Climate Energy Finance
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Green Metal Statecraft: Forging Australia's Green Iron Industry

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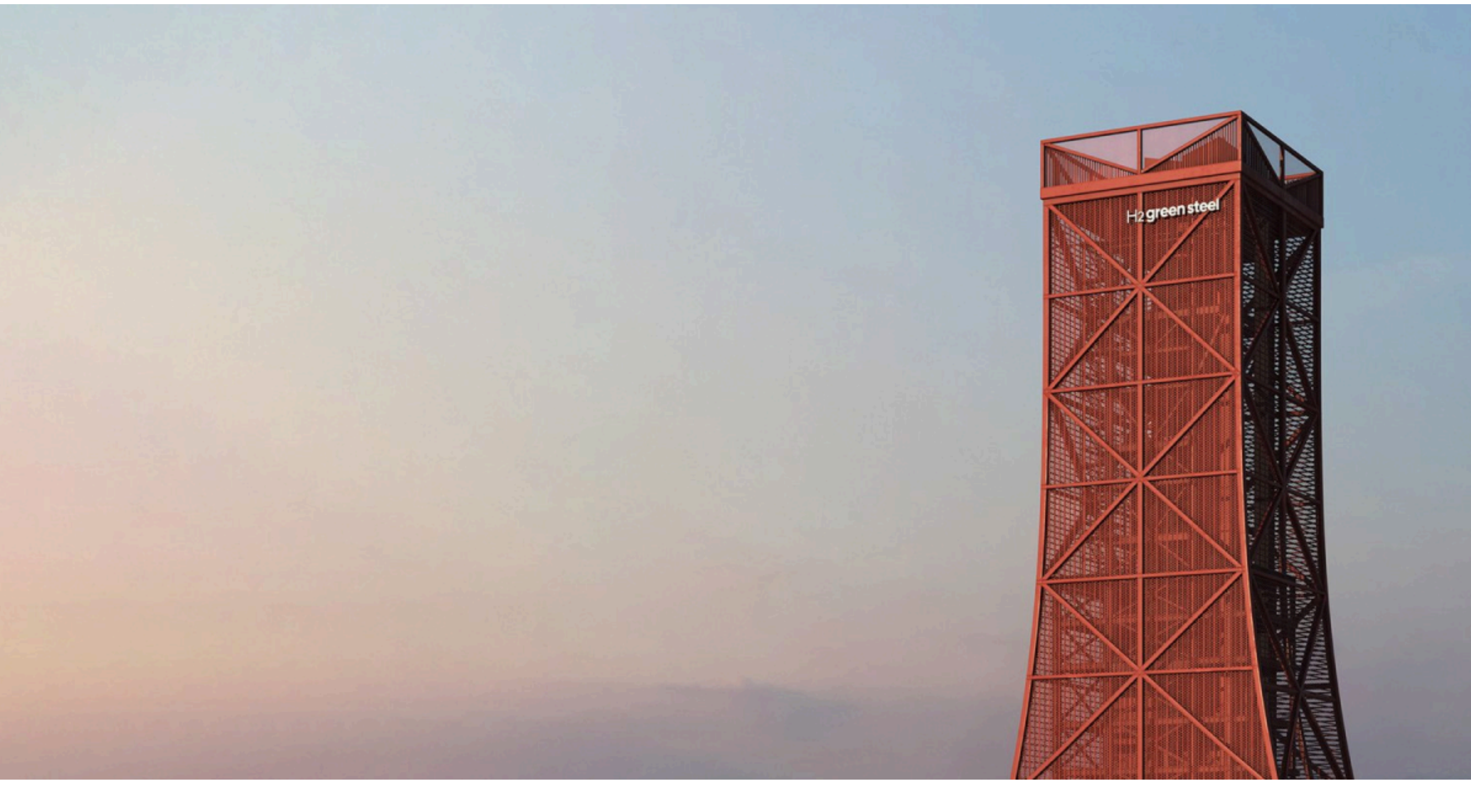

About Climate Energy Finance

Climate Energy Finance (CEF) is an Australian based, philanthropically funded think tank established in 2022 that works pro-bono in the public interest on mobilising capital at the speed and scale needed to accelerate decarbonisation and the energy transition consistent with the climate science.

We conduct research and analyses on global financial issues related to the energy transition from fossil fuels to clean energy, as well as the implications for the Australian economy, with a key focus on the threats and opportunities for Australian investments, regional employment and value-added exports. Beyond Australia, CEF's geographic focus is the greater Asian region as the priority destination for Australian exports, particularly India and China. CEF also examines convergence of technology trends in power, transport, mining and industry in accelerating decarbonisation. CEF is independent, works with partners in the corporate and finance sector, NGOs, government and the climate movement.

About the Authors – Matt Pollard

Matt Pollard, Net-Zero Transformation Analyst, focuses on the significant growth opportunities future-facing companies have in the electrified transport and energy transition. He has a Bachelor of Economics from the University of Queensland, majoring in International Trade and Finance. Previously, Matt spent 2.5 years studying biotechnology, focusing on chemistry and nanotechnology at the University of Queensland. Matt has published numerous reports and op-eds on the energy transition, with a focus on the strategic opportunities for Australia to become a renewable energy powered value-added critical minerals superpower, ideally in partnership with our key trade partners.

About the Authors – Tim Buckley

Tim Buckley, CEF's founder, has 35 years of financial market experience covering the Australian, Asian and global equity markets from both a buy and sell side perspective. Before starting CEF as a public interest thinktank in 2022, Tim founded the Australia and Asian arms of the global Institute for Energy Economics and Financial Analysis in 2013 and was Australasian Director until 2022.

Prior to this, Tim was a top-rated equity research analyst over 2 decades, including as head of equity research in Singapore at Deutsche Bank; MD and head of equity research at Citigroup for 17 years; and head of institutional equities at Shaw & Partners. From 2010-2013, Tim was co-MD of Arkx Investment Management, a global listed clean energy investment start-up jointly owned with Westpac Bank. Tim is widely recognised and extensively published as an expert on Australian and international energy transition and the accelerating shift of global capital to decarbonisation, and is a sought after commentator and advisor.

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Important information

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Foreword

Professor Elizabeth Thurbon

Australia stands at a nation-defining crossroads with our country's security at stake.

In the next decade, we will see global demand for Australia's two largest exports – iron ore and coal – contract as Northeast Asia continues its ambitious clean energy shift, Europe's carbon border adjustment mechanism kicks in, and the nascent restructuring of global iron ore supply chains gains pace. This threatens our economic security.

At the same time, we will see continued volatility in global energy markets, especially those for oil, coal and gas. This threatens our energy security.

And we will see the impacts of unchecked climate change intensify, creating chaos in our weather and fragile ecosystems. This threatens our environmental and social security, risking lives and livelihoods not just in Australia, but across our region and the globe.

We can choose to ignore these national security challenges and continue our business-as-usual trajectory, swimming against the Northeast Asian and European tide and taking the long term hit to our national prosperity. Or we can choose to confront these challenges head-on and to not just survive, but thrive in the global clean economy-in-the-making while reaping the large and connected national security-enhancing rewards on offer. This is the path laid out in this vital report.

This report is vital because it sets out a comprehensive national security-enhancing agenda centred on the embrace of an ambitious green iron and steel national development strategy.

In short, it sets out an ambitious green metal statecraft. Executed swiftly and with discipline, this statecraft promises to boost our nation's economic, energy, environmental and social security and to significantly strengthen our crucial geostrategic relationships in an increasingly tumultuous world.[1]

By embracing green metal statecraft, Australia can create the new technology-intensive, job-creating, high-value, export-oriented clean energy intensive industries of the future, boosting economic security.

We can produce abundant and cheap energy, leveraging our world-class wind and solar resources, boosting energy security.

We can decarbonise some of the dirtiest industries in the world, boosting environmental security.

And we can deepen and extend our economic collaborations with some of our most important geostrategic partners, creating a safer and more prosperous region.

This report outlines the urgent changes needed to advance this comprehensive security-enhancing agenda.

The changes must start with the policymaking mindset. Australia's political and policy leaders must start thinking about the development of a local clean metals industry as an

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[1] see Thurbon, E., Hynd, A. Tan, H. Park, S. and Walter, A. (2024): Green Energy Statecraft for Comprehensive National Security. *AP4D Studies in Statecraft* #2024-1. Asia-Pacific Development, Diplomacy & Defence Dialogue, Canberra | Reimagining the Economy, Harvard Kennedy School, Boston, M.A.

unmissable opportunity to address our nation's pressing economic, energy, and environmental security challenges, and to bolster our geostrategic positioning. And they must embrace the idea of a more ambitious and strategic role for the government in bringing this new industry to life - just as other governments around the world are doing.

This change in thinking will help drive and sustain the ambitious policy and regulatory changes required. This includes changes to economic policy - on both the demand and supply side - to induce and enable private sector investment, combined with complementary changes to foreign policy to lock in the capital, technology, and demand required, and social policy to ensure all Australians benefit from the riches on offer, not least our First Nations custodians.

These changes will require political will, sustained commitment from across the political spectrum, and a high degree of discipline and oversight to ensure that the precious dollars invested deliver true value for all Australians. As a nation, we cannot afford to replicate the existing model whereby generous government support is extended to industry without a commensurate long term return to Australian taxpayers.

The creation of a green metals industry in Australia is not a "nice to have". It is absolutely essential to our national security, comprehensively conceived.

I am grateful to the Climate Energy Finance team for their vision. The responsibility to take it forward now lies with all of us.

Elizabeth Thurbon is Professor of International Political Economy, Deputy Head of School, and Director of Research in the School of Social Sciences at UNSW Sydney. She is also Director of the Green Energy Statecraft Project, a collaborative initiative between UNSW Sydney, the University of Melbourne and the University of Sydney.

Report at-a-Glance

AUSTRALIA'S #1 FUTURE EXPORT OPPORTUNITY NEEDS URGENT POLICY FOCUS

1. Repositioning Australia as a global leader in green iron exports has the potential to double the value of its iron exports to >$250bn pa, key to securing economic prosperity.

2. This requires renewables-powered processing of its world #1 iron ore reserves onshore pre-export.

3. As world #1 exporter (56% market share), iron ore generates $138bn pa export revenue in Australia, 1/3 of total resource export revenues.

4. Failure to pivot to green iron risks halving Australia's export revenues, as China (86% share of Australian iron ore exports) et al decarbonise and restructure iron and steel supply chains.

5. Australia must urgently prioritise strategic national-interest green metal statecraft and associated investment incentives.

6. Steelmaking is 6.7% of global emissions, >3.6bn tpa. Australian green iron production could slash this by 1bn tpa (>2x our domestic emissions).

SECURING AUSTRALIA'S GREEN IRON LEADERSHIP REQUIRES AMBITIOUS GREEN METAL STATECRAFT:

A NATIONAL GREEN IRON AND STEEL STRATEGY WITH CLEAR, MEASURABLE TARGETS.

DEMAND-SIDE POLICIES AND INCENTIVES, including:

- Trilateral Clean Commodities Trading Company (Australia, South Korea & Japan).
- Australasian Green Iron Corporation JV between Australia & key trade partners.
- Public procurement for green metals to create a national demand signal.
- 'Contracts for difference' to bridge the gap between pricing & production costs.

SUPPLY-SIDE POLICIES AND INCENTIVES, including:

- $20bn Future Fund mandate for renewables-powered green metals processing.
- Production tax incentives for green metal refining.
- Exclusion of state investment in fossil fuel-powered onshore strategic metals refining; capping of Fuel Tax Credit Scheme to incentivise mine-to-product decarbonisation.

POLICIES TO ADDRESS TECHNICAL CHALLENGES:

- $500m over 10-yrs to the CSIRO for RD&D into commercialisation of green iron tech.

FOREIGN POLICY & INTERNATIONAL COLLABORATION, including:

- DFAT & Austrade mandate to build collaboration on an Asian Carbon Border Adjustment Mechanism, creating a premium price signal for green iron.
- Australian/Asian steel supply chain decarbonisation collaboration pre-COP31.

ACCELERATED RENEWABLES DEPLOYMENT, including:

- Overriding Public Interest Test to speed renewable energy project approvals.
- Renewables investment conditional on community benefit/First Nations benefit sharing.
- Accelerated development of Renewable Energy Industrial Precincts.
- Industrial demand response mechanisms to optimise renewables supply/demand.

Key Recommendations

Climate Energy Finance (CEF) sees an urgent imperative for the Federal Government to work with the state governments to jointly establish the policy and budget support to accelerate the development of a globally competitive Australian green metals industry. This requires investing a minimum of an additional $10-30bn capital and direct budget support in the 2024-25 Mid-Year Economic and Fiscal Outlook (MYEFO), building on Treasurer Jim Chalmers' $22bn budget support provided in May 2024, and the $40-45bn of capital support established in May 2023 (via the NRF, NAIF, EFA, CEFC, ARENA).

The employment, export and investment potential of this opportunity is huge, and the strategic need is likewise compelling given the long-term terminal threat to Australia's A$220bn of fossil fuel exports in 2022-23 as the world accelerates decarbonisation.

CEF recommends the total investment of $10-30bn be deployed strategically via a complementary mix of financing mechanisms, including instruments and budgetary measures designed to support both the demand-side and supply-side, as well as expand Australia's research, development and demonstration (RD&D) capacity in the iron and steel value chain, and to accelerate the deployment of the renewable energy capacity required to unlock Australia's green iron opportunity at speed and scale.

The recommendations below, implemented together as a coherent, complementary set of support mechanisms can form the basis of Australia's 'green metal statecraft'.

GREEN METAL STATECRAFT

1. National Green Iron and Steel Strategy

Recommendation 1.1:
At the core of this report, CEF recommends the establishment of a **National Green Iron and Steel Strategy** in partnership with the state governments. Australia needs a well-designed strategy with measurable targets, **delivered by bold and deliberate statecraft**, to ensure Australia maintains our global relevance across the iron and steel value chain. It is clear Australia's key trading partners, as well as jurisdictions that are rapidly emerging as suppliers of decarbonised iron and steel products, are acting with strategic, intergenerational planning and policy, acknowledging the opportunity a global reorientation of supply chains can have for sustained economic and employment growth.

2. Demand-Side Policies and Incentives

Recommendation 2.1:
Establish a **Trilateral Clean Commodity Trading Company** (CCTC), jointly owned by Australia, South Korea, and Japan to accelerate the development of decarbonised, value-added industries in Australia, initially green iron. The CCTC's mandate would be to contract, purchase, and trade commodities produced via low-carbon pathways, while optimising the economic, political, environmental, and geostrategic benefits for the parties, and minimising

government financial support by operating with a commercial mindset, while understanding governments' enabling role.

Globally, the largest obstacle to private sector investment into commodity decarbonisation is the lack of ***long term contacts for clean commodities*** **at a predictable price**.

The absence of willing and creditworthy contracting counterparties is now throttling investment in clean commodity projects. The CCTC's participation in the market will aid in accelerating price discovery in the emerging low-emission global iron market, especially in countries without a price on carbon.

The offtake contracts created by the CCTC could allow for the 'clean' nature of the value-added iron to be stripped from the iron product, and retained by the CCTC in the form of a clean commodity carbon credit. This would allow for the CCTC to separately sell the credits generated from the lower-emission iron production, replicating established mechanisms like in Australia's power markets, in which the green nature of the electricity is routinely traded separately from the energy itself, and is a similar design to carbon markets and trading systems introduced globally.

The formation of a CCTC will enable the Federal Government to share in the costs and benefits of industry creation, as the CCTC will be jointly capitalised by Australia, South Korea and Japan, reducing the risk profile to each country, as well as collectively sharing the benefits of demand creation and trading of both the physical commodities and the clean commodity credits generated from the production of those commodities.

Mechanisms that will support the creation of offtake agreements are vital for securing supportive financing and debt facilities from domestic public financing institutions, including the NRF, NAIF, EFA, and the CEFC, as well as international export credit agencies from offtakers' countries.

Recommendation 2.2:
Establishing an **Australasian Green Iron Corporation Joint Venture** between Australia and other key regions like China - our largest iron trading partner - to enable international partnerships and collaboration across the green metals value chain, facilitating the involvement of Australia's iron ore mining majors and China's leaders in steel production. This will facilitate the transfer of critical skills, technology, investment, and alignment of decarbonisation objectives to reduce domestic and exported emissions.

Recommendation 2.3:
Public procurement for green metals to create national demand signals for decarbonised strategic metals, introducing emissions intensity requirements for public infrastructure, defence projects, and government-funded renewable energy and associated transmission and distribution projects.

Buildings and infrastructure represent more than half of global steel demand. Whilst smaller steel use sectors, like the automotive industry, are the likely first mover, the world will not achieve the necessary investments into decarbonised iron and steelmaking without clear demand signals for reduced embedded emissions in large-scale infrastructure.

Recommendation 2.4:
Time-restricted **Contracts-for-Difference** (CfD) to bridge the gap between pricing and production costs during the early development of low-emission value-added capacity before

'green premium' price signals are in place, supporting Australia's first movers to export resources processed using our world-leading renewables to our key trading partners.

