot
Description	CSIRO are developing a better way to prepare Australian iron ores for green ironmaking. The new method, called the Lime Magnetite Pellet (LMP) process, can bind iron ore particles together using less heat than traditional methods while still creating pellets that are strong enough for use in furnaces.	BHP, RioTinto and BlueScope are building Australia's first electric smelting furnace. The project will use WA iron ore to produce Direct Reduced Iron (DRI) by adding an electric smelting furnace to existing technologies. The companies are determining the test facility site, based on workers, infrastructure, and supply chains.

Source: Climate Change Authority (2023) *Sector Pathways Review.*

Green iron production will need 16TWh of renewables by 2030 and 775TWh by 2050

Green iron production will require a large scale-up of Australia's renewable energy generation in addition to planned renewable energy investments.

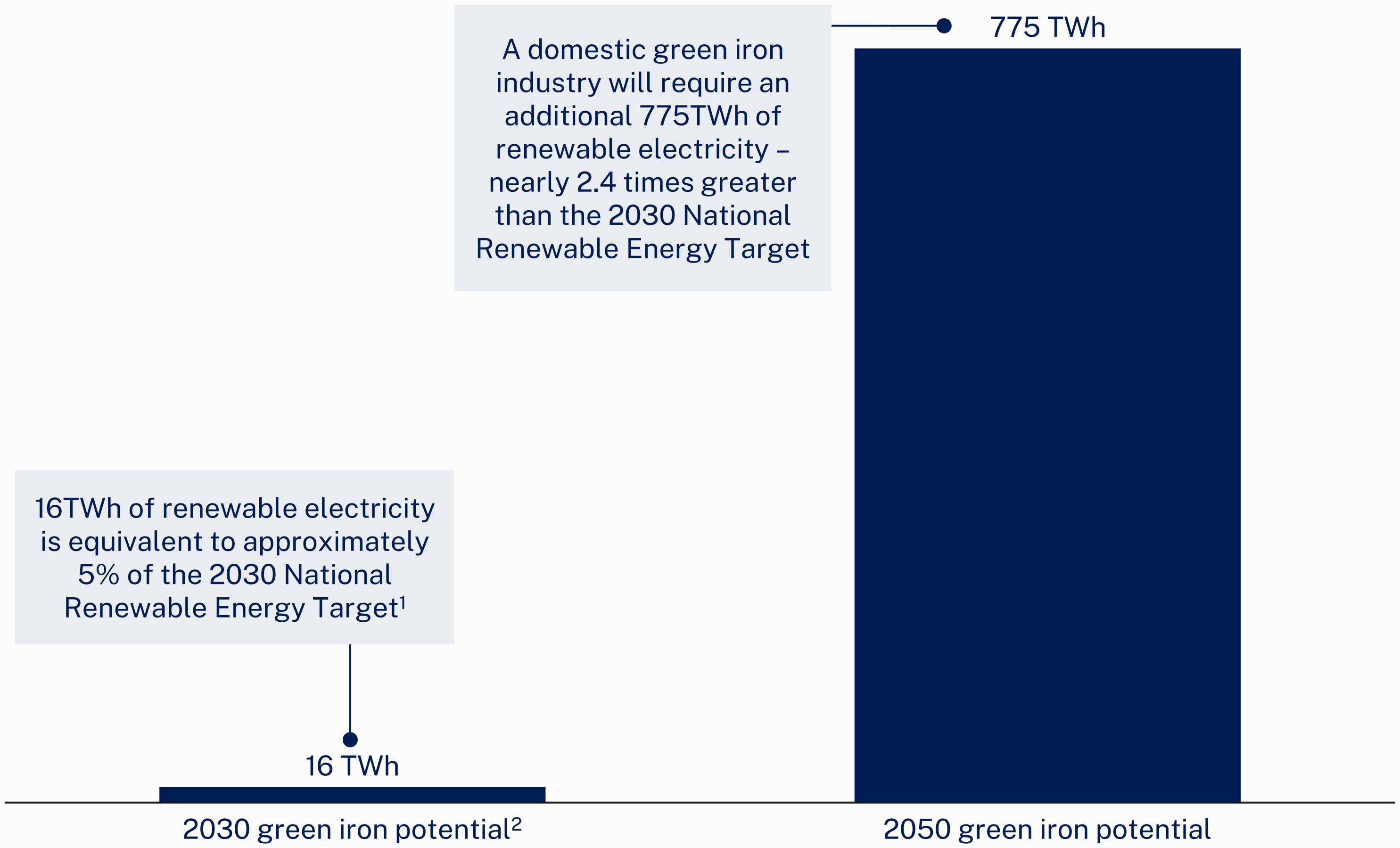
To produce Australia's 2030 supply potential (6.3 Mtpa of green iron or 20% of global green iron production), over 16TWh of additional renewable electricity will be required. This is equivalent to approximately 5% of the National Renewable Energy Target for 2030. Over 90% of the electricity forecast to be required to make green iron is used in the production of green hydrogen, where electrolysis of water is key component in the production process, while the remaining portion is used for direct iron ore heating. Australian companies have developed some of the most efficient hydrogen electrolysers in the world.

Reaching Australia's 2050 green iron supply potential (310 Mtpa of green iron or 20% of global green iron production) will require a further step-change in Australia's renewable energy generation capacity. The industry will require 775TWh of additional renewable electricity by 2050 – nearly 2.4 times greater than the 2030 National Renewable Energy Target. This investment can support the broader transition to a renewable energy grid and accelerate the transition in industrial areas with low renewable energy capacity to date, including in Western Australia.

Sources: Department of Climate Change, Energy, the Environment and Water (2024) *Australian Energy Update 2024*; Clean Energy Australia; Clean Energy Council (2023) *Bridging the gap to 82% renewable electricity generation by 2030.*

Estimated electricity required to meet Australia's green iron potential

Terawatt hours (TWh), by year



[1]The 2030 Renewable Energy Target is taken as the level of national renewable energy generation in 2023, with a 33TWh increase each year to 2030.
[2]Assumed that 2030 potential supply is 6.3 Mtpa and 2050 supply is 310 Mtpa.
Sources: Department of Climate Change, Energy, the Environment and Water (2024) *Australian Energy Update 2024*; Clean Energy Australia; Clean Energy Council (2023) *Bridging the gap to 82% renewable electricity generation by 2030*; Mandala Analysis.

$28.8B of investment will be required by 2030 to kick-start green iron production

Green iron production is highly capital intensive and will require integrated infrastructure development. This includes production plants, hydrogen facilities, renewable energy generation, transmission and storage.