Recommendation 2.5:
Expand the FMIA's Guarantee of Origin (GO) Scheme to deploy a **Green Metals Standard for Australia** as the next stage of certification. Certification that is complementary to standards implemented in key export market economies is critical to supporting demand for resources produced via low-emission pathways. The Product GO (PGO) provides certification for renewable energy derivatives, including hydrogen and ammonia, incorporating the Renewable Energy GO (ReGO). As value-adding green iron uses different technologies and pathways, CEF recommends a Green Metals GO (GMGO) that builds on both the ReGO and PGO for different stages of refining.

3. Supply-Side Policies and Incentives

Recommendation 3.1:
Production Tax Incentives for green metal refining, expanding on the Critical Minerals Production Tax Incentive introduced in the Federal Government's 2024-25 Budget to cover strategic metals imperative to Australia's economic resilience and security, and to the global transition to net zero, and complementing the Hydrogen Production Tax Incentive to lower the cost-differential for first movers in embedding decarbonisation.

CEF recommends Australia prioritise the capitalisation of demand-side incentives to support market creation across Asia, as Australia's historical iron ore market is almost exclusively Asia. However, stackable production tax incentives provide diversification of Australia's public capital support to Australia's green iron opportunity.

A time-limited production tax incentive will help support producers between now, where Australia lacks a carbon price in international trade, and the inevitable policy response of international carbon price. This ensures Australia's green iron industry gets moving, and helps align the trajectory of Australia's resource sector with the acceleration of policy responses to climate change.

Recommendation 3.2:
Establishing a **new $20bn mandate in the Future Fund** to undertake strategic, public interest, patient public and private equity plus infrastructure investments into value-adding Australia's world leading critical minerals and strategic metals onshore powered by renewable energy so we export "embodied decarbonisation", in turn enabling the decarbonisation objectives of our key Asian trade partner economies. This is key to starting the pivot of Australia's current commodity export profile away from its massive overreliance on fossil fuels ($220bn in 2022-23 of LNG and coal).

Recommendation 3.3:
Governments should **formally exclude investment in and budget support for fossil fuel-powered projects** for the onshore refining of strategic metals and critical minerals, **unless** there is a clearly defined, binding path medium-term to decarbonisation, e.g. in conjunction with a phased renewable energy buildout and/or the blending in of green hydrogen (GH_2).

CEF also recommends **capping historical fossil fuel subsidies (such as the Fuel Tax Credit Scheme)** to Australia's resource industry to transform a decarbonisation headwind into a tailwind to incentivise corporate leaders to align with the Federal Government's national interest objectives i.e. the Future Made in Australia (FMIA). This supports first movers in decarbonising whole of value chain emissions across iron production, providing greater support to projects that will utilise renewable energy and its derivatives.

4. Policies to Address the Technical Challenges of Green Iron

Recommendation 4.1:
Provide an additional **$500m over 10-years to the CSIRO of strategic support for RD&D into the commercialisation of technologies that will unlock and accelerate Australia's green iron industry.** The role of the CSIRO is to provide innovative scientific and technology solutions to national challenges and opportunities to benefit industry, the environment and the community, through scientific research and capability development, services and advice.

CEF recommends a proportion of the $500m be deployed through CSIRO's partnerships in Australian cooperative research centres. An example for this is the Heavy Industry Low-Carbon Transition Cooperative Research Centre (HILT CRC), which supports R&D projects in iron and steel decarbonisation across industry and academic institutions, leveraging expertise and knowledge sharing across the global heavy industry value chain, with a key focus on overcoming the direct barriers and challenges for Australia.

5. Foreign Policy and Enhancing International Collaboration

Recommendation 5.1:
A new DFAT and Austrade mandate to build international collaboration and consensus to work towards establishing an **Asian Carbon Border Adjustment Mechanism** (CBAM) to extend and reinforce the merits of the EU CBAM introduced in October 2023. Enhancing the value of Australia's key resource exports by onshore value-adding, powered by firmed renewable energy, is a $100-200bn annual trade value uplift opportunity, but only if there is the right price signal incorporated in Asian trade.

Foreign Minister Penny Wong and Trade Minister Don Farrell need to step up internationally and support the domestic decarbonisation efforts of Ministers Chris Bowen and Ed Husic and leverage the domestic progress made with the Safeguard Mechanism and the ambitious 82% Renewables by 2030 target.

Recommendation 5.2:
Prioritise a focus on building **Australian/Asian collaboration in iron and steel decarbonisation for the prospective Australia/Pacific-hosted COP31**. The scale of the challenge to build a world-scale green metals industry in Australia to enable global decarbonisation, will require strategic and coordinated international public finance, knowledge sharing, trade and investment. Enhanced globalisation and adjustment to existing value chains is critical to achieving globally significant industrial emissions reduction.

6. Accelerating Renewable Energy Deployment

Slow and complicated development approval processes for renewable energy and enabling infrastructure are a critical barrier that must be overcome for Australia to deploy the capex at speed and scale to unlock Australia's green metals and critical minerals industries.

Recommendation 6.1:
Given the scale of the task to accelerate firmed renewables infrastructure deployment rates, CEF recommends the introduction of an **Overriding Public Interest (OPI) test**, like in the EU, to streamline approvals process and expedite deployments.

CEF supports the recommendations made by the Climate Change Authority's Sector Pathways to prioritise approvals processes for net zero transition projects, fast-tracking development of renewably-powered industrial hubs. Net Zero Economy Authority (NZEA) expertise should be utilised to coordinate local, state and federal governments to expedite approvals for firmed renewable projects that will support the production of green metals.

To minimise the extensive grid transmission infrastructure investment for green metals, we recommend the establishment of a **Renewable Energy Approvals Initiative** for distributed behind-the-meter generation and storage projects that will power GH_2 production and electricity demand for value-added projects critical to underpinning the Government's Future Made in Australia initiatives and its Net Zero Transformation Stream (projects that make significant contributions to the global net zero transition) and Economic Resilience and Security Stream (to expand Australia's position in the global iron and steel value chain).

Recommendation 6.2:
Introduce clear **community benefit principles** and **First Nations capacity building and benefit sharing** as conditions for investment recipients. Onshoring a green iron industry will require investment into renewable energy, enabling infrastructure, and zero-emission firming capacity at an unprecedented speed and scale. This has the potential to negatively impact surrounding communities and First Nations lands if equitable and sustainable community principles are not a critical component to the approvals process, but also presents immense opportunities for benefits to flow to host communities.

Recommendation 6.3:
For grid-connected green metals projects, prioritise the development of low-emission, **Renewable Energy Industrial Precincts**,[2] leveraging economies of scale for energy transmission and hydrogen pipelines with common user infrastructure, industrial heat and workforce skills development. This will also reduce planning approval duplication, as well as minimise the development footprint.

Recommendation 6.4:
Support the integration of industrial **demand response mechanisms** (DRM) into Australia's grid-connected, energy-intensive refineries, starting with aluminium smelters. The electrification and scaling of Australia's onshore capacity in green metals refining will spur significant new electricity demand. Leveraging DRM during periods of peak power demand and renewable energy droughts will significantly lower the need for additional renewables generation, long-duration storage projects and transmission.

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[2] BZE Economic Analysis: Renewable Energy Industrial Precincts, July 2021

Executive Summary

With a 56% export market share, Australia is the world's dominant iron ore supplier. However, ore quality issues, a lack of long term strategic national interest planning, a lack of decarbonisation policy and investment urgency, and the absence of an Asian trade carbon price signal all see our incumbent historically-privileged industry complacent to the strategic risks, and insufficiently active on our massive opportunities for global domination of the emerging green iron industry. While iron ore major Fortescue is making strides in decarbonising whole of scope emissions, it can't do it alone. Australia needs public-private collaboration and strategic public interest investment, in partnership with our key North Asian customers, to forge leadership in the green iron sector, helping our partners decarbonise and slashing emissions as the climate crisis escalates.

Based on average market prices, value-adding ~40% of Australia's iron ore exports could generate $174bn in export revenues from green iron. Coupled with additional iron ore export revenues of $77bn, this would translate to a doubling of export revenues from the iron export industry to $250bn.

However, failure to overcome the technical and economic challenges of green iron would mean Australia risks the reality that our iron exports could halve, as traditional importers restructure and decarbonise supply chains, and prioritise regions of high-quality iron ore and low-cost ironmaking.

The implications for Australia's key iron ore export partnership with China

China accounted for 86% of all Australian iron ore exports in 2023, having delivered a staggering 6% compound annual growth rate (CAGR) in volume growth over the last decade. This has been a key partnership of profound strategic value for Australia. But with Chinese steel production having likely peaked in 2020 (China's steel output was -6% yoy in September 2024), and with China now leading the world in almost all zero-emissions industries of the future and accelerating its economy-wide decarbonisation, including potentially of its steel supply chains, Australia must invest in green iron to maintain and enhance this partnership even further, noting the massive long term downside risk if we don't.

While steel is the current exception to China's absolute domination of future-facing zero emissions industries, pressure is building. By volume the Chinese ETS is already four times the size of the EU ETS, and ETS coverage is likely to be extended to the Chinese steel sector in 2025. China likes to move, then talk about it. As the number one input supplier to China's steel industry, Australia's current complacency is a massive strategic threat.

Emissions implications of iron and steel supply chain decarbonisation

The emissions implications are also profound. Steelmaking produces 6.7% of global emissions, over 3.6 billion tonnes in 2022 (making it the world's 5th highest emitter behind China, USA, EU27 and India). Australia's total domestic emissions currently run at 440 Mtpa.

Based on aggregate scope 3 emissions processing by our top 3 iron ore producers, a pivot by Australia to the export of green iron would drive a 1 billion tpa emissions reduction opportunity globally, double our domestic emissions. Given Australia's globally dominant iron ore market share as the #1 exporter, the decarbonisation of the processing of Australia's iron ore in blast furnaces is the #1 global opportunity to reduce industrial emissions.

Technological barriers to iron decarbonisation

As of April 2024, there is 148.7 Mtpa of Direct Reduced Iron (DRI) capacity globally – a production process which reduces steel supply chain emissions significantly compared to traditional blast furnace technology – with a further 34.7 Mtpa currently under construction, and a further 138 Mtpa worth of capacity announced. In 2023, global DRI production reached 135.7 Mtpa, up 6.5% above the previous record set in 2022 (127.4 Mtpa). Global DRI is forecast to grow 30% in the seven years to 2030, but could grow dramatically faster if DRI plants could utilise lower-grade, higher-impurity iron ores than what current DRI technologies can currently process.

To really drive steel sector decarbonisation, global DRI growth needs to see a clear path to commercial viability of green hydrogen and non-fossil fuel based reduction of hematite ores, typically in Australia low- to mid-grade iron ore, with higher levels of impurities. To-date, the investment pipeline is being undermined by high, and even rising, electrolyser capital costs, and levelised costs of hydrogen hamstrung by still too high renewable energy costs.

The 2021 GH_2 hype has clearly deflated as we cross the decade-long 'valley of death' to commercialisation.

Geopolitical dynamics in iron and steel supply chain decarbonisation

North Asia dominates current global steel production. Despite lots of talk of decarbonisation pathways in 'future decades', actual investment in lower emissions solutions to-date remains entirely underwhelming. This is largely the result of insufficient policy ambition combined with high-emission industry incumbents clearly not yet feeling stakeholder pressure commensurate with their massive collective carbon emissions profile.

Carbon pricing and an Asian CBAM to provide the required price signal for green iron should be a critical strategic priority to drive supply chain transition regionally and globally.

Hard decisions also need to be made to support the geographic decoupling of iron and steelmaking, shifting iron production to regions with close proximity to iron ore supply and high renewable energy resources, to really drive decarbonisation at a speed and scale commensurate with the climate crisis.

In iron ore producing economies like Australia – which also enjoys an abundance of renewables potential – the investment requirements for the decarbonisation of iron are a significant hurdle. However, these will likely come down as capex intensities of renewable energy, electrolysers, and low-emission firming technologies fall, enabling higher utilisation factors across key inputs of production, lowering the cost of production of green iron.

The success of Australia's future green iron industry in the global trade landscape is dependent on the coordinated development of renewables infrastructure to support the scale of green hydrogen necessary to reduce iron at a price and volume competitive to that of traditional fossil fuel-based ironmaking.

Despite limited iron ore resources, low domestic steel demand and little manufacturing, the Middle East is rapidly emerging as a globally-significant intermediate production hub for the global seaborne steel value chain market, and a key threat to Australia's current global dominance of ore iron supply chains, and future potential for iron production.

With low-cost renewables key to decarbonising supply chains, a 3.7GW solar tender in October 2024 in Saudi Arabia delivered pricing of a world record low of US$13/MWh. Methane based DRI in other economies also has a massive price advantage over Australia due to entrenched multinational gas cartel capture in Australia inflating domestic prices.

Additionally, China aims to develop Guinea into the third largest seaborne iron ore supplier, a strategic threat to both Australia and Brazil.

Electricity infrastructure and water demands of onshore green iron processing

At current technical and economic conditions, CEF's model of green iron in Australia will require 3-4.3 TWh of electricity per million tonnes of green iron for the hydrogen demands alone, supported by 496-698 MW of electrolyser capacity. Given the additional electricity demands associated with heating and operating iron reduction plants, the total energy demand per million tonnes is expected to be between 4.1-5.3 TWh/Mt. For comparison, the NEM generated 213 TWh of electricity in FY2024. Producing 50 Mtpa of green iron (~25 facilities across Australia) would require 204-266 TWh of green electricity, which would translate to a doubling of the NEM's current annual generation, driving home the critical need to upscale installed renewables capacity at speed.

Given the hydrogen requirements, this would also require 1.35-1.9 gigalitres of water per million tonnes. Whilst this is greater than the water demands of methane gas-based DRI production, as well as water use in metallurgical coal mining, producing green iron from Australia's entire iron ore export base would consume just 17-24% of the water used in Australia's cotton industry, and generate significantly higher export revenues and GDP.

Key regional opportunities for an Australian green iron industry

Whilst the Pilbara in Western Australia absolutely dominates Australia's current export supply of iron ore, which brings massive scale potential, the remoteness brings a massive capex and opex cost premium that is a major hurdle, as are high methane prices, next to no renewables investment and investment approval inertia. The WA Government's new Pilbara Energy Transition Plan shows promise.

Ambitious new WA iron ore value-adding investment proposals – from POSCO's Port Hedland DRI, Element Zero, Fortescue green iron, Rio Tinto's BioIron, Progressive Green Solutions' MidWest DRI to Green Steel of WA – show rising investor interest. But patient public financial support is urgently needed.

South Australia long promised a renewal of its ageing steel sector. But financial leverage and a failure to land credible private investment at scale leaves a dire current state. This adversity could allow a recapitalisation of Whyalla in the hands of a strategically-minded, credible public-private-foreign investment coalition, freeing up monopoly port infrastructure and leveraging the strategic value of the state's magnetite resources, world-leading renewable energy position, and state leadership on building a commercial scale GH_2 base to position it as a green iron and steel hub.

Queensland's Energy and Jobs Plan put the state on an enviable path to electricity sector growth, decarbonisation and renewal at a scale that promises to underpin a shift away from the strategic over-reliance on coking coal exports, a sector in a slow but structural decline as the world belatedly aligns with the climate science. Quinbrook Infrastructure Partners has an early stage green iron proposal of merit.

Australia must invest now for nascent steel supply chain realignment

Whilst longer term a credibly high price is needed on carbon emissions in international trade in Asia, like in the EU, Australia will miss the boat if we don't start investing now in preparation for the inevitable, massive Asian steel supply chain realignment. Both policy ambition and strategic public financial support at scale is needed to de-risk onshore investment in iron ore value-adding.

The Asian steel value chain requires a credible path to a high and progressively rising price on carbon emissions in international trade in Asia, like in the EU with its CBAM – a regulatory measure which Australia should be assiduously advocating and the key to creating a green premium price signal for our decarbonised iron and valuing it appropriately in international trade.

As carbon pricing pressures build, Fortescue's strategic pivot from GH_2 to green iron is likely to be proven on-the-money.

Currently, value-added refining of green iron necessitates significant investment in associated enabling firmed renewable energy generation and grid infrastructure, when the financial returns profiles over the last decade of iron ore mining are high, and 'dig and ship' has a dramatically lower capex intensity relative to a shift into green processing and steel manufacturing.

The heavy upfront enabling capex for onshore refining means that patient strategic national interest public investment support is a principal enabler of a potential green iron export industry in Australia, especially in an investment environment where shareholder pressure to maintain returns weakens corporate resolve to invest strategically for the long term.

The near-term compensation alignment of senior executives also undermines consideration of the long term strategic risks of failure to invest in decarbonised processing onshore.

The huge ongoing royalty and corporate tax contributions of the Australian iron ore majors, and economic imperatives and trade implications, further build the case for state industry support to underpin a strategic pivot commensurate with the scale of our opportunity.

This calls for 'green metal statecraft' – a coordinated program of ambitious, strategic national interest decarbonisation policy and investment as set out in our recommendations and the body of this report – and for other major private players, in addition to Fortescue, to get on board and drive with the degree of urgency required.

At this pivotal moment in global energy transition, Australia cannot afford the opportunity cost of failure to act with the requisite speed and scale to capitalise on its opportunity to reposition as a global leader in green iron, as steel supply chains are dramatically reconfigured for a zero-emissions future.

Section 1. Australia's Role in the Decarbonisation of the Iron & Steel Value Chain

Section summary:

- Having delivered a staggering 6% CAGR in volume growth over the last decade, China accounted for 86% of all Australian iron ore exports in 2023. This has been a key partnership of profound strategic value for Australia.
- Collectively, China, Japan and Korea account for over 96% of all iron ore exports, generating $131bn in revenues, predominantly to Rio Tinto, BHP and Fortescue. This has resulted in significant annual tax contributions and royalty payments to the Federal and state budgets respectively.

Implications for Australia:

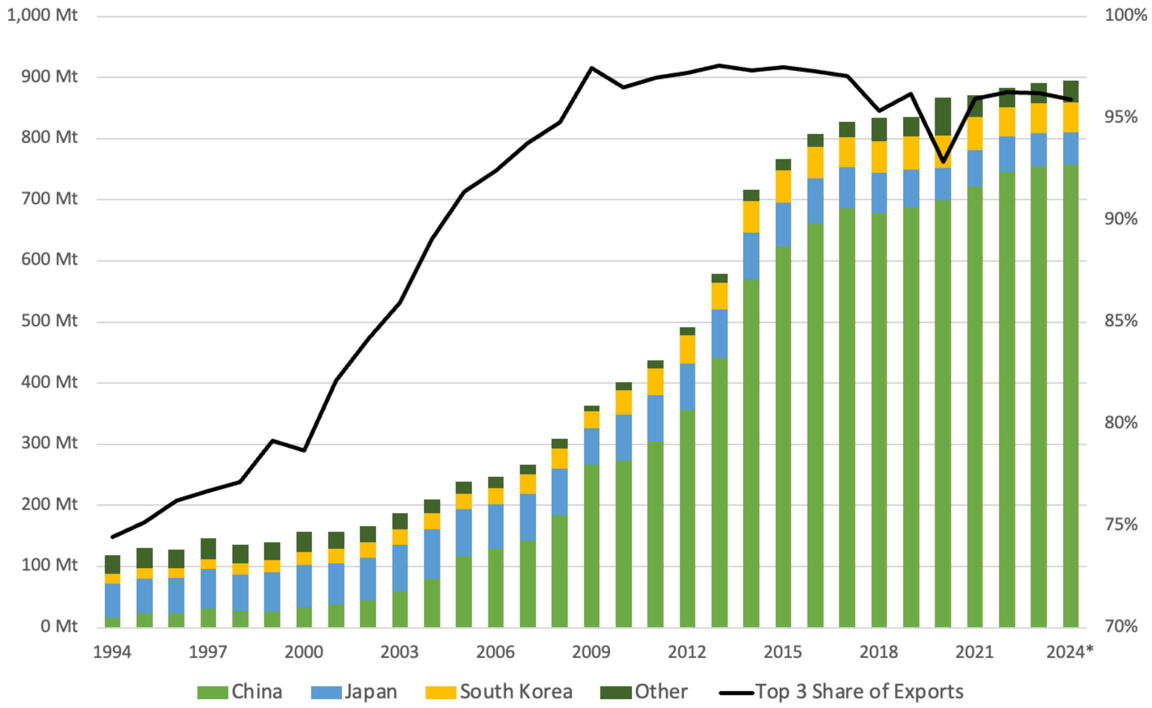
- With China's steel production having likely peaked in 2020, and with China now leading the world in almost all zero emissions industries of the future, Australia must invest in green iron to enhance this partnership even further, ensuring Australia remains a global leader in the iron and steel value chain as our partners decarbonise.
- Failure to act commensurate with the climate objectives of our key trading partners risks Australia losing out to emerging iron regions that will potentially displace Australia's iron exports and dilute market share as importers prioritise higher quality resources.
- Failure to act risks a massive decline in royalties, tax contributions and GDP from iron ore exports as our traditional fossil fuel exports begin their slow but terminal decline.

Australia has benefited tremendously from the rapid growth of global steelmaking. Over the past 20 years, iron ore exports have grown at a compound annual growth rate (CAGR) of 8%, reaching 892 Mt in 2023. The rapid growth in Australia's exports has been driven by the industrialisation of China, with iron ore exports to China growing at a 14% CAGR over the same time frame. In 2023, China accounted for 85% of Australia's iron ore exports.

In recent years, global steel production has plateaued, due largely as well to the asymptotic production of steel from China over the 2020s. 10-year growth in Australia's exports have slowed, growing at 4% CAGR, with Chinese imports also slowing to 6% CAGR. Japan, Australia's largest export market prior to 2005, has declined by a 4% CAGR over the past 10 years. South Korea will likely become the second largest importer of Australian iron ore, with only a 5.4 Mt deficit to Japan over 2023. The rapid growth in North Asia's steel industry has seen a substantial concentration of Australia's iron ore exports over the last decade, with China, Japan and Korea accounting for 96% of total exports over 2023 - see Figure 1.1.

The vast majority of iron ore exports are from Western Australia (WA), with an even greater concentration to the central Pilbara region of WA. In 2023, 98.9% of the 958 Mt of iron ore produced in Australia was in WA. The resource industry of WA has been a primary driver of the state's economic, employment and government revenue growth. In 2022-23, royalties to the WA State Government exceeded $11bn, with iron ore royalties accounting for 83%. Following the December 2023 WA Government budget update, royalties are forecast to generate $31.4bn from 2023-24 to 2026-27, with $24.7bn from iron ore. Australian iron ore exports generated $138bn in sales over 2023-24.

Figure 1.1: Australian Iron Ore Export Markets



Source: Office of the Chief Economist [3]
Note: 2024 is annualised 1H2024

The vast majority of Australia's iron ore exports are in the form of hematite direct shipped ore (DSO) – fines and lumps, which undergo basic processing onshore (e.g. crushing and screening) before being shipped to regions where all the value-adding of iron ore into iron and then steel occurs. The iron content, impurities and nature of Australia's DSO means they are processed in blast furnaces in North Asia, which use metallurgical coal (processed in coke ovens to produce coke) to reduce (remove the oxygen from iron oxides) the iron ore into hot metal (liquid iron). The smelting of iron produces a metallic iron product, pig iron. Blast furnaces have been the most economical way to produce hot metal, however produce significant emissions from the ironmaking process.

Average emissions intensity across the iron and steel value chain was 1.91 t-CO_2-e/tonne crude steel (t-cs) cast in 2022. 1,890 Mt-cs was produced, generating 3.6 billion tonnes of CO_2-e, accounting for 6.7% of global emissions.[4] Steel value chain emissions have seen 2.8% CAGR since 2010, increasing its share of global emissions from 5.2% to 6.7% - Figure 1.2.

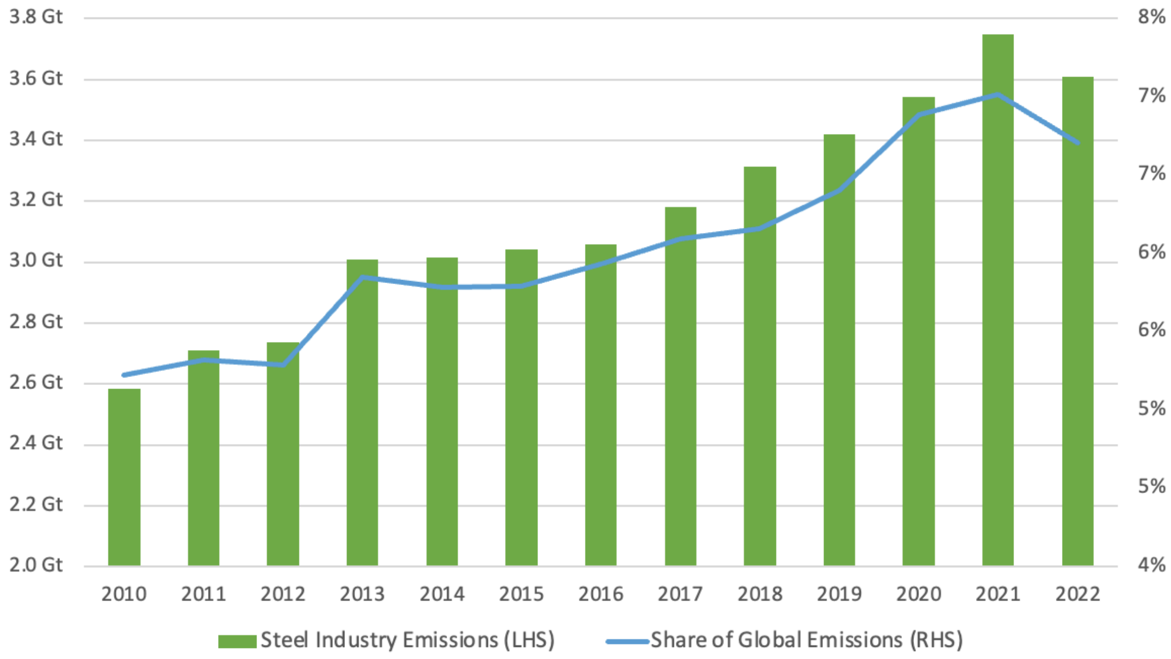
From a global perspective, if the iron and steel industry was a country, it would be equivalent to the 5th highest emitter, behind China, USA, EU27 and India. In 2022, Australia's direct domestic activities generated 463.9Mt CO_2-e, or 0.8% of global emissions (excluding exported emissions).[5] The global iron and steel industry emits 7.8x that of Australia annually.

An increasing number of steelmakers globally have now set net zero targets, however not all these targets are on course for 2050 or earlier. And with China still holding to a 2060 net zero target, and accounting for 86% of Australian iron ore exports, this is problematic for

[3] OCE, Resources and Energy Quarterly: September 2024, 30 September 2024
[4] World Steel, World Steel in Figures 2024, 27 May 2024
[5] DCCEEW, Australia's GHG Emissions: December 2022 Quarterly Update, 31 May 2023

Australia's miners, who have 2050 or earlier commitments to their global shareholders and evident climate science imperative for decisive action.

Figure 1.2: Annual Global Emissions from Steel Production (Bn tonnes)



Source: Our World in Data [6]

In October 2024, Global Energy Monitor identified that less than half of the top 50 steelmakers have set net zero targets by 2050, despite the top 50 producers generating more than 60% of the steel sector's emissions.[7] Out of the top 15 steelmakers, of which only 2 are outside of Asia, only 9 have set 2050 targets or earlier, and 2 have set net zero by 2060 targets - see Figure 1.3.

Figure 1.3: Top 15 Global Steelmakers and Their Net Zero Targets

Rank	Country	Company	2023 (Mt)	2022 (Mt)	Growth	Market Share	Net Zero
1	China	China Baowu Group	131	132	-0.8%	7%	2050
2	Luxembourg	ArcelorMittal	69	69	-0.5%	4%	2050
3	China	Ansteel Group	56	56	0.4%	3%	2060
4	Japan	Nippon Steel Corporation	44	44	-1.5%	2%	2050
5	China	HBIS Group	41	41	0.8%	2%	2050
6	China	Shagang Group	41	41	-2.2%	2%	-
7	S. Korea	POSCO Holdings	38	39	-0.5%	2%	2050
8	China	Jianlong Group	37	37	1.2%	2%	2060
9	China	Shougang Group	34	34	-0.7%	2%	-
10	India	Tata Steel Group	30	30	-2.3%	2%	2045
11	China	Delong Steel	28	28	1.3%	1%	-
12	India	JSW Steel Ltd	26	23	11.8%	1%	2050
13	Japan	JFE Steel Corporation	25	26	-4.2%	1%	2050
14	China	Hunan Steel Group	25	26	-6.2%	1%	-
15	USA	Nucor Corporation	21	21	2.9%	1%	2050
	Rest of World		1,247	1,239	0.7%	66%	
	Total		**1,892**	**1,885**	**0.4%**	**100%**	

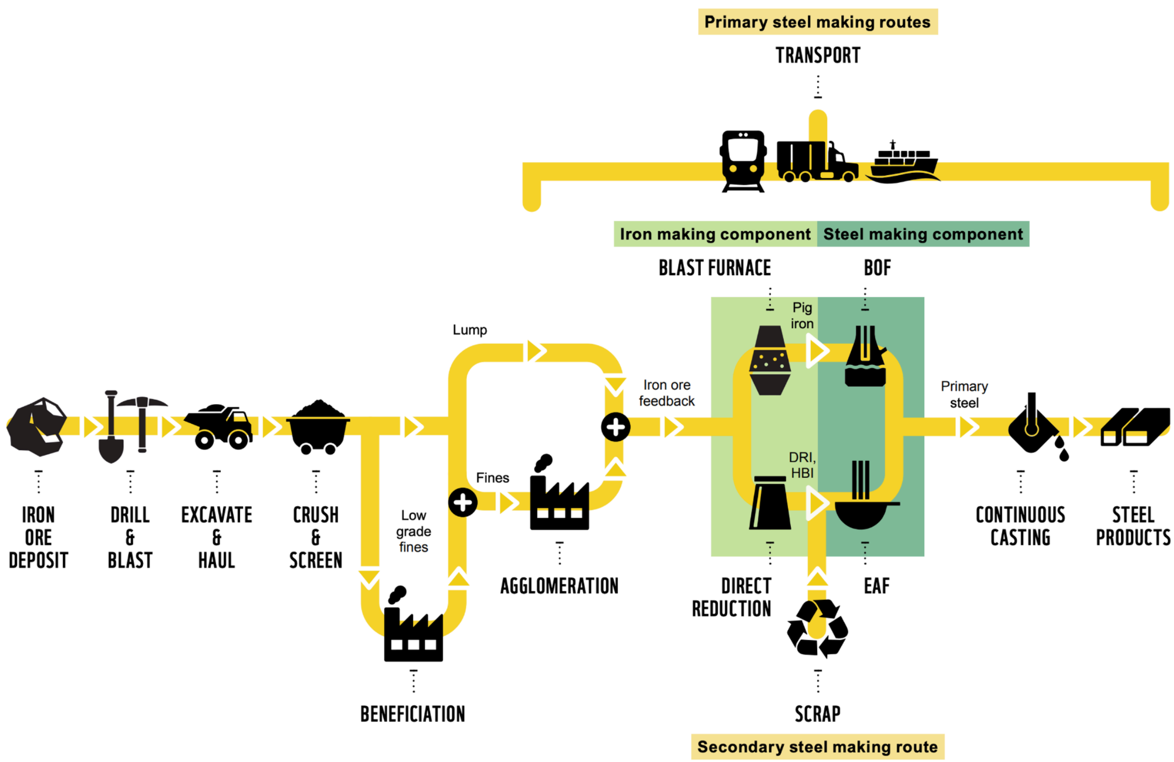
[6] Our World in Data, Global CO_2 and Greenhouse Gas Emissions, accessed September 2024
[7] GEM, A Matter of Transparency: 2024 Insights on Steel Industry Commitments to Net Zero, October 2024

Of the top 50 steelmakers, 80% of steelmaking capacity is BF-BOF (explained below), well above the 71% global average. As of 2023, only steelmakers with a combined capacity of 45 Mtpa have set net zero targets prior to 2050.[8]

Historically, ironmaking and steelmaking have been integrated into continuous single-site facilities, accessing often imported coal and iron ore. The decarbonisation of the global steel value chain will likely necessitate a drastic re-orientation of supply chains. This would see the decoupling of ironmaking from steelmaking, shifting iron production to regions with close proximity to iron ore supply and high renewable energy resources. Final stage steelmaking capacity remains in regions with existing large manufacturing bases that utilise steel, and regions with high steel consumption to increase circularity of scrap steel into steel mills.

As illustrated in Figure 1.4 below, steel is primarily produced via the blast furnace - basic oxygen furnace (BF-BOF) route, with currently the majority of the remaining steel produced via secondary steelmaking, recycling scrap in an electric arc furnace (EAF). In 2023, 71.1% of the crude steel production was produced from BF-BO, with 28.6% of crude steel produced in an EAF.

Figure 1.4: Current Iron and Steel Value Chain



Source: WWF [9]

Primary steel can also be produced using direct reduced iron (DRI), which is charged into an EAF with scrap steel. The BF-BOF process emits an average 2.2 t CO_2/t-cs. Comparatively, the DRI-EAF pathway (using methane gas as a replacement for coking coal) emits 1.4 t CO_2/t-cs, a 36% reduction. Scrap-EAF currently emits the lowest emissions, at 0.34 t CO_2/t-cs, an 86%

[8] GEM, A Matter of Transparency: 2024 Insights on Steel Industry Commitments to Net Zero, October 2024
[9] WWF, Australia's Green Iron Key, 01 August 2024

reduction relative to BF-BOF.[10] The emissions intensity of scrap-EAF production varies geographically, with the largest source of emissions related to the electricity consumption of operating an EAF. Regions with high renewable energy penetration will have lower embedded emissions intensity in steel production. IEEFA's analysis indicates that the scrap-EAF pathway emissions intensity could be further reduced when powered by renewable energy. If indirect emissions (via purchased electricity) are mitigated through 100% renewable energy, the intensity can fall to 0.04 t CO_2/t-cs, or a 98% reduction.[11]

In the BF-BOF route, typically low- to mid-grade hematite ores are extracted and exported to integrated steel mills, primarily in North Asia. Iron ore lumps are able to be directly charged into the blast furnace, whereas fines require an intermediary process, sintering, in which fines are agglomerated into larger granules. BF-based plants also employ coke ovens to produce coke from metallurgical coal. In the BF, iron ore is reduced (oxygen is removed from the iron) in a molten state by the carbon in the coke. The reaction between carbon and iron oxide generates CO_2. The resulting hot metal, pig iron, is refined into crude steel in a BOF, which produces semi-finished steel products, e.g. flat and long steel.