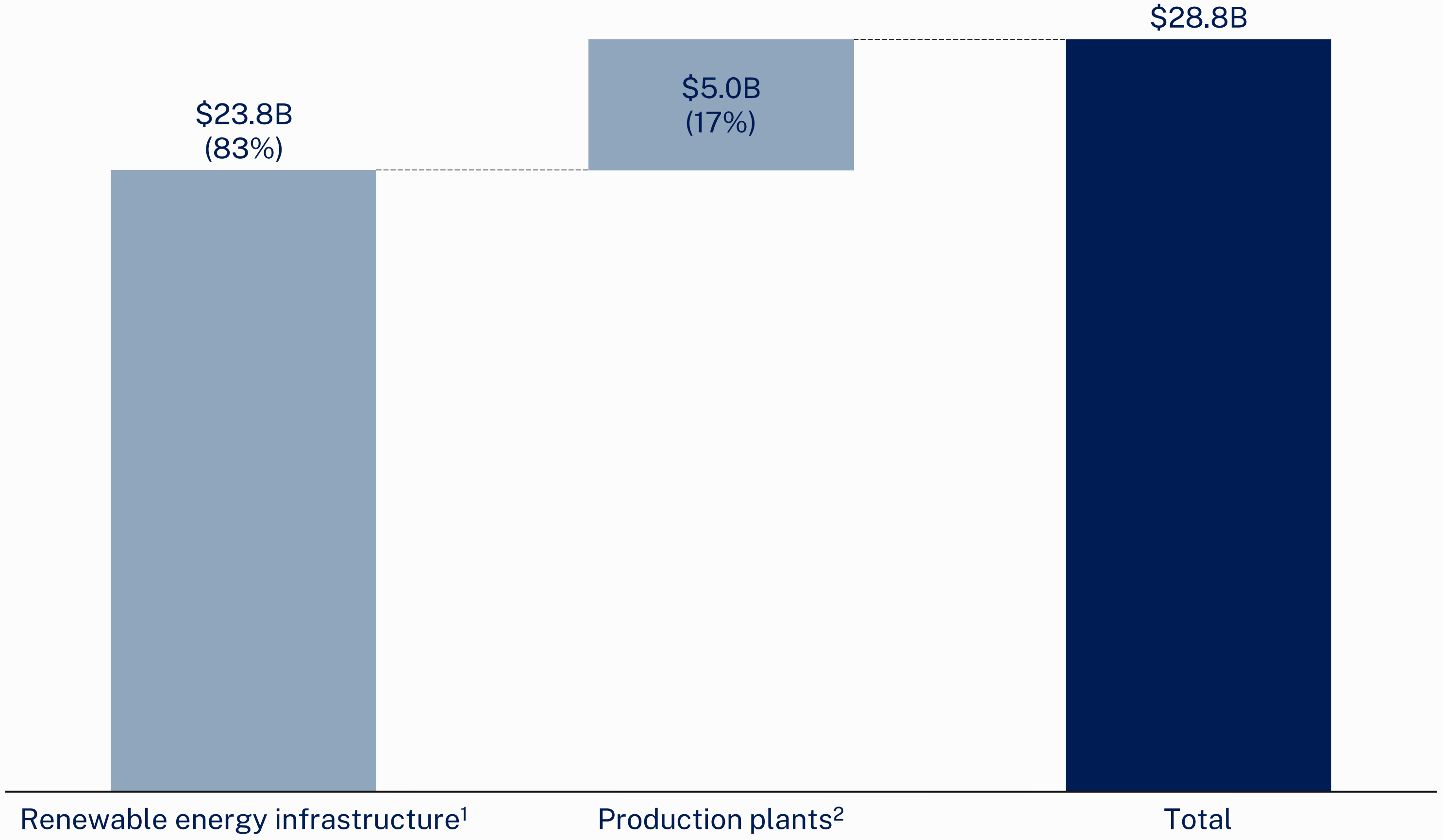
Australia's 2030 green iron potential (6.3 Mtpa of green iron or 66% of global green iron demand) is estimated to require approximately $28.8 billion in capital expenditure. This is greater than the total Australian investment in renewables in 2023 ($21 billion).[2]

Most of this investment (83%) is required to build the supporting renewable energy infrastructure. Delays in renewable energy projects will have flow-on effects for production facility development, increasing the risk of production facility investments. The approvals and planning process for renewable energy infrastructure is the longest phase in the green iron development process – taking 2 years to complete on average.[3]

This infrastructure will need to be co-located to avoid hydrogen transportation challenges and reduce overall transportation and transmission costs. This introduces a notable coordination challenge between industry and government to ensure that assets are constructed in sequence to avoid any flow-on effects from delays and can achieve the economies of scale required to be viable – potentially through common user infrastructure and multiple offtake agreements.

Indicative capital costs for Australia to produce forecast green iron supply in 2030

$B, by capital expenditure item



Note: Assumed that 2030 potential supply is 6.3 Mtpa.
1 Assumes a 50/50 mix of wind and solar energy. 2 Hot Briquetted Iron (HBI) production plant, including hydrogen facilities. 3 ANU (2024) *Renewable projects are getting built faster – but there's even more need for speed* and Clean Energy Investor Group (2022) *Delivering major clean energy projects in NSW*.
Source: Mandala analysis of Minerals Research Institute of WA (2023) *Western Australia's Green Steel Opportunity Report* and Wang and Walsh (2024) *South Australian Green Iron Supply Chain Study*.

Demand for green iron is unlikely to accelerate until it is cost-competitive

Green steel is forecast to cost 20-50% more than conventional steel in the short term due to the higher costs of new technologies, and the lack of a carbon price. Demand for green steel is unlikely to accelerate until it is cost-competitive with conventional steel.

The higher costs associated with green iron include higher costs from developing green hydrogen, necessary expansions to renewable energy generation, especially in remote regions, and the additional R&D spending required to develop, realise and commercialise new technologies.

While this cost premium is significant in the short term, it is forecast to decrease rapidly as green iron, and green steel, production scales. For example, the impact of green steel on the final price of a car has been estimated to be just 1%.[1]

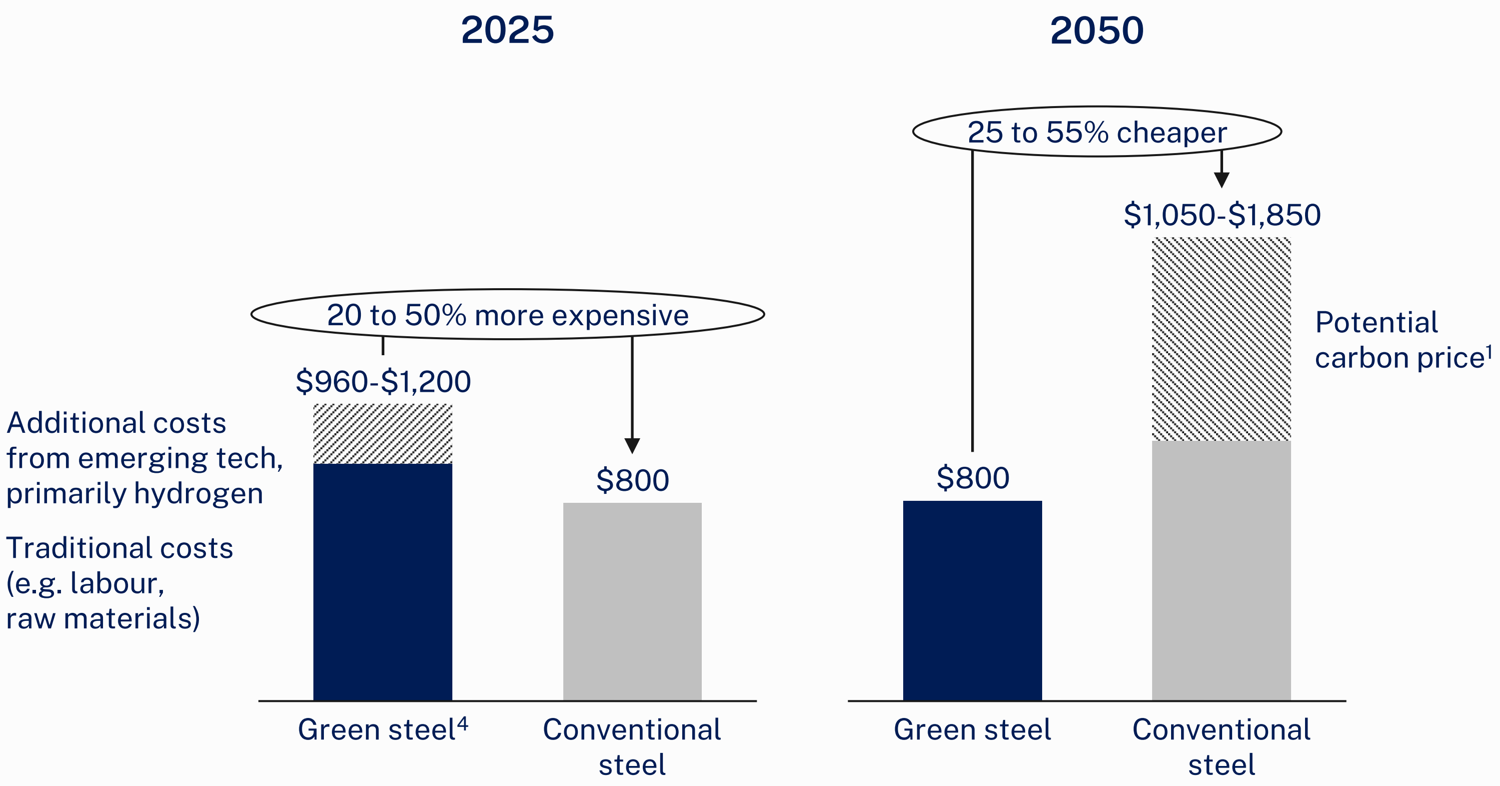
The green premium for green iron is significant in the short term. However, the EU's rising carbon price is expected to begin closing the price gap between conventional and green steel from 2026 onwards and other countries are beginning to follow suit.[2] China is expected to measure carbon intensity by 2027, and the United Kingdom and Turkey have indicated interest in developing their own carbon price.[3]

Source: 1 ICCT (2024) *Major automakers in the red when it comes to using green steel*. 2 The EU carbon price is expected to commence in 2026 and is projected to rise over time. A range of estimates vary; for example $240/kg of CO2 by 2030 and $812/kg of CO2 by 2050; VanEck, Bloomberg NEF. 3 S&P Global (2024) *EU'S CBAM to spur other countries to introduce carbon border levies: IETA.*