In the DRI route, iron is reduced in the solid state, i.e. without melting as occurs in a blast furnace, meaning the reducing agent directly removes oxygen from the iron ore. Reductants in the DRI process are carbon monoxide (CO) and hydrogen (H_2), with current CO and H_2 almost entirely produced from methane gas or recovered from metallurgical off-gases (in particular from coke ovens). The three main employed DRI techniques include gas-based shaft furnace process (e.g. MIDREX and Energiron), gas-based fluidised bed processes (e.g. FINMET / FINORED), and thermal-coal based rotary kilns, deployed almost exclusively in India. The DRI technologies are explored further in Section 2.

Gas-based DRI processes require iron ore feedstocks to be pelletised prior to reduction. As such, high-grade magnetite ores with low impurity levels are used in DRI production, largely due to the improved economics of beneficiation of magnetite over hematite due to the ferromagnetic properties of magnetite, hence the name. A more in-depth explanation is shown below.

[10] IEEFA, Steelmaking Fact Sheet, June 2022
[11] IEEFA, Steelmaking Fact Sheet, June 2022

Section 2. Australia's Iron Ore Resource and the Implications of Steel Decarbonisation

Section summary:

- Australia has the world's highest Economic Demonstrated Resource (EDR) of iron ore (30%), of which magnetite is 38%. However, over 95% of Australia's iron ore exports are hematite, primarily in the form of fines, or Direct Shipped Ore (DSO). Australia's DSO is typically low- to mid-grade iron ore, with higher levels of impurities.
- Sintering (agglomeration of fines into lumps) and blast furnaces are the largest emissions sources in the traditional BF-BOF steelmaking value chain, together accounting for up to 91% of emissions across the entire steel value chain.
- This is a massive risk for Australia, as the vast majority of Australia's current iron ore production is not suitable for the commercially-demonstrated iron processing technologies which directly reduce iron using a combination of methane gas and hydrogen, called Direct Reduced Iron (DRI).
- DRI plants require high-grade, low-impurity iron ores. High-quality magnetite is used in DRI facilities, as their properties allow for the lowest-cost, and highest-yield beneficiation to the required iron and impurity content.
- There are other technologies being researched globally to reduce emissions, e.g. direct electrolytic iron reduction (DEIR), however only methane gas based DRI has been proven at scale.

Implications for Australia:

- The decarbonisation of ironmaking is the largest opportunity to reduce emissions from the steelmaking value chain. This will require a global decoupling of ironmaking from steelmaking.
- The common factor amongst all pathways to decarbonisation is the need for significant amounts of electricity.
- The decarbonisation of the steel industry will likely catalyse a global restructuring of supply chains and global re-industrialisation on a massive scale. This presents a massive opportunity for Australia to onshore value-added iron processing.
- The decoupling of ironmaking and steelmaking allows for increased global collaboration, supporting the deployment of renewable energy in large mining jurisdictions with superior land availability, wind resources and solar irradiation, like Australia.
- Despite our comparative advantages, this is still a global race. Australia needs to overcome significant technology, grade and capital cost barriers. Yet with the right **green metal statecraft**, Australia is well-positioned to emerge as a major decarbonised iron producer. This could potentially double the value of our current iron ore exports.
- To overcome the technical barriers to commerciality, CEF recommends an **additional $500m over 10-years to the CSIRO** of strategic support for RD&D into the commercialisation of technologies that will unlock and accelerate Australia's green iron industry.

Iron (Fe) is the fourth most abundant element in the Earth's crust. Iron ores are mineral formations in which metallic iron can be economically extracted. The main minerals present in iron ores extracted globally are hematite (Fe_2O_3) and magnetite (Fe_3O_4), both of which are iron oxides. By molecular mass, hematite contains 69.9% Fe, and magnetite contains 72.4% Fe.

The processing of both hematite and magnetite begins the same, with both ores requiring initial crushing and screening (separation of particles by size by vibrating screens). Generally, hematite ores mined in the Hamersley Province of Australia (Pilbara) are 56-62% Fe in situ (in its original place, i.e. in the ground). Thus, it requires only simple processing prior to being directly shipped, hence referred to as Direct Shipped Ore (DSO).

Magnetite ores are typically at lower Fe content in situ, generally 20-30% Fe with higher presence of impurities, and thus require further processing. Magnetite is ferromagnetic, meaning it can be concentrated using magnetic separation. The magnetic properties allow for iron ore to be concentrated and pelletised to an Fe content of +67%. The biggest differentiating factor in terms of value-in-use is the exothermic reaction of magnetite in the sintering and pelletisation processes (providing up to 60% of required heat), which significantly lowers energy and costs.

Iron ore pellets can be produced from either hematite or magnetite feedstock, but will always **become hematite** once pelletised due to the temperature-induced oxidation reaction in their formation. However, the ability to beneficiate magnetite to a higher iron content with a lower presence of gangue (impurity elements), means they can be economically reduced (remove oxygen) in a direct reduction process, as opposed to reduction by coking coal in a blast furnace.

Over 95% of Australia's current iron ore exports are hematite, primarily in the form of fines, which require sintering (agglomeration of fines into lumps) prior to reduction in blast furnaces. Sintering and blast furnaces are the largest emissions sources in the traditional BF-BOF steelmaking value chain. As the world begins to decarbonise, DR-grade ores will quickly rise in demand as the emissions reduction potential of direct reduction technologies, even processing with methane gas, is significant compared to the traditional BF-BOF route that accounts for 71% of global steel production in 2023.

Australia has the world's highest Economic Demonstrated Resource (EDR) of iron ore (30%), of which magnetite is 38%. 81% of Australia's magnetite resources are in WA, but only 3% of WA's iron ore production is magnetite. It is important to note that a significant portion of WA's magnetite production is not suitable for DRI plants, largely due to the high silica content. South Australia (SA) is the second largest region for magnetite deposits (13%), with more than 90% of SA's iron ore in the form of magnetite.

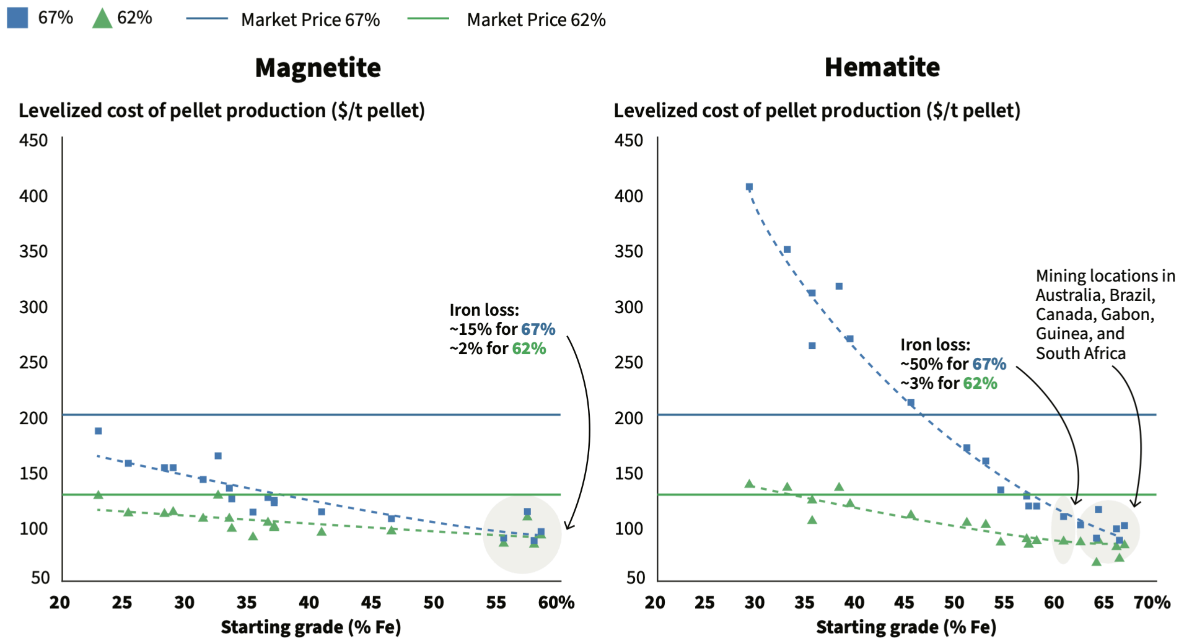
With Australia's best renewable resources, and without the geographic isolation of WA, SA has an immense opportunity and potential advantage over WA to be a first mover for Australia's green iron industry to facilitate the decarbonisation of iron & steelmaking in collaboration with our key trading partners. However, Australia's economic powerhouse of Pilbara hematite is at a great risk given the current technical limitations of decarbonising the emissions-intensive hematite processes. Australia must recognise the risks global decarbonisation has to our no.1 export (and to coking coal, our #3 export), and step up our ambition and collaboration with key trade partners to address the challenges to ensure Australia's economic security and resilience.

To facilitate iron storage and shipment, DRI needs to be compressed into Hot Briquetted Iron (HBI) at high temperatures, due to sponge iron's high porous and reactive nature, posing hazards from rapid corrosion, reoxidation, hydrogen gas generation, etc.[12] Compacting into HBI mitigates these risks and allows for safer transportation.

DRI plants prefer iron ore pellets with an Fe content of a minimum 67%, with lower concentrations of impurities and acid gangue (silica, alumina and phosphorus), as the economics of operating the facility improves, and allows the resulting product to be charged into an EAF, which has less ability to remove impurities into slag compared with the BF-BOF route.[13] Currently, only ~ 13% of seaborne iron ore has an iron content of 65% or more, and just ~ 3% with an Fe content >67%.[14]

It is physically possible for higher-grade hematite ores (>50% Fe) to be beneficiated to an iron content compatible with DR feedstock. However, the levelised cost of production against current market prices, in addition to the significant iron and mass loss from the beneficiation process, drastically decreases the final product volume and profitability for the producer compared to DSO. Hematite ores, such as those produced in the Pilbara, would result in ~ 50% losses of iron content when processed to 67% Fe content, the minimum required for DRI-EAF. However, beneficiating to 62% Fe, results in just 3% iron and mass losses, but precludes this in DRI processing - see Figure 2.1.

Figure 2.1: Cost-competitive Pellet Production for Magnetite and Hematite



Source: RMI

For steelmaking, higher impurities in DRI products result in greater slag production, which current EAFs cannot handle. Investigations are underway globally to test electric smelting furnaces (ESF) as an intermediate stage between initial reduction and final steelmaking, which can remove the impurities of lower-grade pellets, and provide additional reduction

[12] Monash University, South Australian Green Iron Supply Chain Study, 19 January 2024
[13] RMI, Green Iron Corridors: Transforming Steel Supply Chains for a Sustainable Future, September 2024
[14] MPP, Making Net-Zero Steel Possible: Steel Transition Strategy, September 2022

through smelting. ESFs for ironmaking are based on existing, proven technologies in other industrial processes, including ferroalloy production.[15]

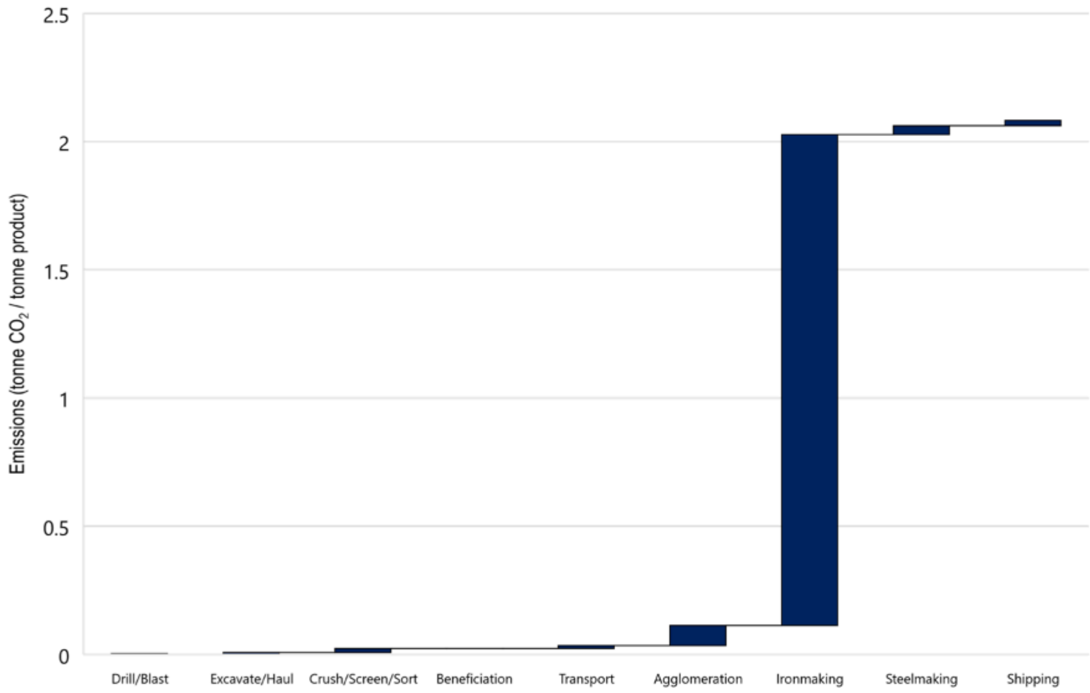
ESFs produce hot metal that can be fed directly into either a BOF or EAF, or alternatively packaged into granules similar to pig iron and exported to final steelmaking locations.[16] Pig iron from lower-grade pellets via DRI-ESF has yet to be proven at commercial-scale, however multiple studies and pilot plants are currently under development to test the commerciality of this process, discussed in various sections below.

The challenge for Australia is not in the reduction technologies, which are only concerned with the reducibility of the iron ores. Pilbara DSO ores are typically more reducible than competitor ores from Brazil, Africa and North America. However, given the gangue content of Australian iron ores, the critical enabler is the melting technology, to efficiently and economically remove the gangue/slag before the metal product is processed into steel.

A summary of the commercial DRI technologies deployed globally, as well as key technology pathways under research and development is available in section: **Additional Information: Current Iron and Steel Decarbonisation Technologies**.

The critical challenge for the global iron and steel value chain is the decarbonisation of iron reduction, which increases the degree of iron metallisation to >90% in terms of mass. The processing of iron ore in a blast furnace can generate up to 1.9t CO_2/t-cs, accounting for 87% of the value chain emissions per tonne of crude steel. The agglomeration of iron ore into sinter is another significant contributor to the emissions profile of BF-BOF steelmaking, which also uses coal, accounting for up to 4.2% of emissions - see Figure 2.2.[17]

Figure 2.2: Emissions Intensity across Steelmaking Value Chain



Source: MRIWA

[15] BHP, Pathways to Decarbonisation - Episode 7: The Electric Smelting Furnace, 16 June 2023
[16] RMI, Green Iron Corridors: Transforming Steel Supply Chains for a Sustainable Future, September 2024
[17] MRIWA, WA Green Steel Opportunity, updated 06 November 2023

The decarbonisation of ironmaking is the largest opportunity to reduce emissions from the steelmaking value chain. Transitioning to electrified or green-hydrogen based ironmaking technologies, even with a proportion of methane gas used in the reduction of iron ore, can have significant emissions reduction potential. Further, gas-based DRI plants abate the need for coking coal in the steelmaking value chain, eliminating need for coal in the ironmaking process.

The common factor amongst hydrogen-based DRI processes, as well as emerging alternative pathways, including direct electrolytic iron reduction (DEIR) or DRI-ESF, is the need for significant amounts of electricity.

The decarbonisation of the steel industry will likely catalyse a global restructuring of supply chains and global re-industrialisation on a massive scale. This will require the coordination of some of the world's largest investors and companies, low-emission technologies, public capital and strategic government subsidies and budget support, and most critically, regions with abundant renewable energy resources.[18] This is a global race, and while we have some technology, grade and capital cost barriers to overcome, Australia is well-positioned to emerge as a major decarbonised iron producer. This could potentially double the value of our current iron ore exports.

The decoupling of ironmaking and steelmaking allows for increased global collaboration, supporting the deployment of renewable energy in large mining jurisdictions with superior land availability, wind resources and solar radiation, as well as maintaining the vast majority of the skilled employment base of downstream processes with countries and regions that have become dependent on the steel industries for job creation, with up to 75% of jobs across the steel value chain occurring in steelmaking and manufacturing.[19]

[18] FT, Can Sweden Deliver its Much Hyped Green Energy Boom, 13 August 2024

[19] RMI, Green Iron Corridors: Transforming Steel Supply Chains for a Sustainable Future, September 2024

Section 3. State of Play: Direct Reduced Iron and Low-Emission Steelmaking

Section summary:

- In 2023, global DRI production reached 135.7 Mtpa, up 6.5% from 2022. The Middle East is the largest producer of gas-based DRI.
- Global DRI is forecast to grow 30% in the seven years to 2030, but could grow dramatically faster, driving steel sector decarbonisation with the right market signal.
- All gas-based DRI produced in 2023 was from fossil gases, not green hydrogen. The current DRI landscape highlights the competitive nature of producing DRI from methane gas in regions with large low cost methane gas resources as opposed to coal-based pig iron.
- As a result, the Middle East is rapidly emerging as a global hub for DRI production.
- The lack of a clear carbon market price signal in international trade to value lower emissions solutions is throttling investments globally.
- The world currently has 675 Mtpa of EAF capacity operating. The largest opportunity to reduce emissions is increasing circularity in the steel value chain via the scrap-EAF pathway.
- There are still technical challenges to global adoption of commercial DRI technologies, namely the high quality iron ore requirements.
- Economic challenges to green hydrogen continue globally, primarily due to higher-than-anticipated electrolyser costs, too high levelised cost of renewable electricity, and lack of a carbon price.

Implications for Australia:

- **Australia cannot compete** on a cost-competitive basis **if we prioritise methane gas**. Australia is the third largest LNG producer globally. Yet as a consequence of poor domestic policy and regulatory capture from the multinational methane gas cartel, Australia has domestic methane gas prices multiples the price prevailing in the Middle East and America.
- Australia is exhausting its higher-grade mineral deposits. Average iron content is falling in our exports, whilst impurity levels continue to rise. It is critical Australia address the technical challenges to iron ore quality in decarbonised iron technologies.
- For the world to achieve its emission reduction objectives, we must accelerate, at scale, global collaboration on steel decarbonisation policies.
- For Australia to be competitive, this **must include effective carbon pricing in international trade** to underpin the coordinated deployment of renewably-powered iron production.

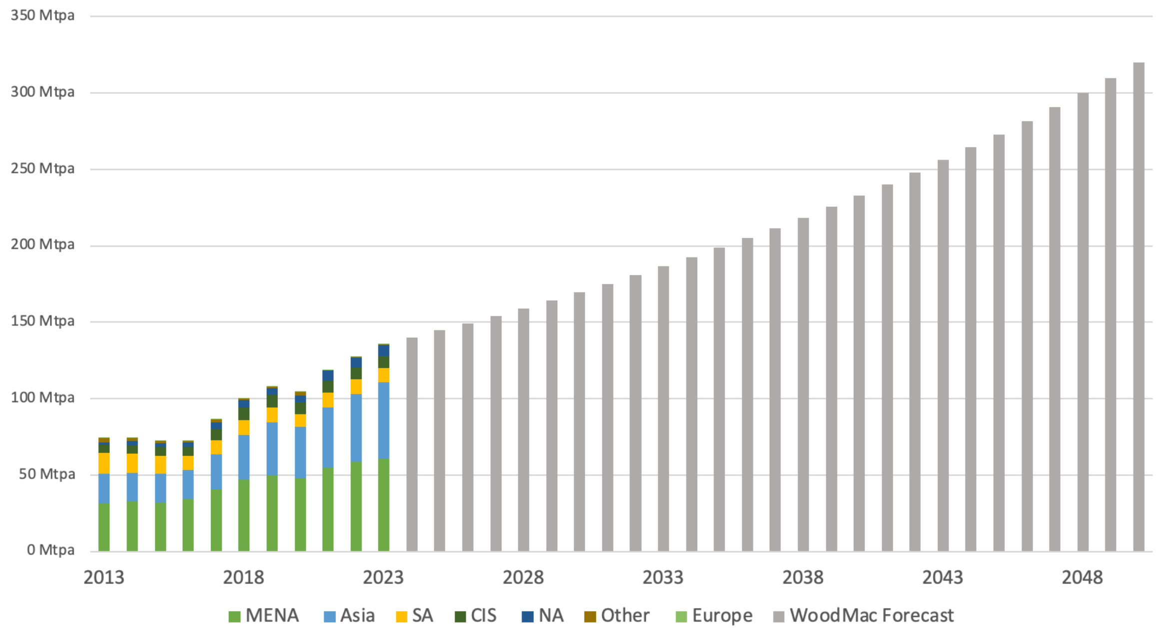
In 2023, global DRI production reached 135.7 Mtpa, up 6.5% year-on-year from the previous record set in 2022 (127.4 Mtpa).[20] The largest producer of DRI is India, which produced a record 49.3 Mt in 2023. However, 81% of India's DRI is produced using rotary kilns, which use low quality non-coking coal in the process. Rotary kiln processes are still considered DRI because the reduction reaction occurs with the iron ore in a solid state, but require the use of coal as a reductant, thereby eliminating any emissions reduction potential in the process.

Iran is the largest producer of methane gas-based DRI, producing 33.4 Mt in 2023, of which 90% was produced using MIDREX platforms. MENA is the largest region for DRI production, producing 60.9 Mt in 2023. Including rotary kiln products, Asia is the second largest

[20] MIDREX, 2023 World Direct Reduction Statistics, 2024

producer at 50.2Mt. Excluding rotary kiln production from Asia (39.9 Mt), the region falls below North America (13.0 Mt) as the second largest DRI producer globally. World Steel Dynamics (WSD) forecasts global DRI production will expand by 30% to 2030 vs 2023, reaching 175 Mtpa, with the EU and MENA dominating expected growth.[21]

Figure 3.1: Forecasted Global DRI Production



Source: MIDREX, Wood Mackenzie

WSD predicts DRI production from Middle East and Northern Africa (MENA) will grow 35% by 2030 to up to 69 Mtpa, followed by the EU, producing up to 20 Mtpa. Wood Mackenzie forecasts global DRI production to grow at a CAGR of 3.4% to 320 Mtpa by 2050, dominated by the Middle East with an estimated output of 95-105 Mtpa.[22]

The current state of play highlights the competitive nature of producing DRI from methane gas in regions with large low cost methane gas resources as opposed to coal-based pig iron. The Middle East and North America are home to the top 2 largest LNG producers globally: USA and Qatar. Other nations across the Arabian Peninsula, i.e. Saudi Arabia, UAE, and Oman, also have significant methane gas production capacity for domestic use.

Australia is the third largest LNG producer globally, yet, as a consequence of poor domestic policy and regulatory capture from the multinational methane gas cartel, Australia has domestic methane gas prices multiples of the price prevailing in the Middle East and America. This is explored in Section 7.

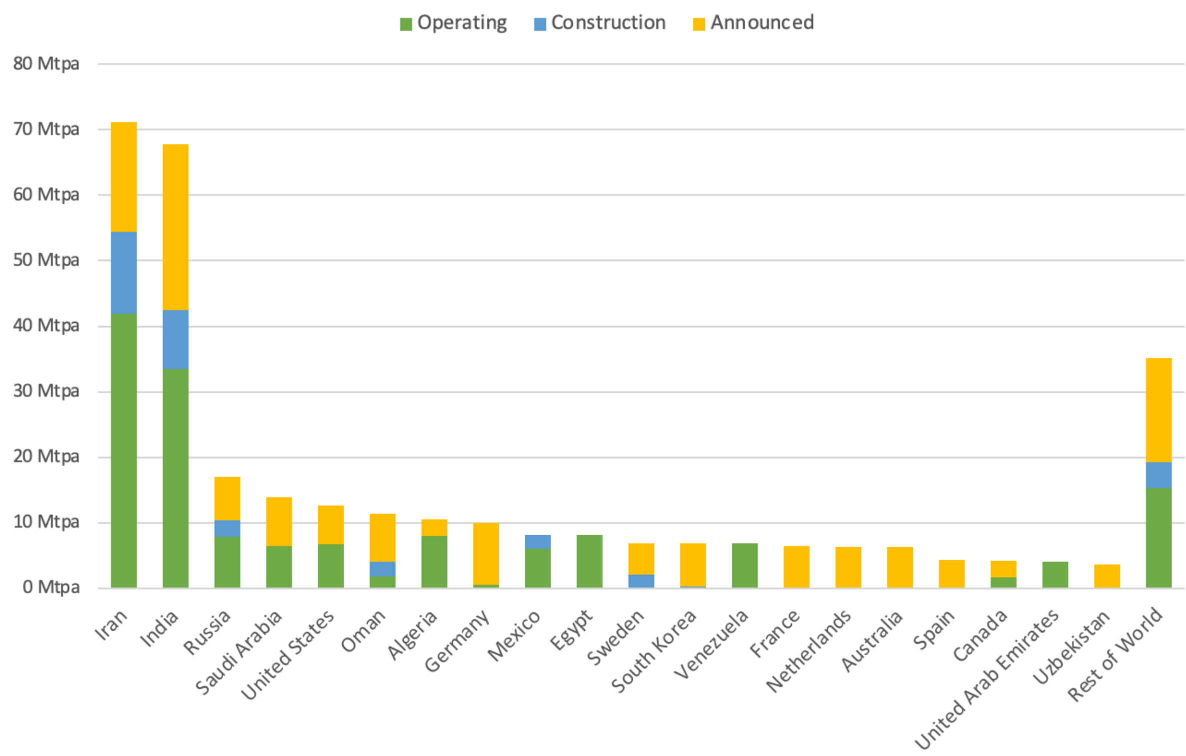
As of April 2024, there is 148.7 Mtpa of DRI capacity, with a further 34.7 Mtpa currently under construction. A further 138 Mtpa worth of capacity has been announced - Figure 3.2.

As of April 2024, Iran has 42 Mtpa of operating DRI capacity, 90% of which uses MIDREX technology. Whilst India has the largest capacity of rotary kiln DRI plants in the world, it also has the largest pipeline of new DRI capacity under construction and announced, with an

[21] GMK Center, Global DRI Production will Increase to 175Mt by 2030 - WSD, 28 September 2023
[22] Wood Mackenzie, Metalmorphosis: How Decarbonisation is Transforming the Iron and Steel Industry, October 2023

increasing proportion of gas-based DRI projects that could be transitioned to low-emission hydrogen in the future.

Figure 3.2: Global DRI Capacity Investments as of April 2024



Source: Global Energy Monitor [23]

MENA is rapidly emerging as a global hub for lower-emission ironmaking. The existing steel centres of Iran, Saudi Arabia, Algeria, Oman, Egypt, UAE etc. have world-leading new capacity pipelines for methane gas-based DRI production, which at current levelised costs of green hydrogen, even in regions with comparative advantages in Australia, Brazil, and the Middle East, will have materially lower costs of production for value-added iron and steel absent a pricing on embodied decarbonisation in international trade (detailed further in Section 7).

As discussed further in Section 6, there is significant new announced capacity in Europe, heavily supported by carbon pricing and strong public capital support for capex to accelerate the transition away from existing BF-BOF capacity in Germany, Sweden, France, Belgium, Spain, and Netherlands, as well as multiple rounds for production-based support for low-emission hydrogen production to further expedite the economic transition of new DRI plants to green hydrogen. However, the shock of sustained high energy price volatility relating to Putin's Ukraine invasion and the resulting ongoing sanctions against Russia, has really undermined investor confidence, suggesting a likely reorientation to importing DRI and green iron from regions with energy price comparative advantages.

The largest opportunity to reduce emissions is increasing circularity in the steel value chain, with scrap-EAF routes offering the most material reductions in emissions intensities and improvements in sustainability of steelmaking. Although China is the world's largest

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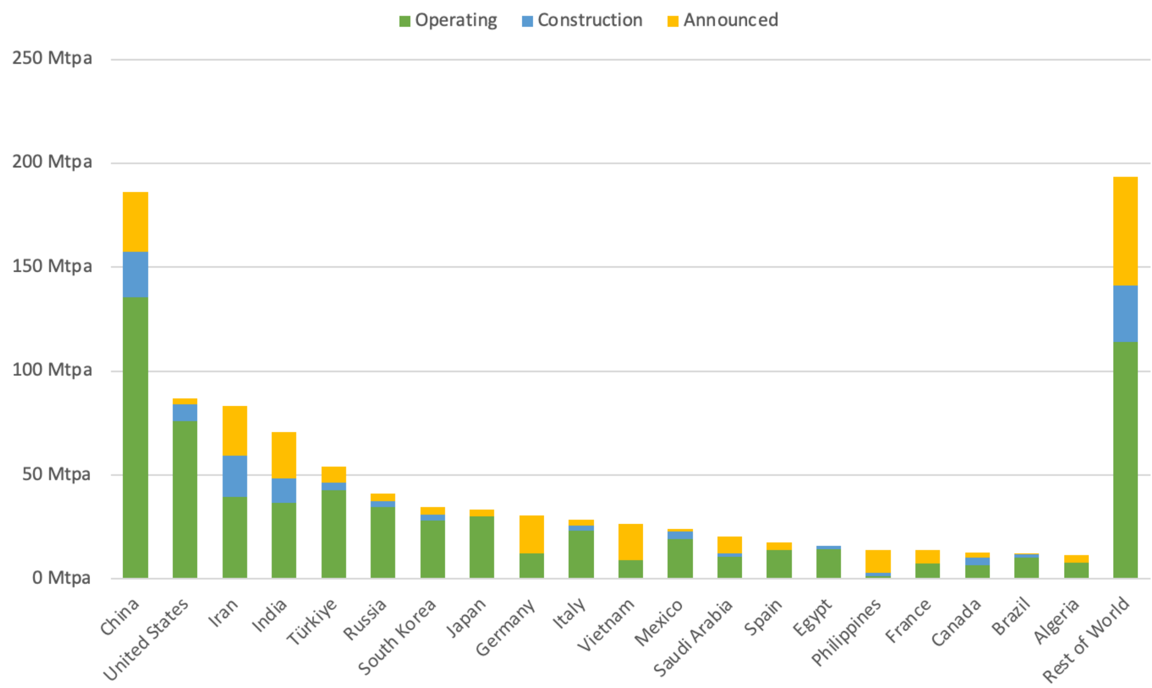
[23] GEM, Iron Capacity by Method and Development Status in Each Country, April 2024

producer of steel via the BF-BOF route, with over 832 Mtpa of BOF capacity operating as of April 2024, China is now also the largest producer of secondary steel, produced via EAFs.

Figure 3.3: Global EAF Capacity Investments as of April 2024



Source: Global Energy Monitor [24]

The world currently has 675 Mtpa of EAF capacity operating, with China the world leader by a significant margin, with over 135 Mtpa, more than 20% of global capacity, and 78% more than the second largest secondary steel producer, the USA - see Figure 3.3. Globally, there is over 114 Mtpa of EAF capacity under construction as of April 2024, with a further 222 Mtpa of capacity announced.

Whilst there is 172.8 Mtpa of new DRI capacity announced or under construction globally, which, if built, would more than double the current global DRI market, the lack of a credible high price signal to value decarbonisation, means investors collectively are still backing the highest emissions steel technology. There remains a further 99.8 Mtpa of BF capacity currently under construction, adding to the existing 1,262 Mtpa BF capacity globally. In addition, a further 207.7 Mtpa of BF capacity has been announced, largely in high-growth economies in the Global South that are prioritising the security of domestic steel production.

For the world to achieve its emission reduction objectives, we must accelerate, at scale, global collaboration on steel decarbonisation policies, including effective carbon pricing in international trade, to underpin the coordinated deployment of low-emission iron & steel technologies. CEF applauds the global leadership of the EU CBAM and encourages China to replicate this leadership.

[24] GEM, Steel Capacity by Method and Development Status in Each Country, April 2024

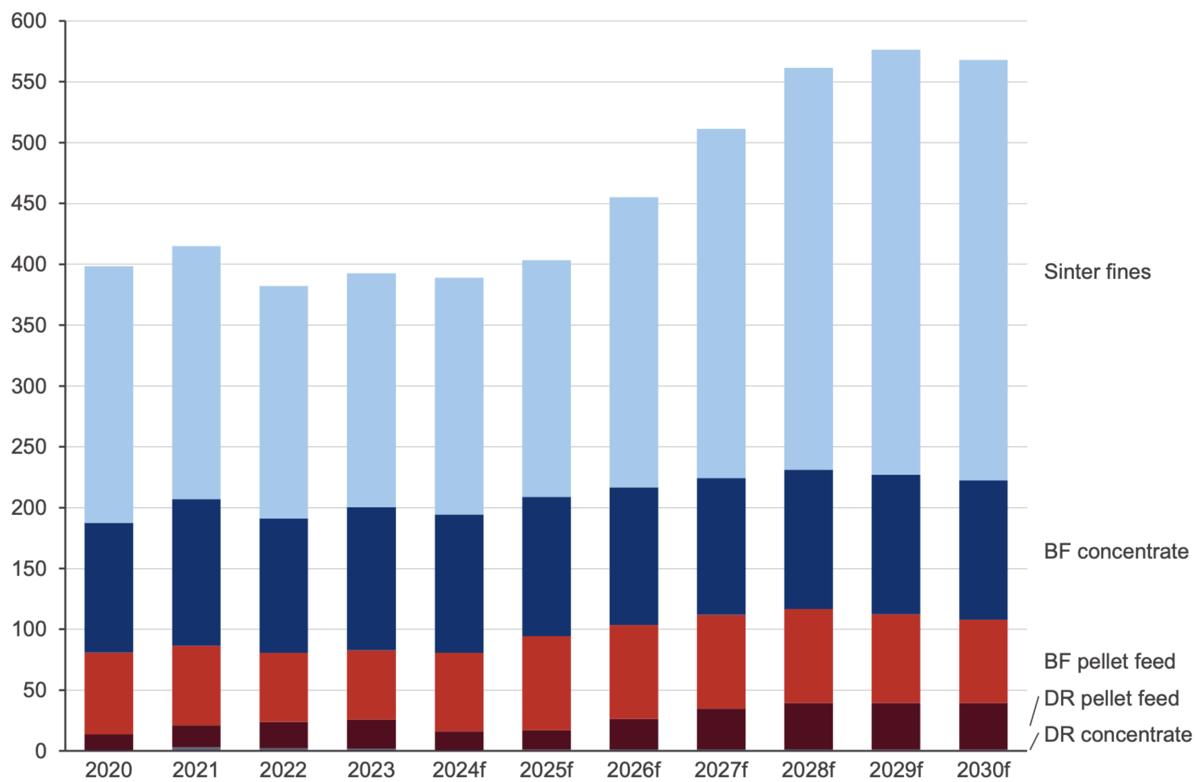
Challenges to Scaling DRI: Iron Ore Quality and GH_2

There are a number of technological challenges still to be addressed before global deployment of hydrogen-based ironmaking, largely due to the nature of the chemical reaction, balancing carbon content in the steel products, removal of gangue, and access to cost-competitive renewable hydrogen supply, which requires a dramatic 50-75% reduction in the total installed capital cost of electrolysers and ongoing renewable energy deflation and technology improvements.