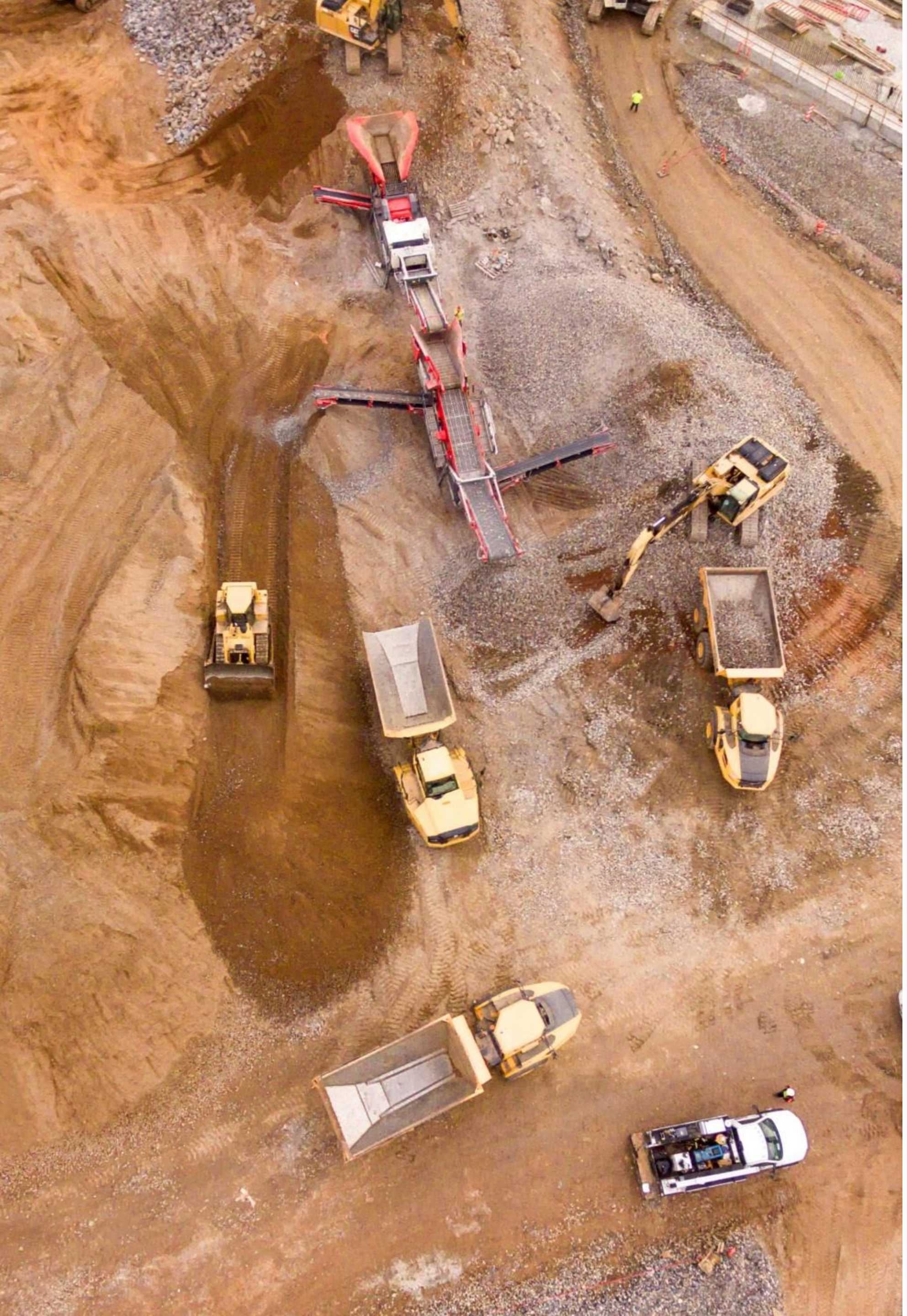
Price premium of green steel compared to conventional steel

$, levelised cost of steel, crude steel

By 2050, the cost of green steel production technology is expected to fall steeply, primarily due to falling hydrogen costs, whilst carbon prices are expected to be introduced and grow steeply.



4 Assumes a hydrogen price of US$5/kg, falling to US$1/kg.
Source: Bloomberg NEF (2024) *EU ETS Market Outlook 1H 2024: Prices Valley Before Rally*, Global Efficiency Intelligence (2024) *Green Steel Economics*, VanEck Australia (2024) *An EU carbon price by 2040?*; Mandala Analysis.



Policy support is best directed at feasibility and scale in the immediate term

Despite Australia's natural advantages, commercialising green iron technologies, access to capital and coordination between industry and government are immediate barriers to industry development. These are common challenges for new technologies but also reflect the major investment required in renewable infrastructure.

Policy support options include targeted grant programs for green iron technologies and increased coverage of R&D incentives to support commercialisation activities. Investment incentives for renewable energy infrastructure and priority approval pathways will also be necessary to de-risk private investment. Existing mechanisms, such as the National Reconstruction Fund, could effectively be directed to green iron and enabling infrastructure to efficiently address short term capital challenges.

Cost competitiveness will be a persistent challenge during scale up – between green iron and substitute products and between Australia and other potential producers. Australia's forecast competitiveness is reliant on realising renewable energy generation at scale and does not account for future interventions made by other countries. As the industry scales, production incentives may be increasingly necessary to ensure Australia capitalises on our natural advantages.

Additional support will be required as the industry scales. This could include facilitating trade partnerships with green iron importers and broadening an accreditation scheme for green exports.

Potential policy options to further develop the green iron industry in Australia

Urgent priority | Short term priority

BARRIER	POTENTIAL SOLUTIONS	Priority
Feasibility	Co-fund commercial-scale trials and pilot projects	Urgent priority
	Increase R&D tax incentive	Urgent priority
Scale	Investment tax incentives for renewable energy	Urgent priority
	Designated green iron precincts	Urgent priority
	Streamlined and accelerated project approvals	Urgent priority
	New Renewable Energy Zones	Urgent priority
	Accelerated asset depreciation	Short term priority
	Education and training	Short term priority
International supply chain development	International R&D partnerships	Urgent priority
	Guarantee of origin scheme for green iron	Short term priority
	Offtake agreements	Short term priority
Cost competitiveness	Production tax incentives	Short term priority
	Market development	Short term priority

Source: Mandala analysis.

Suggested policy initiatives to address urgent development barriers focus on technology feasibility and enabling investment at scale

INITIATIVE	SUMMARY OF RECOMMENDATION	BARRIERS ADDRESSED
Co-fund commercial-scale trials and pilot projects using Australian ore	• Introduce additional grant funding rounds targeting commercialisation of green iron technologies, building on recent ARENA programs for hydrogen and green iron / steel	• High costs of research and development and proving feasibility of technologies
Increase R&D tax incentives	• Increase coverage of the Research & Development Tax Incentive (RDTI) to incorporate the research and prefeasibility phases through to larger-scale commercialisation phases, particularly for green iron or enabling technologies (such as green hydrogen or renewable technologies)	• High risk of early-stage technology investment prevents private and public companies from investing in technology development
Introduce investment tax incentives for renewable energy	• Introduce an investment tax credit to offset a percentage of investment costs associated with large-scale renewable energy generation • The incentive will maintain Australia's cost competitiveness in the short and medium term, where capital costs were relatively high compared to other countries	• Burden of upfront capital expenditure with slow rates of return (due to long timelines for return on investment), and unlock first input to green iron (renewable energy)
Establish designated green iron precincts	• Identify green iron precincts that are eligible for additional support including coordinating the co-location of infrastructure, community consultation, and 'priority' approvals processes (alongside establishing additional Renewable Energy Zones)	• Green iron production is dependent on major inputs including renewable energy and hydrogen • Co-locating energy generation, hydrogen and production
Establish additional Renewable Energy Zones	• Identify and establish additional Renewable Energy Zones (REZs) in prospective green iron production areas (likely WA and SA)	• Substantial scale of low-cost renewable energy required
Streamline and accelerate project approvals	• Ensure proposed 'Front Door' (in consultation) applies to green iron projects • Clarify approval requirements across federal and state government • Develop 'priority' system for designated precincts (above)	• Lengthy project assessment timelines lead to costly delays • Assessment process can be disjointed across federal and state governments developing environmental reforms
International R&D partnerships	• Support industry (through funding and agency networks) to collaborate with overseas companies and research institutions – leveraging existing partnerships for green hydrogen	• Need to quickly prove feasibility of green iron technology and supporting technologies