Typically, DRI plants require high-grade iron ore feedstock with very low levels of impurities. DRI plants require an Fe content above 67%, with a combined acid gangue (silica + alumina + phosphorus) of less than 3%. In 2022, Mission Possible Partnership calculated only 13% of seaborne iron ore is above 65% Fe content, with less than 3% above 67% Fe content.[25]

However, DR-grade iron feedstock is also critically dependent on impurity content. Rio Tinto estimates current seaborne DR-grade concentrate and pellet feed at 20-25 Mtpa, ~ 6% of seaborne high grade iron ore (>64% Fe) - see Figure 3.4.

Figure 3.4: Seaborne Supply of High-Grade Iron Ore (>64% Fe), Mt



Source: Rio Tinto [26]

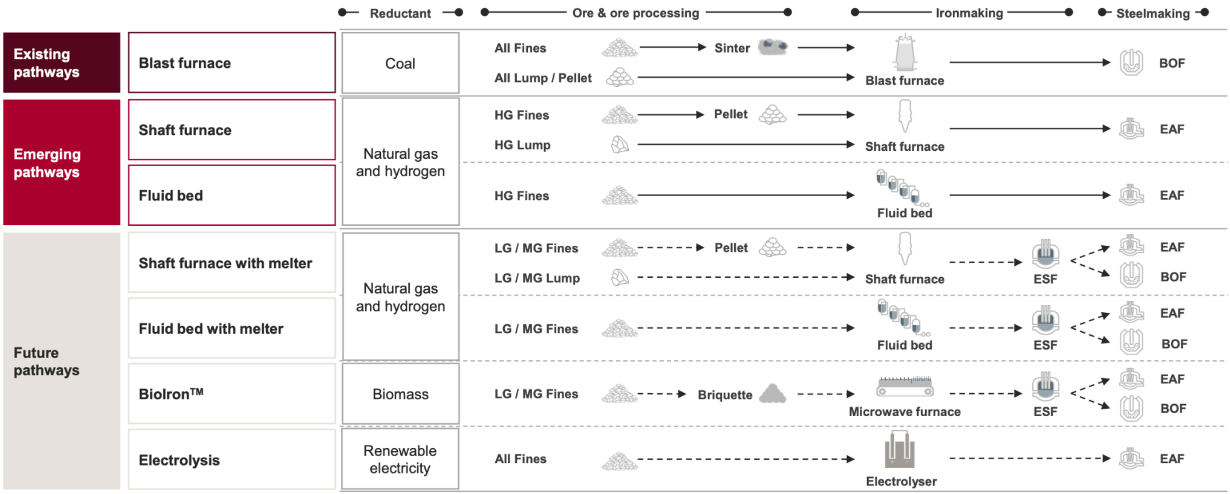
To unlock global decarbonisation of iron ore, we must address and overcome the technical challenges associated with iron ore qualities (particularly challenging for Australia), as we exhaust high-grade mineral deposits, meaning average iron content is falling, and the degree of impurities continues to rise. Reducing emissions from the iron and steel value chain will

[25] MPP, Making Net-Zero Steel Possible: Steel Transition Strategy, September 2022
[26] Rio Tinto, Financial Community Visit to North American Operations, 24 September 2024

require new technologies to be developed that enables the use of low- to mid-grade ores high impurities in an economically-viable process.

There are multiple pathways under development globally, however all are early-stage, with the majority still only in lab-, bench-, and pilot-scale trials. Such pathways are not likely to be deployed at a commercial-scale this decade. A summary of potential pathways, including Rio Tinto's BioIron (further detailed in Section 10) is shown in Figure 3.5.

Figure 3.5: Potential Emissions Reduction Pathways for Iron and Steel



Source: Rio Tinto [27]
Note: LG: low-grade, MG: mid-grade, HG: high-grade

Renewable Hydrogen Challenge

The second significant challenge to decarbonisation is the access to the massive volume of green hydrogen required to transition the gas-based ironmaking capacity away from fossil fuels. This is a significant bottleneck to global adoption at the necessary speed and scale. Whilst the expectation at the start of this decade was for green hydrogen electrolyser capital costs to fall 50-75% by 2030, this optimism has failed to emerge, with electrolyser prices actually rising in the first 3-4 years of this decade. The global hydrogen hype of 2020 rapidly deflated into 2022, witnessed by share price declines of pure hydrogen focussed firms like Plug Power and NEL Hydrogen of >50-95%.

Existing gas-based DRI plants use fossil-derived hydrogen and carbon monoxide blends to reduce iron ore. Green iron production generates a fraction of global hydrogen demand currently (<1%), with deployment and adoption of electrolysis-derived hydrogen technologies progressively scaling up, but at a rate far lower than expected. This has contributed to incredibly low manufacturing utilisation rates and inflating electrolyser stack capex costs. Combined with renewable energy costs rising in the western markets due to capital cost inflation and significantly higher long term interest rate expectations, the path to GH2 commercialisation is well into next decade, particularly absent a high price on carbon on high emissions fossil fuel alternatives.

[27] Rio Tinto, Finding Better Ways to Progress Steel Decarbonisation, 07 May 2024

Using 100% hydrogen as a reducing agent, the DRI process involves the reduction of hematite to magnetite, then wüstite, and then pure iron, as seen below.

Eq.1. hematite to magnetite: $3Fe_2O_3 + H_2 \longrightarrow 2Fe_3O_4$

Eq.2. magnetite to wüstite: $Fe_3O_4 + H_2 \longrightarrow 3FeO + H_2O$

Eq.3. wüstite to pure iron: $FeO + H_2 \longrightarrow Fe + H_2O$

Operating at a stable temperature is critical for the reaction to occur as well, with the reduction of hematite unstable at temperatures below 570ºC, and the reaction rate dropping significantly above 900ºC due to sintering (agglomeration, or sticking).[28] H_2-based reduction is an endothermic process, meaning additional heat must be supplied to enable the reaction of hydrogen and iron. As shown in Figure 3.6 below, the minimum amount of hydrogen required to reduce all iron is 54 kg/t.

Figure 3.6: Estimated Hydrogen Demand from Various Sources (Reductant Only)

Reference / Source for Hydrogen Requirements	GH_2 (kg/t-DRI)
Stoichiometry Stoichiometric demand required for the reaction of hematite and hydrogen to form iron and water. I.e. minimum volume for reducing.	54
Minerals Research Institute of WA Green Steel Value Chain Model, November 2023	59
RMI Green Iron Corridors, September 2024	54
HYFOR Mitsubishi Heavy Industries Technical Review, June 2022	54
MIDREX Fuelling the Future of Ironmaking, March 2024	58

The reduction of iron ore in a DRI plant will require significantly more hydrogen if also used as a source of heat. The Minerals Research Institute of WA's Green Value Chain Model estimates the hydrogen demand for ironmaking at 59 kg/t-HBI, in addition to the hydrogen requirements to pellet the iron ore feedstock (4.3kg/t-DRI magnetite feed, or 7.3kg/t-DRI hematite feed).[29]

MIDREX, the largest gas-based DRI platform operating globally, estimates 76-80 kg/t-DRI is required if using 100% green hydrogen.[30]

McKinsey & Co estimates the total hydrogen demand for producing 2Mtpa of H_2-based steel requires 144,000 tpa, working out to 72kg/t-cs.[31] McKinsey also estimates the total energy

[28] Journal of Cleaner Production, Decarbonisation and Hydrogen Integration of Steel Industries: Recent Development, Challenges and Techno-economic Analysis, 01 April 2023

[29] MRIWA, WA Green Steel Opportunity, updated 06 November 2023

[30] MIDREX, Fuelling the Future of Ironmaking: MIDREX Flex, March 2024

[31] McKinsey, Decarbonisation Challenge for Steel, 03 June 2020

required to produce 2Mtpa-cs is 8.8 TWh, or 4.4 MWh/t-cs. We use these estimates in our calculations in subsequent Sections.

There are currently no industrial-scale DRI plants in the world that operate on 100% hydrogen. The notable caveat is Stegra's green steel plant in Boden, Sweden, which will be powered by 100% green hydrogen, however this is still under construction.

A 2023 analysis by multiple researchers, including Prof. Geoffrey Brooks of Swinburne University of Technology, and a lead researcher with HILT CRC's iron & steel program, identified the total hydrogen required to replace the existing BF-BOF pathway is 104 kg/t-cs, with a 1 Mtpa steel plant requiring at least 660 MW of electrolyser capacity to produce the sufficient volume of hydrogen (assuming a 70% efficiency).[32] In 2023, 1,345 Mt of steel was produced globally via the BF-BOF pathway. This would require 140 Mtpa of green hydrogen, or 43 Mtpa more than all hydrogen produced globally in 2023, of which less than 1% was low-emission.[33]

Given Australia's exposure to lower grade iron ore resources, CEF urges stakeholders of Australia's iron industry, including the Federal Government, to implement urgent measures that support RD&D of new technologies and pathways.

CEF recommends providing an additional $500m over 10-years to the CSIRO of strategic support for RD&D into the commercialisation of technologies that will unlock and accelerate Australia's green iron industry. The role of the CSIRO is to provide innovative scientific and technology solutions to national challenges and opportunities to benefit industry, the environment and the community, through scientific research and capability development, services and advice.

CEF recommends a proportion of the $500m be deployed through CSIRO's partnerships in Australian cooperative research centres. An example for this is the Heavy Industry Low-Carbon Transition Cooperative Research Centre (HILT CRC), which supports R&D projects in iron and steel decarbonisation across industry and academic institutions, leveraging expertise and knowledge sharing across the global heavy industry value chain, with a key focus on overcoming the direct barriers and challenges for Australia.

[32] Journal of Cleaner Production, Decarbonisation and Hydrogen Integration of Steel Industries: Recent Development, Challenges and Techno-economic Analysis, 01 April 2023
[33] IEA, Global Hydrogen Review 2024, 02 October 2024

Section 4. State of Play: Green Hydrogen

Section summary:

- As of May 2024, only 1.75 GW of electrolyser capacity has been deployed globally, producing just 185 ktpa, or 0.2% of total hydrogen production.
- Despite massive manufacturing overcapacity, electrolyser capex still remains too high for projects without long-term offtake agreements to be bankable.
- In 2023, manufacturing overcapacity reached almost 30 GW compared to stacks shipped.
- BloombergNEF forecasts 50 GW of overcapacity in 2024, with stack shipments reaching a new all-time annual deployment record of 4.3 GW, less than a tenth of manufacturing capacity.
- In 2023, around 68% of global electrolyser manufacturing, or 21GW, is in China, with less than 10% of that manufacturing capacity owned by Western firms. Of the total installed production capacity globally, China has over 65%.

Implications for Australia:

- Like almost all cleantech industries, China dominates the manufacturing of electrolysers. **Australia must work collaboratively with China** to ensure we utilise its world-leading manufacturing base to lower the capital intensity of hydrogen production facilities to power Australia's green iron opportunity.
- CEF recommends policy support and financing mechanisms for hydrogen projects be primarily dedicated to powering green metal facilities in Australia. This is likely the most commercially-viable pathway for Australia, with much of the green hydrogen hype in recent years deflating globally, and the investment pipeline passed FID declines significantly.

As of May 2024, only 1.75 GW of electrolyser capacity has been deployed globally, with operational renewable hydrogen producing just 185,000 tpa. In comparison, CCS-based hydrogen production capacity supplies ~ 710,000 tpa, primarily in North America. More than 99% of the 90 Mtpa of hydrogen produced today is derived from hydrocarbons, with almost all supplied from grey hydrogen.[34] Hydrogen produced via electrolysis accounts for just 0.2% of global demand.

Of the 1.75 GW of installed electrolyser capacity, over 65% is in China - see Figure 4.1. China is home to the two largest operational renewable hydrogen projects in the world, the 260 MW Kuqa project[35] in Xinjiang Province, developed by state-owned China Petroleum and Chemical Company (Sinopec), and the 150 MW alkaline electrolyser project in Ningxia, developed by Ningxia Baofeng Energy Group.[36]

The Hydrogen Council has identified over 430 clean hydrogen[37] projects globally that have reached final investment decision (FID) in 2024, representing ~ US$75bn.[38] This is significant growth from the estimated US$10bn committed to clean hydrogen projects identified by the Council in 2020. Should these projects move beyond FID into construction and operation, global investments identified have the potential to produce up to 4.6 Mtpa of clean

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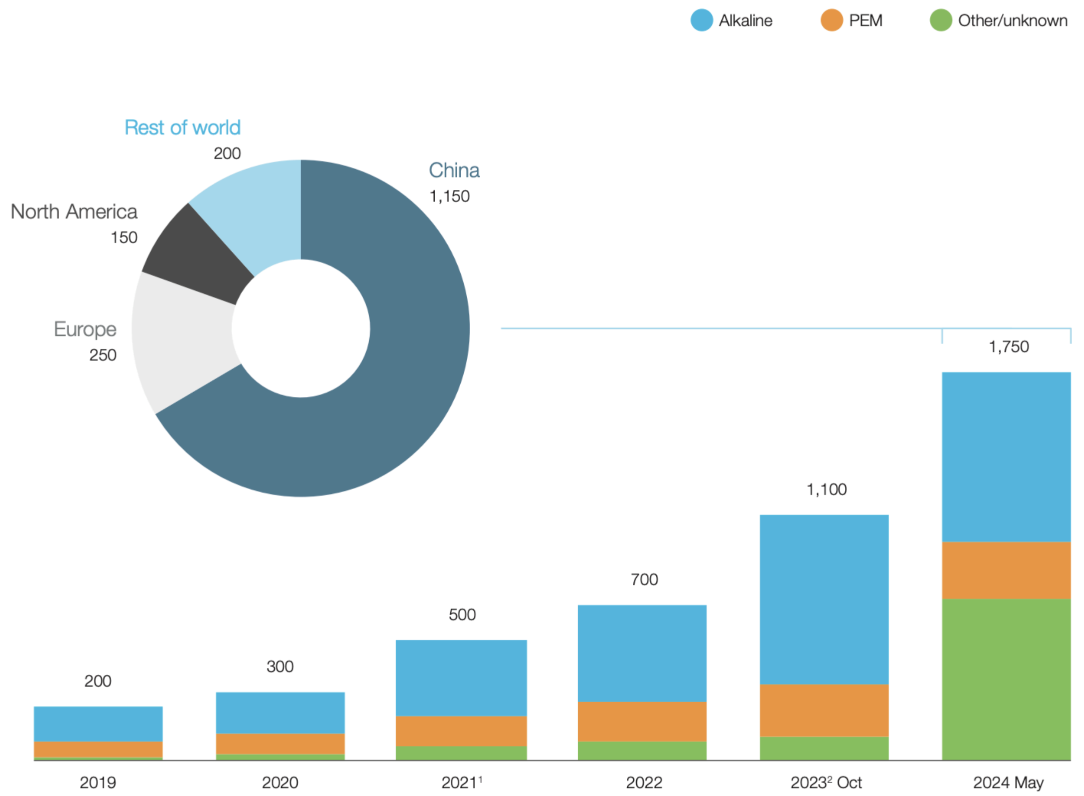
[34] McKinsey, Global Energy Perspective 2023: Hydrogen Outlook, 10 January 2024
[35] Hydrogen Insight, World's Largest Green Hydrogen Project Begins Production in China, 30 June 2023
[36] Hydrogen Insight, World's Largest Green Hydrogen Project Brought Online in China, 01 February 2022
[37] Note: clean hydrogen refers to both renewable (green) hydrogen and low-carbon (blue) hydrogen
[38] Hydrogen Council, 2024 Hydrogen Insights, September 2024

hydrogen by 2030. North America holds over 90% of global low-carbon hydrogen capacity that has passed FID, largely attributable to significant policy incentives for CCS (US$85/t tax credit 45Q under the IRA).