Source: CSIRO (2024) *International partnerships in the mineral world*, CEDA (2024) *Clean Energy Precincts*, ARENA (2024) *Transformative Research Accelerating Commercialisation*, CME (2024) *Green Metals Consultation Paper*, Treasury (2016) *Tax Laws Amendment*, Treasury (2024) *'Front Door' consultation.*

Foreign investment has previously played a pivotal role in unlocking investment and driving growth and productivity in Australia's biggest industries

Case studies of foreign investments advancing Australia's key industries

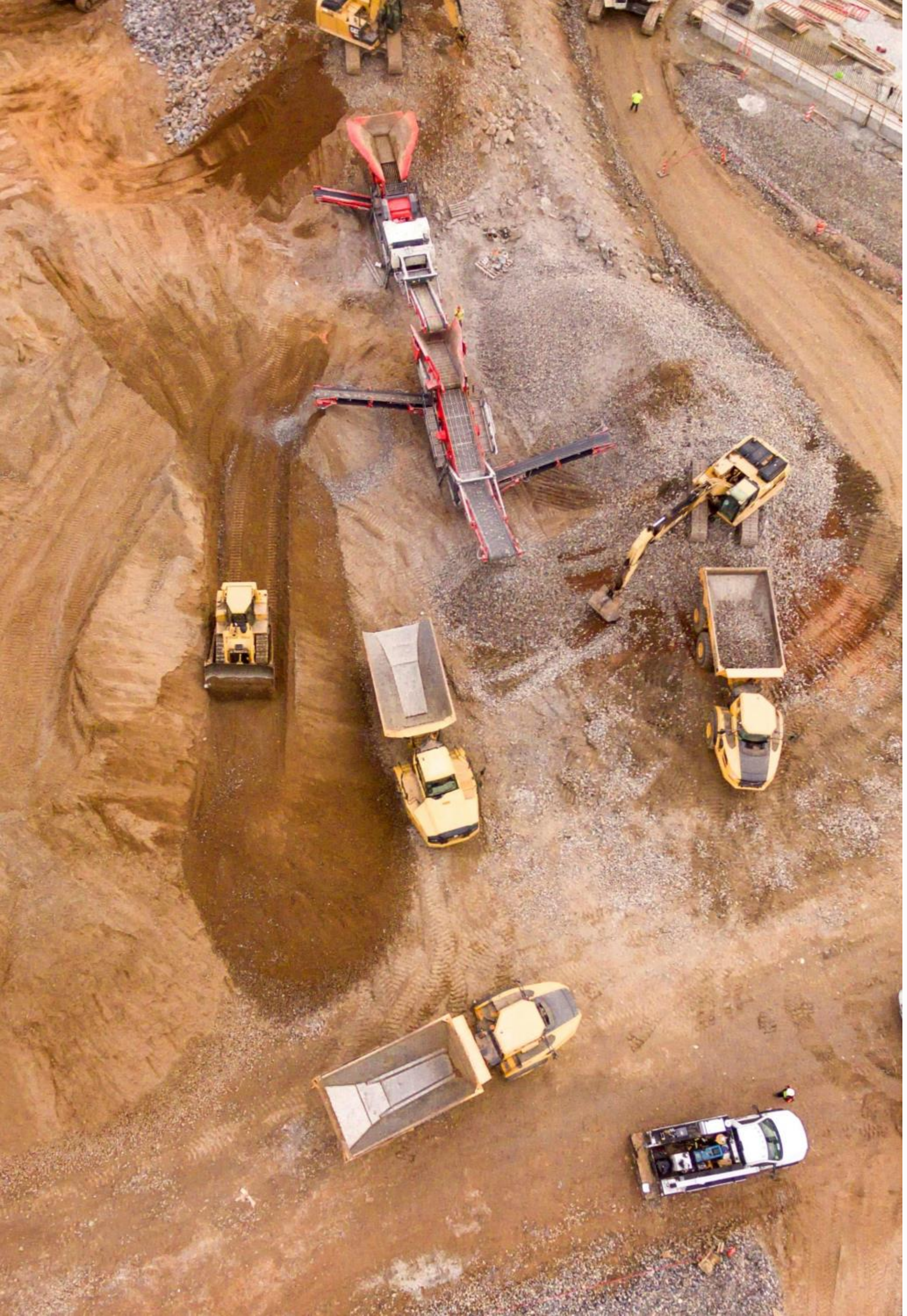
BHP Mitsubishi Alliance (BMA)	Tomago Aluminium	Gladstone Liquefied Natural Gas Project (GLNG)	South Australia's Hornsdale Power Reserve
MINING	ALUMINIUM SMELTING	OIL AND GAS	RENEWABLE ENERGY
BMA is a joint venture between Australia's BHP Group and Japan's Mitsubishi Development. BMA operates five coal mines in Queensland's Bowen Basin. It is Australia's largest producer and supplier of seaborne metallurgical coal, holding a 30% share of the global steelmaking coal market. Mitsubishi's partnership contributed financial support and industry expertise, strengthening Australia's position in the global coal market.	Tomago Aluminium is a joint venture between Rio Tinto (UK-Australia), CSR (Australia), and Hydro Aluminium (Norway). Tomago is Australia's largest aluminium smelter, producing 37% of Australia's primary aluminium. 90% of its production is exported to the Asia-Pacific region. Hydro Aluminium's partnership contributed operational efficiency, expertise, and capital to Australia's aluminium industry.	The GLNG project is a joint venture involving Santos Ltd (Australia), PETRONAS (Malaysia), TotalEnergies (France), and KOGAS (South Korea). The project focuses on converting coal seam gas (CSG) into liquefied natural gas (LNG) for export. The facility has a design capacity of 7.8 million tonnes of LNG per year, accounting for 10% of Australia's total LNG capacity. PETROS, TotalEnergies, and KOGAS contributed to the project's operational capabilities and reinforced Australia as a leading LNG exporter.	French energy supplier, Neoen, owns and operates the Hornsdale Power Reserve (HPR) in South Australia – the world's first "big battery." HPR provides essential grid-support services, delivering over $150 million in market savings during its first two years of operation. In 2020, a 50MW expansion supported by Tesla (USA), further enhanced its ability to stabilise the grid. Neoen's expertise and investment was critical to developing and strengthening Australia's renewable energy infrastructure.

Source: BHP (2023) *BHP and BMA's Community Contribution Report Queensland*; Clean Energy Finance Corporation (2021) *SA big battery a game changer*; Mitsubishi Australia (n.d.) *Coal*; Mitsubishi Development (2021) *Steelmaking Coal*; Neoen (2019) *Neoen and Tesla to deliver Australia's most innovative battery*; Santos GNLG (2012); Santos GNLG (n.d.) *About us*; Tomago (n.d.) *Our Story*); Mandala analysis.

Short-term industry development will require government support with demand and supply-side interventions

INITIATIVE	SUMMARY OF RECOMMENDATION	BARRIERS ADDRESSED
Accelerated asset depreciation	• Apply accelerated depreciation provisions to green iron facilities and supporting infrastructure (including renewable energy generation)	• Reduce burden of upfront capital expenditure with slow rates of return (due to long timelines for return on investment) and unlock first input to green iron (renewable energy)
Education and training	• Forecast workforce demand in potential green iron locations and conduct a skills gap analysis • Develop location-specific skills pipelines including co-developing new training and education programs for clean energy industries • Fund additional apprenticeships in identified clean energy trades	• Ensure supply of green iron can meet forecast demand • Support new workers to start careers in sectors related to the Future Made in Australia agenda
Guarantee of Origin scheme for green iron	• Establish an agreed definition of 'green iron' which requires that iron is produced using renewable inputs only, such as renewable energy and renewable hydrogen • Expand the Guarantee of Origin Scheme for green hydrogen to incorporate standards for green iron production, with accelerated approvals for projects using accredited Australian green hydrogen	• Develop globally consistent 'green' standards to ensure level playing field for Australian industry
Offtake agreements	• Coordinate non-binding offtake agreements between prospective Australian green iron producers and first-mover green steel producers (green iron importers) • This can include reciprocal non-binding agreements between the Australian government and green steel producers to procure goods made with Australian green iron	• Uncertainty of demand during scale-up phase
Production tax incentive (PTI)	• Develop a production tax credit designed to maintain Australia's cost-competitiveness in green iron production • Production tax incentives for green iron should be additional to green hydrogen PTI to reflect additional capital expenditure and incremental cost of renewable energy in the production process	• Maintaining Australia's cost competitiveness compared to other countries in the short and medium term
Market development	• Continue ongoing activities related to the EU's Carbon Border Adjustment Mechanism and the Carbon Leakage Review	• Green iron's price premium compared to conventional iron in the short to medium term • Ensure level playing field for Australian industry

Source: Australian Taxation Office (2024) *Hydrogen Production and Critical Minerals Tax Incentives*; Australian Taxation Office (2024) *Backing business investment – accelerated depreciation;* Clean Energy Regulator (2024) *Guarantee of Origin*; OECD (2022); Jobs and Skills Australia (2023) *The Clean Energy Generation;* Mandala analysis.



Government support for the green iron industry clearly aligns with the Future Made in Australia National Interest Framework

	Criteria	Demonstrated	Notes
1 Priority industry	Identified as a priority sector ▪ Sustained comparative advantage ▪ Public investment is needed for the sector to make a significant contribution to emissions reduction at an efficient cost	✓	▪ Green metals and renewable hydrogen have been identified by Treasury as priority industries in the Net Zero Transformation Stream ▪ Comparative advantage (as potentially the most globally competitive producer after China) derived from renewable energy potential ▪ Decarbonising iron production will lower global emissions to a greater extent than reaching net zero domestically ▪ The scale of infrastructure, development of nascent technology and unpriced carbon make green iron costly
	Energy intensive and capable of reducing carbon emissions via renewable energy	✓	▪ Iron production highly emissions intensive (coal-based) and can be replaced with renewable hydrogen
	Output embodies low carbon emissions and can help contribute to decarbonisation economy	✓	▪ Steel fundamental to global (and domestic) economic growth and transformation, decarbonising iron production will lower global emissions to a greater extent than reaching net zero domestically
	Leverages Australia's highly skilled workforce, using technological improvements to reduce labour intensity	✓	▪ Existing highly skilled coal mining workforce requiring transition opportunities into similar roles
	Is able to achieve economies of scale in Australia	✓	▪ Australia is forecast to be a cost-competitive producer of green iron in 2030 and 2050 ▪ Australia can supply 20% of global green iron in 2050 (310Mt)
	Aligns with our international trading partners' current or future needs	✓	▪ Current steel producers unable to decarbonise production with limited renewable energy, and therefore renewable hydrogen, capacity
2 Policy approach	Failure of markets to price in externalities including emissions and positive externalities generated by early movers	✓	▪ Conventional steel does not have a carbon price ▪ Industry still in nascent phase with large opportunity for first-mover advantage
	Non-financial barriers e.g. uncertainty of approvals	✓	▪ Large scale renewable energy generation and industrial production processes
	Financial barriers e.g. high up-front capital costs, difference between low emissions product and emissions intensive competitor	✓	▪ High capital expenditure requirements ▪ Conventional steel does not have a carbon price
3 Community benefit	Investment in local communities, supply chains and skills		▪ Australia's green iron potential would add $103 billion to the economy and support 27,500 direct jobs in 2050
	Promotion of diverse workforces and secure jobs		

Potential destination markets for green iron will diversify Australia's exports

Primary steel production is forecast to diversify as production in developing markets offsets declining production in China and advanced economies.[1]

This diversification means a broader range of countries are likely to demand Australian green iron, especially compared to Australia's current iron ore trade flows (85% is exported to China).[2] As China is actively seeking to reduce reliance on Australian iron ore, these new green iron export markets could help offset any decrease in iron ore exports to China in the long run.[3]

Climate commitments in advanced economies such as Europe and Japan will be more likely to drive demand for green iron by these countries in the near term. However, these regions are forecast to see a decrease in primary steel production as they increasingly use scrap steel for production, leading to lower long-term demand for green iron in these regions.[1]

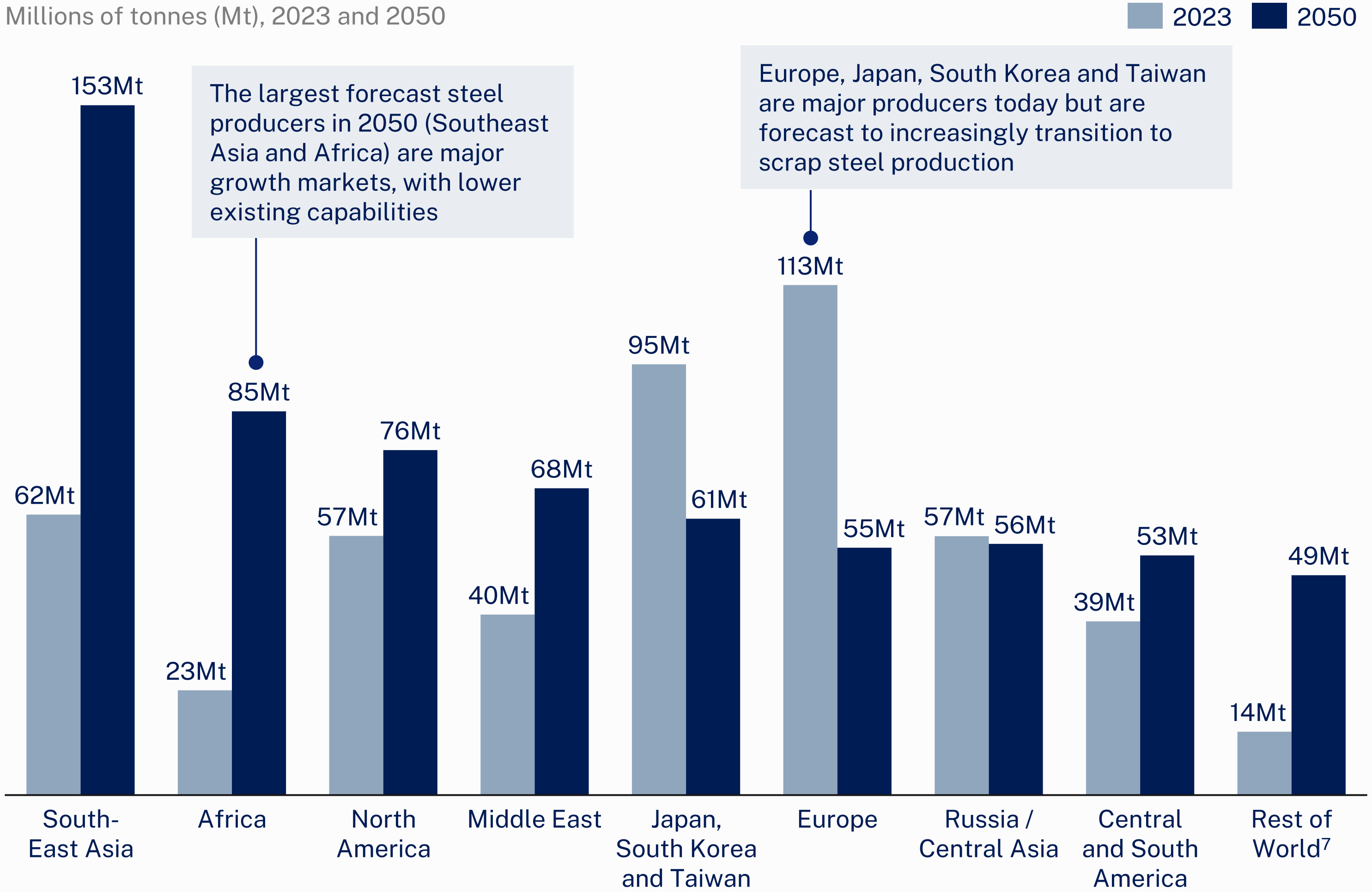
Almost all other regions are forecast to experience an increase in primary steel production by 2050. In particular, Southeast Asia and Africa are forecast to have the largest increase in primary steel production, driven by significant Chinese investment in the region,[4] and to encourage industrialisation.[5]

Australia's ability to supply these markets as a cost-competitive producer of green iron will drive demand for Australian product.