Figure 4.1: Cumulative Global Installed Electrolysis Capacity



Source: Hydrogen Council, McKinsey [39]

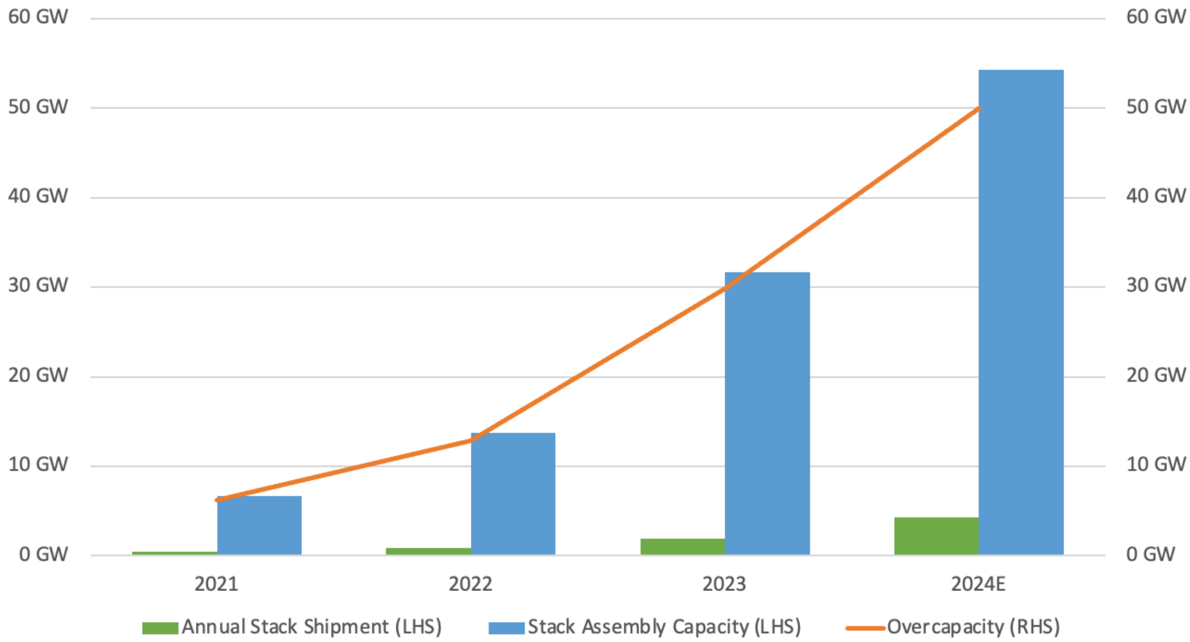
Of the 375 GW of electrolysis capacity announced through 2030, only 26 GW has passed FID, and this is largely being deployed in China. As of 2024, China accounts for 65% of committed electrolyser capacity, followed by North America (10%), Middle East (10%), and Europe (5%). Within China, 95% of the deployed capacity is based on alkaline technology. In contrast, PEM technology accounts for 60% of installed electrolyser capacity across North America and Europe.

The low adoption and deployment of green hydrogen projects is not a product of limited manufacturing capacity, restricting supply in booming demand. The reality is in fact the opposite. BNEF's 2024 Electrolyser Manufacturing report identified nearly 30 GW of manufacturing overcapacity compared to stacks shipped in 2023, with 31.7 GW of manufacturing online, nearly 17x that delivered - see Figure 4.2.

Despite this, electrolyser OEMs have announced further expansions, with BNEF forecasting annual stack assembly capacity to exceed 54 GW in 2024, and rising to nearly 75 GW by 2025.[40] BNEF forecasts 50 GW overcapacity in 2024, with stack shipments reaching a new all-time annual deployment record of 4.3 GW, less than a tenth of manufacturing capacity.

[39] Hydrogen Council, 2024 Hydrogen Insights, September 2024
[40] Hydrogen Insight, Severe Overcapacity: The Global Supply of Electrolysers Far Outstrips Demand from Green Hydrogen Projects, 28 March 2024

Figure 4.2: Global Electrolyser Manufacturing: Significant Overcapacity



Source: BloombergNEF [41]

In 2023, around 68% of global electrolyser manufacturing, or 21GW, is in China, with less than 10% of that manufacturing capacity owned by Western firms. Significant competition emerging in alkaline technology manufacturing saw the market share of the top ten manufacturers account for 50% in 2023, down from 84% in 2021. The PEM technology market remains more concentrated, with five firms accounting for ~ 72% of production by the end of 2024.[42] However, market power from PEM OEMs remains limited in the broader electrolyser market, with alkaline technologies maintaining an 80% market share.

In 2024, BNEF highlighted only one pure-play electrolyser OEM recorded a profit in 2023, with Thyssenkrupp Nucera realised a US$23m net income over 2023 - primarily due to the ongoing fulfilment of the 2.2GW order construct for the Neom project in Saudi Arabia. On the other side, Plug Power recorded a near US$1.4bn loss over 2023.[43]

Thyssenkrupp Nucera (Nucera), a publicly-listed division of Thyssenkrupp, is a leading non-Chinese alkaline electrolyser OEM. As of August 2024, Nucera is actively pursuing 37 projects with more than 22 GW of cumulative electrolyser capacity, with an average project size of ~ 600 MW.[44]

In May 2023, Nucera announced it will supply more than 700 MW of AWE capacity to Stegra's green steel plant in Boden, Sweden.[45] Nucera will install a series of 20 MW Scalum modules to produce green hydrogen for the world's first large-scale green steel plant, powered primarily from hydroelectric and wind power.

[41] BNEF via LinkedIn, Electrolyser Manufacturing 2024: Too Many Fish in the Pond, March 2024
[42] Hydrogen Insight, Severe Overcapacity: The Global Supply of Electrolysers Far Outstrips Demand from Green Hydrogen Projects, 28 March 2024
[43] Hydrogen Insight, Severe Overcapacity: The Global Supply of Electrolysers Far Outstrips Demand from Green Hydrogen Projects, 28 March 2024
[44] Tk Nucera, Q3 2023/24 Results Presentation, 13 August 2024
[45] Tk Nucera, Nucera Supplies the Electrolysers for H2 Green Steel, 22 May 2023

Globally, large-scale green hydrogen plants have faced significant technical challenges and inability to consistently produce at high efficiencies. Sinopec's 250 MW Kuqa alkaline electrolyser has struggled to produce hydrogen at a commercial level since it began operations. Sinopec has confirmed the world's largest operational plant is producing at just 20% of its planned capacity. A report by BNEF highlighted numerous technical problems with the three electrolyser OEMs (Cockerill Jingli, LONGi and Peric), including the inability to safely produce hydrogen when receiving electricity that results in production of less than 50% of its maximum output.[46]

The global lack of manufacturing capacity utilisation for electrolysers has resulted in far slower than anticipated capex deflation. As seen in other cleantech markets, technology learning curves have progressed as demand increases. In June 2024, Hydrogen Europe highlighted electrolyser capex for hydrogen stacks produced in the EU are up to 3-4x that of Chinese OEMs, with the premium reaching up to €600/kW for alkaline technology and up to €1,000/kW for PEM technology, primarily driven by China's world leading deployment and manufacturing capacity.[47]

Even with the relative competitiveness of Chinese OEMs, Wood Mackenzie estimates the capex of alkaline water electrolysis (AWE) at US$180-240/kW in China, and PEM electrolysers at US$830-1,200/kW.[48] AWE can operate at a minimum load of ~ 30%, whereas PEM can operate at ~ 5% minimum load, making PEM technologies far more compatible with variable renewable energy sources. Over 2023, the Chinese domestic average bid-winning prices for Chinese OEMs were US$242/kW for AWE, and US$1,105/kW for PEM, over 4.5x greater capital cost.[49] Chinese OEM capacity is 96% AWE, with just 4% of manufacturing capacity into PEM electrolysers.

The slower than anticipated capex deflation is particularly evident in Australia. CSIRO's 2023-24 GenCost calculated electrolyser capex in 2023 was $3,141/kW for PEM, and $1,919/kW for alkaline. Although lower than the $3,510/kW for PEM and $2,516/kW for alkaline capex from CSIRO's 2020-21 GenCost, it is a 77% and 29% premium respectively above the 2020-21 model's forecast for 2023.[50]

Given China's leadership in electrolyser manufacturing, Australia must work collaboratively with China to ensure we utilise its world-leading manufacturing base to lower the capital intensity of hydrogen production facilities to power Australia's green iron opportunity. CEF recommends policy support and financing mechanisms for hydrogen projects be primarily dedicated to powering green metal facilities in Australia. This is likely the most commercially-viable pathway for Australia, with much of the green hydrogen hype in recent years deflating globally, and the investment pipeline passed FID declines significantly.

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[46] Hydrogen Insight, Problems at World's Largest Existing Green Hydrogen Project will not be Solved until late 2025, 02 January 2024
[47] Hydrogen Europe, Clean Hydrogen Production Pathways, June 2024
[48] WoodMac, Lens Hydrogen: Sinopec Kuqa Case Study, 07 August 2024
[49] WoodMac, Lens Hydrogen: Sinopec Kuqa Case Study, 07 August 2024
[50] CSIRO, 2023-24 GenCost Report, 22 May 2024

Section 5. North Asian Steel Industry: State of Play and Emissions Reduction Pathways

Chinese Steel Decarbonisation

Section summary:

- In CEF's view, China has likely peaked in steel production. Supported by increasing policy measures to decarbonise the domestic steel industry, CEF believes China has also already peaked steel emissions.
- In the 8M2024, China exported 70.6Mt of finished steel products, +21% yoy at unsustainably low prices. Annualised, China is expected to export 106Mt in 2024, a near record high.
- In August 2024, China's MIIT expanded further on the limitations of new steel capacity, publishing a notice to suspend the steel production capacity replacement mechanism, effectively announcing the suspension of all new steel plant permits until further notice.
- It is clear China is prioritising emissions, energy, and capacity reduction through the replacement of BF-BOF integrated facilities with that of scrap-EAF supply chains.

Implications for Australia:

- Australia must recognise and act on the future expectations of carbon pricing mechanisms placed on China's steel sector**.** Whilst the pricing of the Chinese ETS is still averaging only US$10/t, by volume this scheme is the largest in the world, covering 40% of China's total energy emissions, 4x the EU ETS. Coverage is expected to soon include energy-intensive industrial sectors, including iron and steel production.
- As China accelerates its transition to a decarbonised steel industry, there is a huge opportunity for new low-emission iron supply chains into China to cover the deficit between China's steel production and scrap availability.
- To capitalise on this, CEF recommends establishing an **Australasian Green Iron Corporation JV** between Australia and other key regions like China to enable international partnerships and collaboration across the green metals value chain, facilitating the involvement of Australia's iron ore mining majors and China's leaders in steel production. This will facilitate the transfer of critical skills, technology, investment, and alignment of decarbonisation objectives to reduce domestic and exported emissions.

May 2024 saw China's State Council release a plan for energy conservation and carbon reduction over 2024-25, curbing production capacity in coal, crude oil and steel.[51] The State Council expects China's energy consumption to fall 2.5%, and emissions intensity per unit GDP to fall 3.9% this year, with the proportion of non-fossil energy consumption to rise 18.9% in 2024, and further to 20% in 2025. The steel sector decarbonisation objectives would reduce standard coal use by 20 Mtpa, and CO_2 emissions by 53 Mtpa over 2024-25.

China has likely peaked in steel production. Supported by increasing policy measures to decarbonise the domestic steel industry, CEF believes China has already peaked steel emissions. The China property sector slowdown has seen a rapid increase in steel exports at unsustainable prices. In the 8M2024, China exported 70.6Mt of finished steel products, +21% y-o-y. Annualised, China is expected to export 106Mt in 2024, a near record high.[52]

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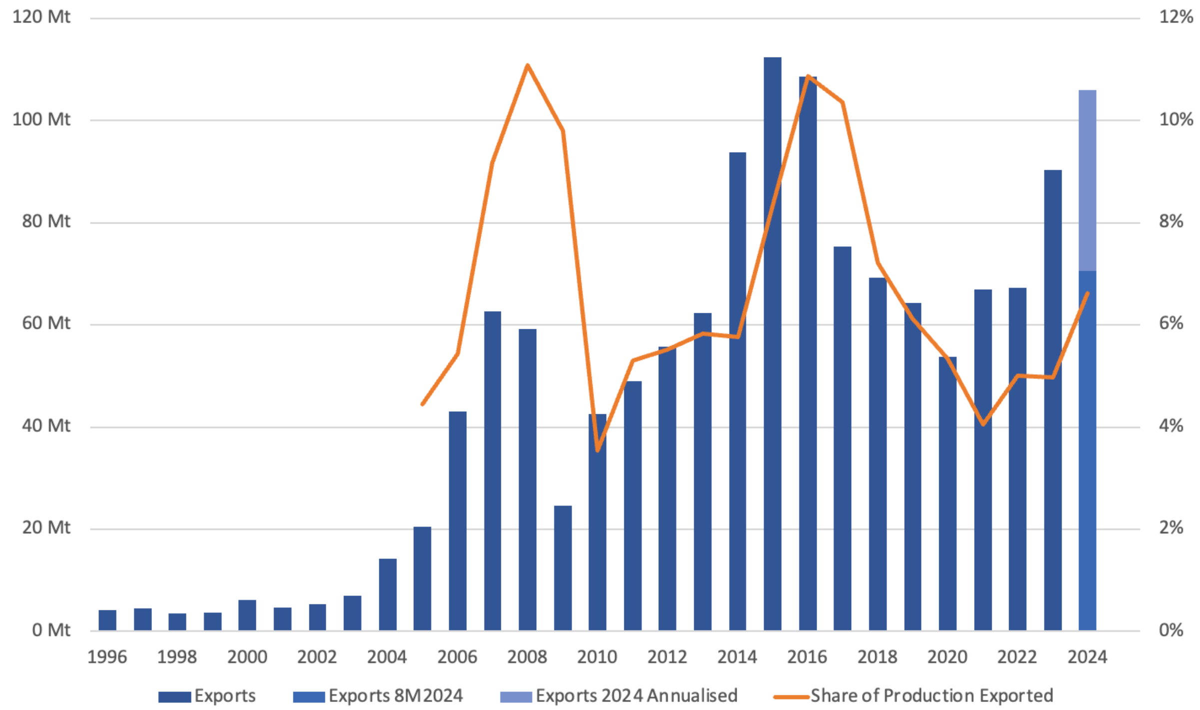
[51] Argus, China Net Zero Plan to Curb Coal, Crude, Steel Capacity, 31 May 2024
[52] CGAC, Monthly Statistics: (13) Major Export Commodities in Quantity and Value, August 2024

Figure 5.1: Chinese Finished Steel Exports



Source: China General Administration of Customs

China is exporting steel at significantly lower prices compared to the previous 5 years. In the 8M2024, average realised export price for finished steel was US$779/t, down 44% from the 2022 high of US$1,391/t. China's total steel production was -6% yoy in September 2024.

This pricing pressure has meant most Chinese steel firms are loss-making in 2024. In August 2024, the AFR reported a MySteel survey of Chinese steelmakers, revealing that only 1% of domestic steel mills were currently profitable.[53]

September 2024 saw Bloomberg report almost 75% of China's steelmakers suffered losses in 1H2024, with Bloomberg Intelligence expecting a wave of bankruptcies and acceleration of consolidation across the domestic steel industry. The Chinese Government is targeting a mass consolidation with the objective of a 40% market share for the top 5 companies by 2025, and the top 10 steelmakers accounting for 60% of the domestic market.[54]

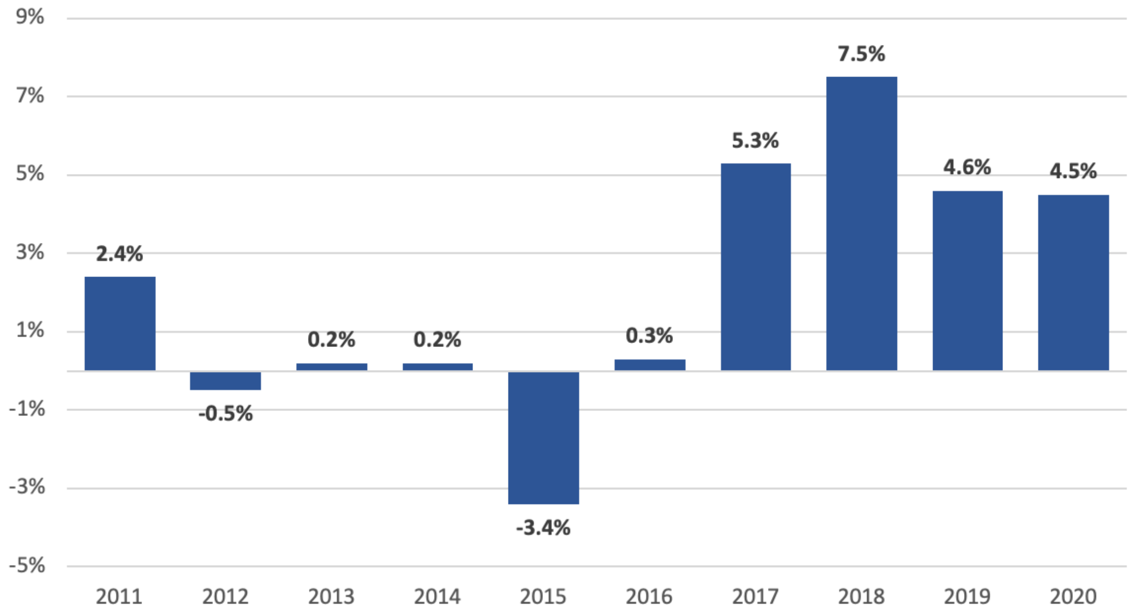
Analysis by Shanghai Metals Market calculated China's top 10 steelmakers combined output of 444 Mt in 2022 represented 43.6% of domestic production, with the top 20 accounting for 57.7% in 2022 (588 Mt).[55]

China's aggregate gross operating profits across all steelmakers have shown countercyclical trends over the 2010s, with periods of high export growth resulting in firms barely breaking even on gross profit, and generating losses - see Figure 5.2. This is largely in part due to periods of low, or reduced, domestic demand for steel products. Figure 5.2 highlights the limited gross profit margins for China's steelmakers, with the objective of domestic producers, historically, focussed primarily on establishing global market share through rapid

[53] AFR, The Number that Should Scare All Australians, 25 August 2024
[54] Bloomberg, China Steel Mills Are Facing a Wave of Bankruptcies BI Says, 23 September 2024
[55] SMM, Chinese Steel Firms are Consolidating and Restructuring, 13 December 2023

scaling of capacity and sustained growth in production volumes to fuel the urbanisation and industrialisation of the domestic economy, with short-term profits taking a back seat.