1 Mission Possible Partnership (2022) *Steel: Pathways to Net Zero.* 2 UN (2024) *Comtrade Database.* 3 Zhou, T., Gosens, J., Xu, H. and Jotzo, F. (2022) *China's green steel plans.* 4 Wood Mackenzie (2021) *Southeast Asia's steel surge: how will the region manage overcapacity?.* 5 Cabaro Group (2024) *Steel Production in Africa: Opportunities and Challenges.*

Primary steel production by potential green iron importers[6]

Millions of tonnes (Mt), 2023 and 2050

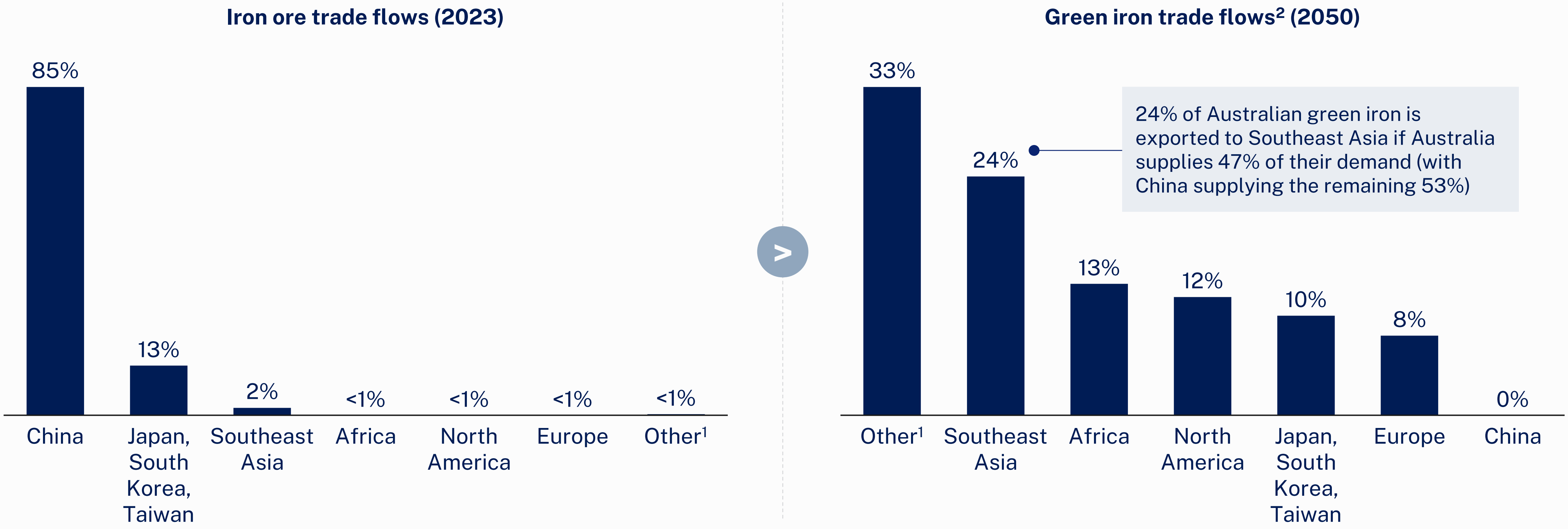


6 Forecast primary steel production in China and India is not shown as we assume these countries produce enough green iron to satisfy domestic demand in 2050. 7 Includes Oceania, Madagascar, Pakistan, Afghanistan, Mongolia and North Korea.
Source: IEA (2023) *Steel and aluminium*; Mission Possible Partnership (2022) *Pathways to Net Zero*; Net Zero Industry (2024) *Net-Zero Steel Pathways;* Wood Mackenzie (2023) *Steel decarbonisation to redefine supply chains by 2050;* Mandala analysis.

85% of Australia's iron ore exports go to China but the majority of Australia's green iron exports are likely to go to Southeast Asia and Africa

Australian exports by destination market

% of all exports, 2023 and 2050



1 Includes Central and South America, Russia and Central Asia, Middle East, Oceania, Madagascar, Pakistan, Afghanistan, Mongolia, and North Korea; 2 Percentages are calculated on the assumption that Australia supplies 47% of each importer's demand (with China supplying the remaining 53% of each importer's demand). We make this assumption because 47% of global green iron exports is exported by Australia. Combined with forecast steel production volumes in each region, the chart shows the share of Australia's green iron production that is exported to each region.

Source: IEA (2023) *Steel and aluminium*; Mission Possible Partnership (2022) *Pathways to Net Zero*; Net Zero Industry (2024) *Net-Zero Steel Pathways;* UN (2024) *Comtrade Database;* Wood Mackenzie (2023) *Steel decarbonisation to redefine supply chains by 2050;* Mandala analysis.

While capital for green projects has been increasing, regulatory restrictions and the risks associated with investing in new technologies continue to be barriers

Ease of accessing finance for infrastructure investment by source of finance

	DEBT FINANCING	EQUITY FINANCING	GOVERNMENT FUNDING AND INCENTIVES
Description	Debt finance involves borrowing funds from banks or issuing bonds to raise capital needed for large-scale projects.	Equity finance involves raising capital by selling shares or ownership stakes in an infrastructure project to investors.	Government funding includes direct investment, grants, subsidies, or financing through public-private partnerships (PPPs).
Key opportunities	• Banks and financial institutions are increasingly interested in financing projects aligned with environmental goals. • Around $13 billion of green bonds were issued in Australia in the first half of 2023 – the highest annual amount on record.[1]	• 59% of investors support the import of green iron as a practical solution in regions where renewable energy capacity is constrained.[2]	• Up to $3 billion of the National Reconstruction Fund (NRF) has been set aside to finance renewables and low-emissions technologies.[4] • The $1.7 billion Future Made in Australia Innovation Fund will fund the deployment of developing technologies and facilities linked to priority industries, including green metals.[5]
Key barriers	• Green iron projects typically require substantial upfront investments with uncertain longer-term returns. Around 50% of investors see cost as a key issue for green steel investment.[2] • Lengthy and complicated project approval processes can create regulatory and delivery risks. • Restrictive foreign investment approval processes can restrict and deter foreign investment. The Foreign Investment Review Board (FIRB) has also increased scrutiny on sensitive sectors such as critical infrastructure, minerals, and technology.[3] • Environmental standards and land use approvals can create project risks.		• Crowded and highly contested market for government funding for renewable projects. • Lack of certainty and stability in government's long-term climate and renewable energy policy.

1 RBA (2023) *Green and sustainable finance in Australia*. 2 Australasian Centre for Corporate Responsibility (2024) *Ahead of the game: investor sentiment on steel decarbonisation*. 3 Clifford Chance (2024) *Australian Foreign Investment review board (FIRB) policy focussed on a risk-based approach*. 4 Austrade (2024) *Australia forges a future made from green steel*. 5 Climate Change Authority (2024) *Sector Pathways Review*.

Source: Austrade (2024) *Australia forges a future made from green steel*; Australasian Centre for Corporate Responsibility (2024) *Ahead of the game: investor sentiment on steel decarbonsation*; Australian Government (2024) *Investments to position Australia as a world leader in green metals production*; Climate Change Authority (2024) *Sector Pathways Review*; RBA (2023) *Green and sustainable finance in Australia*; Mandala analysis.

Over the medium term, introducing green iron exports into the international steel supply chain will require certainty, integration and verification

Challenges to supply chain development for green iron exports

CERTAINTY	INTEGRATION	VERIFICATION
Producers of green steel, like green iron, are vulnerable to the uncertainties of developing an emerging product with uncertain supply and price	Countries aiming to transition to green steel must retrofit or replace existing steel facilities to integrate green iron into their supply chain	To be competitive in the green steel market, Australia must ensure that the green iron it produces is verifiably low in carbon emissions
Uncertainty of supply: As green iron production is still emerging; steel producers may find it difficult to source and select a green iron producer, and the producer may not be able to guarantee large quantitates and long-term supply.	**Transitioning steelmaking infrastructure**: Steelmaking companies in importing countries may have older, coal-dependent infrastructure that has not yet reached the end of its lifecycle. Importers must balance the cost of transitioning to green technologies against the financial burden of early-phasing out their existing infrastructure.	**Transparency and Verification**: Certifications for green credentials. No universally accepted system or set of global standards currently exists to verify the entire lifecycle emissions of green iron.
Uncertainty of price: Choosing a preferred supplier of green iron is challenging as prices are high and volatile. Emerging technology, comparative advantages, and costs of green iron supplying countries are dynamic – making choosing a frontrunner supplier challenging.	**Ensuring green energy infrastructure**: Similar to the large amounts of renewable energy required to produce green iron, producing green steel will call for large amounts of renewable energy. Importing countries will need to have invested in sufficient renewable energy to produce green steel.	**Supply Chain Traceability**: Achieving full transparency requires robust traceability mechanisms to track emissions across the supply chain. Capturing this data reliably will incur additional costs and may require further research to develop new methods.

Source: Mandala analysis.

We have categorised countries into three different ways they access green iron

Categorisation of countries by access to green iron

PRODUCERS

Description
- Countries that have a high potential to produce green iron and could export to other countries
- These countries have at least **two** of
  - Cheap renewable energy
  - Iron ore supply
  - Established iron/steel industry (or expressed interest in developing an iron/steel industry)
  - Government support

Countries
- China
- India
- Australia
- Canada
- US
- Brazil
- Middle East/North Africa
- Germany
- Spain
- Sweden

POTENTIAL PRODUCERS

Description
- Countries that have some potential to produce green iron and are indifferent between producing green iron for domestic use and importing it
- These countries have **one** of
  - Cheap renewable energy
  - Iron ore supply
  - Established iron/steel industry (or expressed interest in developing an iron/steel industry)
  - Government support

Countries
- Africa excluding North Africa
- Russia/Central Asia
- Rest of Europe
- Japan
- South Korea
- Taiwan

IMPORTERS

Description
- Countries that have little potential to produce green iron and will likely choose to import it
- These countries do not have
  - Cheap renewable energy
  - Iron ore supply
  - Established iron/steel industry (nor expressed interest in developing an iron/steel industry)
  - Government support

Countries
- Central and South America excluding Brazil
- Southeast Asia

Source: Mandala analysis.

The availability of renewable resources, iron ore, an existing iron industry and government support varies between countries with green iron production potential

Characteristics of potential competitors to Australia in green iron production

COUNTRY	RENEWABLE ENERGY POTENTIAL	DOMESTIC IRON ORE SUPPLY	EXISTING IRON INDUSTRY	GOVERNMENT SUPPORT
China	✓	✓	✓	✓
India	✓	✓	✓	
Australia	✓	✓		
Canada	✓	✓		
Spain	✓		✓	
United States	✓			✓
Saudi Arabia	✓			✓
Oman	✓			✓
Brazil		✓	✓	
Sweden		✓		✓
Germany			✓	✓
Algeria	✓		✓	
Russia		✓		
Japan			✓	
South Korea			✓	
Taiwan			✓	

Source: Mandala analysis.

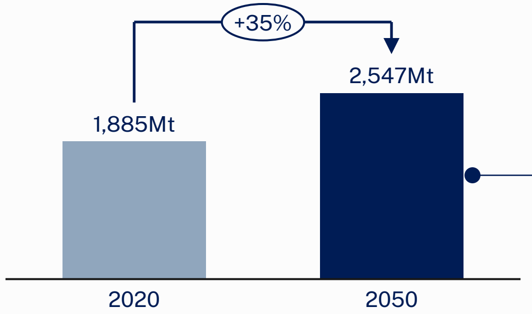
We estimate Australia's green iron opportunity based on Australia's competitive position in the global market

1 Determine future steel demand

DESCRIPTION

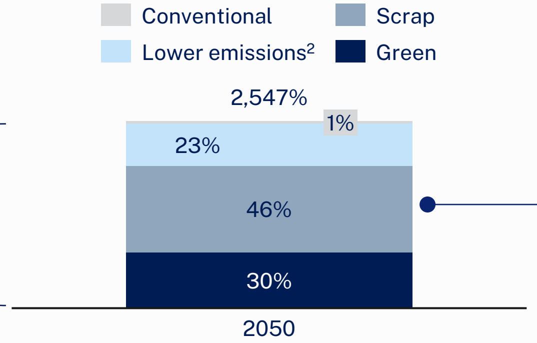
- Population growth and increasing standards of living will drive the continued increase in steel production globally[1]
- The IEA predicts steel production will increase by more than a third on 2020 levels by 2050[1]
- This is 54% primary steel and 46% made from scrap

ILLUSTRATION



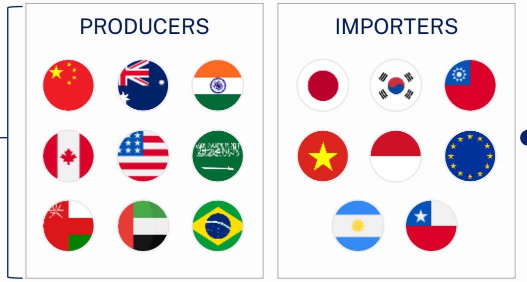
2 Determine green steel demand

- In 2050, 30% of total steel (56% of primary steel) is forecast to be made using green production technologies
- A further 23% of total steel (42% of primary steel) could feasibly use green production methods depending on total green steel demand and other market factors[2]
- 46% of all steel is manufactured from recycled steel scrap



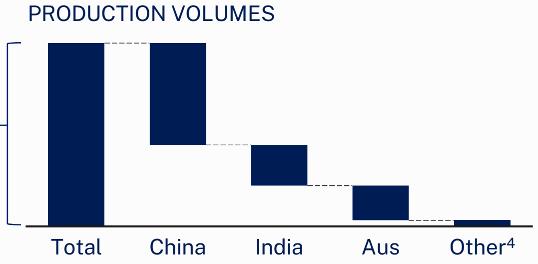
3 Identifying potential producers and importers

- The availability of low-cost green hydrogen, iron ore and an established iron/steel industry (or commitment to establishing) determines potential green iron producers and importers
- China, India, North America, Brazil and the Middle East are key potential producers competing with Australia
- Northeast Asia, Southeast Asia, Europe and South America choose to import green iron to produce green steel



4 Identify Australia's green iron export opportunity

- Commodity demand is determined by cost
- Based on forecast costs of hydrogen-DRI, China is expected to have the lowest production costs then India and Australia[3]
- In this scenario:
  - China is likely to produce green iron for domestic industry and excess production is the first choice of importer countries
  - India utilises domestic iron ore to supply domestic industry
  - Australia captures remaining demand



1 IEA (2020) *Iron and Steel Technology Roadmap.* 2 Refers to steel that is 'lower emissions'. This share of steel production can be made with completely or partially green production methods depending on the availability of such production facilities. If no such facilities are available, conventional methods of production may be used. 3 This study will use hydrogen DRI technology as the basis for modelling, given it is the most progressed and has the most extensive data availability. 4 'Other' refers to an assumed share of green iron production that will be driven by domestic policies instead of cost-competitiveness.

Source: IEA (2023) *Steel and aluminium*; Mission Possible Partnership (2022) *Pathways to Net Zero*; Net Zero Industry (2024) *Net-Zero Steel Pathways;* Wood Mackenzie (2023) *Steel decarbonisation to redefine supply chains by 2050*; Mandala analysis.

Production forecasts for most cost-competitive producers

Methodology and assumptions for modelling Australia's green iron opportunity

Australia's competitiveness	▪ Barriers to industry development are addressed in the short term, allowing Australia to reach its full green iron potential, including achieving renewable energy generation requirements ▪ Global green iron competitiveness is based on cost-competitiveness of green iron per tonne using a green hydrogen DRI production method[1] ▪ Australian green iron production is globally cost-competitive, only more expensive than China and on par with India
Global demand	▪ Global demand is equal to demand for 'green' and 'lower emissions' iron
China's production over time	▪ Planned projects in China open according to their planned timelines and projects that initially use a mix of natural gas and hydrogen move to exclusively using green hydrogen by 2030[2] ▪ Chinese production follows the linear trend of production capacity in planned projects until 2035 ▪ From 2035, Chinese production follows an S curve with total production in 2050 equal to its existing iron/steel production capacity[3] ▪ China exports all production after satisfying domestic demand
India's production over time	▪ Planned projects in India open according to their planned timelines and projects that initially use a mix of natural gas and hydrogen move to exclusively using green hydrogen by 2030[2] ▪ Indian production follows the linear trend of production capacity in planned projects until 2040[4] ▪ From 2040, Indian production follows an S curve[3] with total production in 2050 equal to its domestic demand for iron
Australia's production over time	▪ Planned projects in Australia open according to their planned timelines and projects that initially use a mix of natural gas and hydrogen move to exclusively using green hydrogen by 2030[2] ▪ Australian production follows the linear trend of production capacity in planned projects until 2035 ▪ From 2035, Australian production grows exponentially until 2045 when it tracks remaining demand after Chinese exports ▪ The composition of Australia's green iron opportunity is technology agnostic and may be a combination of hydrogen-, electrolysis-, and biomass-based technology pathways

1 Green hydrogen DRI production is used to estimate costs as it is the most technologically developed production method available and therefore has the best data availability. However, several methods are in development and may achieve cost parity, or lower costs, than the hydrogen DRI pathway. 2 Iron produced using a mix of natural gas and hydrogen will not be counted as green iron in our analysis. 3 The modelled S curve follows the growth in BF-BOF production capacity in China from the 2003 until 2018 using data from Vogl, V., Olsson, O. and Nykvist, B. (2021). 4 India's starting year for industry-wide adoption of green iron production technologies is assumed to be later than China's. We have assumed this because India has committed to net zero by 2070, 10 years later than China (IEA (2024)), and to reflect potential growth in iron/steel production in India beyond 2050. In both countries, green iron production is cost-competitive with conventional production in 2040.
Source: Mandala analysis.

Green iron demand, supply and emission reduction

Methodology overview

Factor	Method	Inputs	Sources
Demand	[Forecast global steel production in 2050] X [Share of production that is primary steel production in 2050] X [Share of primary steel production that is green in 2050] X [Tonnes of green iron needed to produce one tonne of green steel]	[Forecast global steel production in 2050] = [Global steel production in 2020] X [36%]	IEA (2020) Mission Possible Partnership (2022)
		[Share of steel production that is primary steel production in 2050] = 54%	Mission Possible Partnership (2022) Net Zero Industry (2024)
		[Share of primary steel production that is green in 2050] = 98%	IEA (2020) Mission Possible Partnership (2022) Net Zero Industry (2024) Wood Mackenzie (2023)
		[Tonnes of green iron needed to produce one tonne of green steel] = 1.17 tonnes	Grattan Institute (2020)
Production	[Forecast global green iron production in 2050] – [Total green iron production in countries with lower green iron production costs than Australia]	[Forecast global green iron production in 2050] = Global green iron demand in 2050	IEA (2020) Mission Possible Partnership (2022) Net Zero Industry (2024) Wood Mackenzie (2023)
		[Total green iron production in countries with lower green iron production costs than Australia] = [Current Chinese iron/steel production capacity] + [Forecast green iron demand in India in 2050]	Global Energy Monitor (2024) Mission Possible Partnership (2022) Net Zero Industry (2024)
Emissions of steel	[Forecast green iron production] X [Emissions per tonne of iron]	[Forecast green iron production]	Mandala analysis (see previous)
		[Emissions per tonne of steel] x [Share of emissions for iron production] = 1.4t CO_2/t x 89%	IEA (2020), Iron and Steel Technology Roadmap Minerals Research Institute of Western Australia (2023) Western Australia's Green Steel Opportunity

Economic contribution: Additional gross value add and direct ongoing jobs

Methodology overview

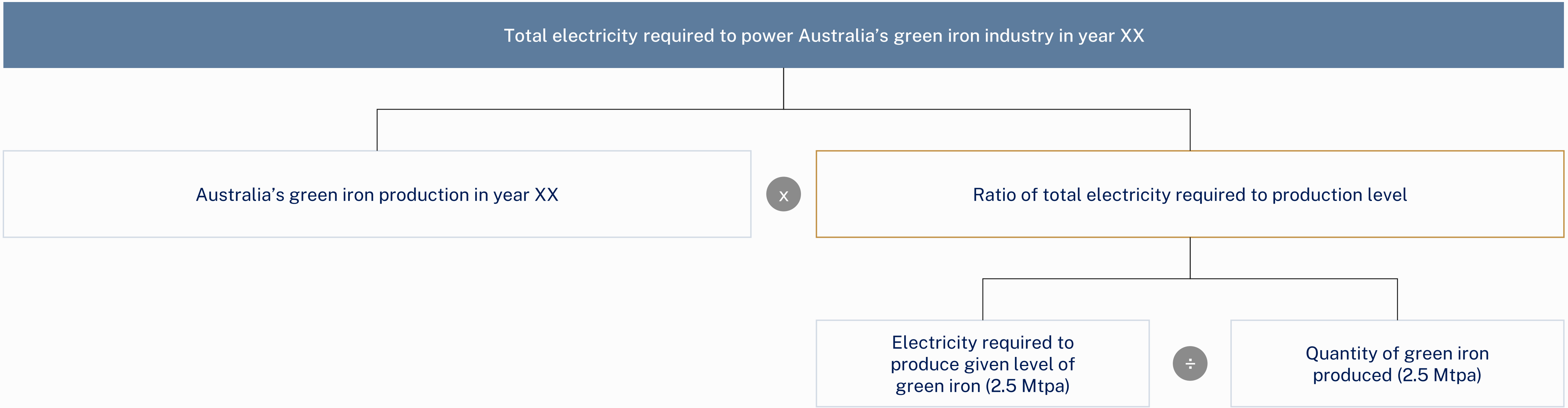
Factor	Method	Inputs	Sources
Gross value added	[Price of green iron] X [Production] – [Total cost of production]	[Price of total product] = [Price of conventional iron] x [Green premium on steel, decreasing over time]	Yahoo Finance (2024) BloombergNEF (2024)
		[Production] = Volumes produced each year	Mandala analysis (see previous)
		[Total cost of production] = Includes costs of hydrogen, ore heating, labour and powering the production plant	Monash University (2024)
Direct ongoing jobs[1]	[Production] / [FTE required per tonne of production]	[Production] = Volumes produced each year	Mandala analysis (see previous)
		[FTE required per tonne of production]	McCoy, Davis, Mayfield, Brear (2022)

1 This refers to jobs that are involved in production. For example, this would include jobs in operating a DRI plant but not in building the DRI plant.

Electricity required to meet Australia’s green iron potential

Methodology to estimate the electricity required to meet Australia’s green iron potential

Input   Calculation



Source: Mandala green iron demand model.

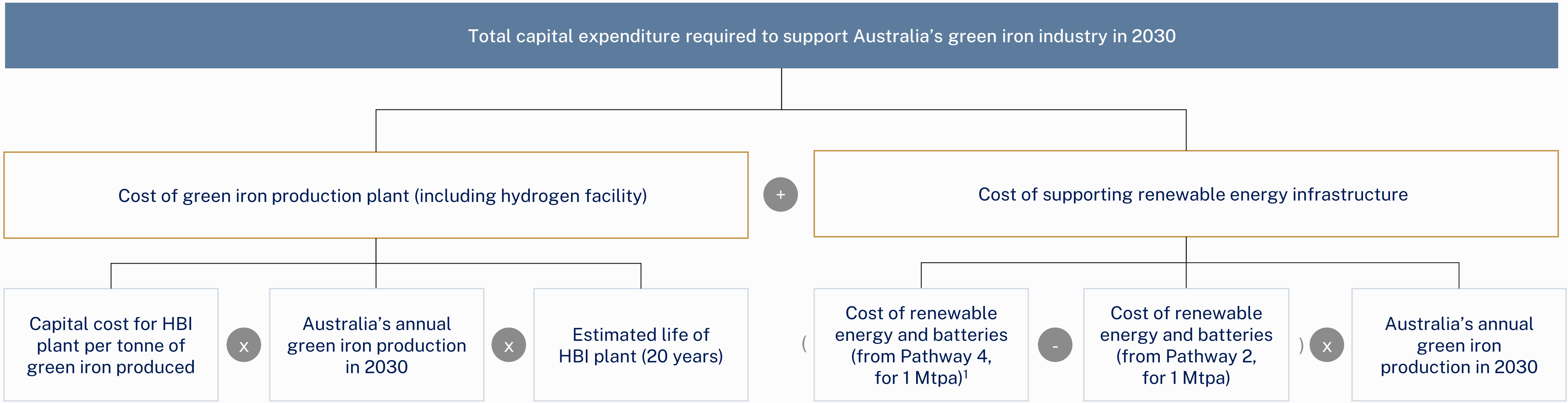
Source: Wang and Walsh (2024) *South Australian Green Iron Supply Chain Study*.

Source: Wang and Walsh (2024) *South Australian Green Iron Supply Chain Study*.

Capital expenditure required to support Australia's 2030 green iron production

Methodology to estimate total capital expenditure required to meet Australia's green iron potential

Input Calculation



Source: Wang and Walsh (2024) *South Australian Green Iron Supply Chain Study.*

Source: Mandala green iron demand model

Source: Wang and Walsh (2024) *South Australian Green Iron Supply Chain Study.*

Source: Minerals Research Institute of WA (2023) *Western Australia's Green Steel Opportunity*

Source: Mandala green iron demand model

[1]The difference between Pathway 4 and Pathway 2 is estimated to isolate for the cost of ironmaking processes and exclude the costs associated with earlier iron ore processing.

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