Figure 5.2: China Aggregate Gross Operating Profit Margin



Source: CEIC Data from MRIWA[56]

With peak domestic steel consumption in China likely back in 2020, the world is now witnessing a pivotal moment in China's steel industries, with central planning shifting from prioritising and incentivising volume, to producing higher-quality steel products, with the 'High Quality Development' national strategy transitioning to a more balanced, sustainable, and economic model.[57]

In May 2021, China's Ministry of Industry and Information Technology (MIIT) announced the 'Implementation Measures for Capacity Replacement in the Steel Industry', which entered into effect on 01 June, 2021.[58] The objective of the policy was to reduce overall pig iron and steel capacity, and increase the share of electricity-based EAFs in China's output.

The result of the policy to limit the growth of fossil-based iron and steelmaking has been clearly demonstrated by the stagnation of pig iron production. From 2004 to 2020, Chinese pig iron production grew at a 7.8% CAGR, peaking at 888Mt in 2020. Since 2021, pig iron production has stagnated, with annualised 8M2024 data indicating a 2024 volume of 867Mt, 2Mt less than 2023.[59]

The capacity swap mechanism included a swap ratio of 1.5:1 for BFs in areas susceptible to atmospheric pollution, i.e. reducing capacity of new plants to ⅔ of that of the retiring BFs, and a ratio of 1.25:1 in other areas.

[56] MRIWA, WA Green Steel Opportunity, updated 06 November 2023
[57] OECD, Steel Market Developments: Q2 2024, 12 June 2024
[58] MIIT, Notice of the MIIT on Issuing the Implementation Measures for Capacity Replacement in the Steel Industry 2021 (No. 46), 06 May 2021
[59] NBS, Monthly Output of Pig Iron, August 2024

If steelmakers switched to new EAFs, the ratio was up to 1:1. The State Council expected the proportion of steel produced via EAF to rise to 15% of total crude steel production by the end of 2025, with scrap utilisation reaching 300 Mtpa, with energy intensity also dropping 2% by 2025, relative to 2023.

In August 2024, MIIT expanded further on the limitations of new steel capacity, publishing a notice to suspend the steel production capacity replacement mechanism, effectively announcing the suspension of all new steel plant permits until further notice.[60] The notice outlined that 'at present, the supply and demand relationship in the steel industry is facing new challenges, and green and low-carbon [transition and] structural adjustment…[have] put forward new requirements'.

This followed on from an unprecedented period of limited steelmaking approvals, with the Centre for Research on Energy and Clean Air (CREA) reporting in 1H2024, approving **no new BOF** capacity, and approving over 7 Mt of new EAF capacity.[61] It is worth noting that through the capacity swap mechanism, 8 Mt of new BF capacity was approved over the same timeframe.

It is clear China is prioritising emissions, energy, and capacity reduction through the replacement of BF-BOF integrated facilities with that of scrap-EAF supply chains. China has a unique, and unreplicable advantage in establishing a majority scrap-EAF steel industry given its share of crude steel production globally, and the fact that the vast majority of China's steel production has remained onshore. Scrap steel recycling is being prioritised.[62]

Even as steel exports peaked in 2015-16, the share of steel exported has always remained less than 12% of production. As a result, Wood Mackenzie forecasts China's scrap steel supply to grow at 1.8% CAGR from 2021 to 2050, accounting for 33% of global scrap supply by 2050, and the majority of China's steel feedstock.[63]

October 2024 China Baowu announced progress on its plans to build a zero-carbon plant, with an investment of 4.5bn yuan (US$631m) and powered by green hydrogen and green electricity in Zhanjiang in the southern province of Guangdong, will be completed in 2025.[64]

October 2024 saw Baowu report 3QCY2024 net profit -65% yoy to 1.34bn yuan (US$188m).[65]

China: Carbon Pricing and the ETS

In September 2020, President Xi Jinping announced that China will "aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060" (the "dual carbon" goals). A key policy step to deliver on this ambition saw China move from seven regional pilot ETS schemes to a national ETS in July 2021. This ETS was initially imposed just on the electricity sector. Whilst the pricing of the Chinese ETS is still averaging only US$10/t, by volume this scheme is the largest in the world, covering 40% of China's total energy

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[60] MIIT, Notice of the General Office of the MIIT on Suspending Steel Production Capacity Replacement Work 2024 (No. 327), 22 August 2024
[61] CREA, Turning Point: China Permitted No New Coal-Based Steel Projects in 1H2024, 11 July 2024
[62] Bloomberg, China's Recycling Push Risks Weighing Down Demand for Metals, 21 October 2024
[63] Wood Mackenzie, Metalmorphosis: How Decarbonisation is Transforming the Iron and Steel Industry, October 2023
[64] Reuters, Simandou to mine first cargo by end of 2025, 30 October 2024
[65] Bloomberg, China's Top Steelmaker Still Turns a Profit as Sector Struggles, 30 October 2024

emissions, 4x the EU ETS.[66] Coverage is expected to soon include energy-intensive industrial sectors – including petrochemicals, chemicals, building materials, iron and steel, non-ferrous metals, paper and domestic aviation – which account for another 30% of energy sector emissions.

In 2024, China tightened regulations governing the national ETS. Previously, there were no laws or administrative regulations for the management of emissions trading in China, with the Ministry of Ecology and Environment (MEE) lacking authority, proving difficulty in regulating trading, ensuring quality of reporting and to punish illegal acts.

From 1 May 2024, stricter regulations that strengthen state control and crack down on emissions data fabrication will come into effect.[67] July 2024 saw MEE issue new rules to tighten the ETS and curb emissions to accelerate the green transition.[68]

The current national ETS covers 2,257 enterprises from China's power sector as of the end of 2023. The facilities covered under the ETS emit ~5.1 billion tonnes of CO_2-e annually.[69] As of the end of 2023, a total of 440 Mt CO_2-e of carbon emissions were transacted, with the transaction volume reaching RMB 24.9 billion (US$3.4bn). The emissions transacted were equivalent to the annual emissions of Australia in the year to March 2024.[70]

However, carbon prices remain relatively low at ~RMB 70-90/t (US$10-12/t), far below the ~US$86/t price under the EU ETS.

As China accelerates its transition to a decarbonised steel industry, there is a huge opportunity for new low-emission iron supply chains into China to cover the deficit between China's steel production and scrap availability.

[66] IEA, Enhancing China's ETS for Carbon Neutrality: Introducing Auctioning, May 2024
[67] SCMP, China Strengthens State Control on Carbon Emissions Trading, 05 February 2024
[68] Bloomberg, China's New Carbon Market Rules Aim to Reduce Oversupply, 02 July 2024
[69] SCMP, China Strengthens State Control on Carbon Emissions Trading, 05 February 2024
[70] DCCEEW, Australia's GHG Emissions: March 2024 Quarterly Update, updated 30 August 2024

Section 5.1. Australian and North Asian Collaboration

Section summary:

- Japan has introduced the GX Roadmap, a public private co-investment strategy aimed at deploying JPY 150 trillion (~ US$1 trillion) into industrial decarbonisation.
- Japan's steel industry remains heavily dependent on BF-BOF production, with Nippon Steel, JFE Steel and Kobelco collectively operating 20 blast furnaces domestically.
- The primary focus of achieving the Japanese majors' 30% emissions intensity reduction target by 2030 is the retrofitment of BFs with COURSE50, which uses a combination of fossil gas recycling, hydrogen injection and **unproven CCS technologies** to achieve a maximum 50% reduction in emissions.
- In its global study of CCS-based pathways for iron and steel decarbonisation in April 2024, IEEFA highlighted that despite decades of implementation and testing in a range of similar sectors, there are no commercial CCS plants for coal-based steelmaking anywhere in the world.
- Reliance on carbon capture is already being left behind globally in the steel sector, just as it has been in other key sectors, including power generation.
- In March 2024, South Korea's financial institutions pledged to provide KRW 420 trillion (US$313bn) in policy loans through 2030 to finance projects that will accelerate Korea's pathway to achieving its 40% NDC emissions reduction target by 2030
- Korea's largest steelmaker, POSCO, is investing KRW 29 trillion (US$21bn) into domestic decarbonisation of its Pohang steelworks.
- POSCO also plans to invest US$40bn into Australia's green metal industry, allocating US$28bn into green hydrogen and $12bn into green iron and steel by 2040.

Implications for Australia:

- Given the continued rise in energy and electricity generation as a proportion of manufacturing and refining costs, heavy industries will see a shift away from co-locating with demand centres – which used historically lower-cost, high-emission fossil fuel imports (of coal, LNG, oil) – to co-locate energy-intensive industries with regions with abundant low-cost, zero emissions renewable resources.
- Australia has a once-in-a-century opportunity to pivot and capture a greater share of value-add across energy and resource industries, leveraging public-private partnerships and inbound foreign direct investment from global sector leaders.

To capitalise on the opportunity for North Asian collaboration with Australia, CEF recommends establishing a **Trilateral Clean Commodity Trading Company** (CCTC), jointly owned by Australia, South Korea, and Japan to accelerate the development of decarbonised, value-added industries in Australia, initially green iron. The CCTC's mandate would be to contract, purchase, and trade commodities produced via low-carbon pathways, while optimising the economic, political, environmental, and geostrategic benefits for the parties, and minimising government financial support by operating with a commercial mindset, while understanding governments' enabling role.

This would also provide the platform to leverage international strategic public capital from the financing institutions of each party, including Australia's domestic EFA, NAIF, NRF, Future Fund, and the CEFC, as well Japan's export credit agencies Nippon Export and Investment Insurance (NEXI) and Japan Bank for International Cooperation (JBIC), as well as Korea's Trade Insurance Corporation (K-SURE) and Export-Import Bank of Korea (KEXIM).

Japanese Steel Decarbonisation

February 2023 saw Japan's Cabinet approve the Green Transformation (GX) Policy, a 10-year roadmap of Japan's decarbonisation strategy in order to achieve its Nationally Determined Contribution (NDC) of 46% emissions reduction by 2030, and carbon neutrality by 2050.[71] Japan's GX Roadmap is the transformation of the entire economic and social system from an economy and industrial structure dependent on fossil fuels to 'structures driven by clean energy' – driving economic growth through emissions mitigation.[72]

The GX Roadmap aims to achieve JPY 150 trillion (~ US$1 trillion) of public and private capital investment into decarbonisation industries. The roadmap also targets carbon pricing mechanisms via an emissions trading scheme (GX-ETS) for high-emission sectors, and the introduction of a carbon levy for fossil fuel importers, with the price on carbon gradually ratcheting up to increase investment into clean energy sources to cut reliance on fossil fuels.

Japan is home to three steel majors: Nippon Steel, JFE Steel, and Kobe Steel. November 2023 analysis by Transition Asia identified the big three are falling well short of their necessary emissions reduction pathways required to limit global warming to 1.5°C. Nippon, JFE and Kobe are projected to exceed their carbon budgets by 821 Mt, 527 Mt and 137 Mt of CO_2-e respectively between 2019 and 2050.[73] The majors all have an interim emissions reduction target of 30% by 2030, relative to 2013, and a target of reaching carbon neutrality by 2050.

Japan's steel industry remains heavily dependent on BFs to produce iron, with Nippon Steel currently operating 11 BFs across 8 steelmills, JFE Steel operating 7 BFs across 3 sites, and Kobelco operating 2 BFs at one steel facility.

The primary focus of steel decarbonisation in Japan is the retrofitment of carbon abatement technologies to blast furnaces. COURSE50 is a technology under development by the three majors. The process involves hydrogen injection into BFs, retrieved from by-product gas emitted during the standard operation of a BF, with the hydrogen used as a reducing agent to partially displace the volume of coking coal used in the iron reduction reactions. The next phase is SUPER COURSE50, which injects external hydrogen in addition to the COURSE50 process. COURSE50 plants will also heavily rely on CCS to achieve emissions reduction.

IEEFA highlighted in a global study of CCS-based pathways for iron and steel decarbonisation in April 2024 that despite decades of implementation and testing in a range of similar sectors, there are no commercial CCS plants for coal-based steelmaking anywhere in the world.[74] The study concluded that prioritising alternative pathways to emissions reduction will provide far more cost-competitive abatement solutions i.e. DRI-EAF and scrap-EAF.

This is highlighted in the investor pipeline of lower-emission iron and steel projects globally. Following the capital flows in respective technology's abilities to achieve cost-competitive emissions reduction, shows that since 2020, the 2030 project pipeline for DRI plants has grown to 94 Mtpa, while the pipeline for commercial-scale CCUS on BFs has amounted to just 1 Mtpa. Reliance on carbon capture is already being left behind globally in the steel sector, just as it has happened in other key sectors, including power generation.[75]

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[71] International Carbon Action Partnership, Japan's Cabinet Approves Plans for National ETS, 22 February 2023
[72] GR Japan, Overview of Japan's Green Transformation (GX), January 2023
[73] Transition Asia, Low Carbon Steel Development in Japan, November 2023
[74] IEEFA, Carbon Capture for Steel? CCUS Will Not Play a Major Role in Steel Decarbonisation, 17 April 2024
[75] IEEFA, Carbon Capture for Steel? CCUS Will Not Play a Major Role in Steel Decarbonisation, 17 April 2024

Korean Steel Decarbonisation

July 2023 saw **POSCO**, Korea's largest steelmaker, announce plans to invest KRW 121 trillion (US$92bn) by 2030 into battery materials, H_2 supply chains and steel decarbonisation.[76]

October 2024 saw POSCO announce plans to invest KRW 29 trillion (US$21bn) of that into steel decarbonisation technologies, with a further KRW 1 trillion (US$730m) into a blue hydrogen supply chain.[77] AS CEF discussed in Section 2, POSCO is building a 0.3 Mtpa demonstration-scale plant of its HyREX technology in its Pohang steelworks precinct.

The media report outlined a significant portion of the capital allocation to steel decarbonisation would be into multiple DRI facilities in Pohang, that would then feed into new EAFs. The first phase of the project, a new EAF, is due to begin construction in June 2025. It also stated POSCO had plans to construct additional DRI facilities at its other key steel precinct in Gwangyang.

Korea's Ministry of Economy and Finance announced it will shorten the planning processes for the Pohang precinct by 11 months, fast-tracking environmental impact assessments, as well as expanding green financing from KRW 6 trillion in 2024 to KRW 9 trillion in 2025, as well as increasing financial support for R&D on carbon neutrality technologies. The Ministry also pledged to increase investment tax credits for new technologies to 10% for nationally strategic technologies, including POSCO's HyREX process.[78]

Korea's first steelmaker, **Hyundai Steel**, has the largest portfolio of EAFs in Korea, with plants in Incheon, Pohang and Dangjin producing up to 12 Mtpa of lower-emission steel. In April 2023, Hyundai Steel announced its Carbon Neutrality Roadmap, aiming for an emissions intensity reduction of 12% by 2030, and achieving net zero by 2050. A key catalyst for the focus on steel decarbonisation was to comply with increasing carbon emissions regulations in key export markets, namely **EU's CBAM**.[79]

Australia's largest trading partners, and their respective fossil fuel energy-intensive industries, have recognised the importance of mobilising capital at speed and scale to achieve the global goal of net zero by 2050.

In March 2024, South Korea's financial institutions pledged to provide KRW 420 trillion (US$313bn) in policy loans through 2030 to finance projects that will accelerate Korea's pathway to achieving its 40% NDC emissions reduction target by 2030, relative to 2018.[80] The green fund would be delivered by Korea Development Bank, Export-Import Bank of Korea, Industrial Bank of Korea and Korea Credit Guarantee Fund. The increase in transition financing would provide KRW 60 trillion (US$45bn) annually, a 67% rise from the 5-year average according to South Korea's Financial Services Commission.

In May 2024, South Korea's Ministry of Trade, Industry and Energy announce a new energy plan that involves a dramatic reduction in reliance on coal (from 33% in 2024 to 10% in 2038) and LNG (from 28% to 11%), and an increase in reliance on nuclear (31% in 2024 to 36% by 2038), renewables (7% to 33%) and hydrogen and ammonia imports (0% to 6%).[81]

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[76] Bloomberg, POSCO to Invest $92bn Through 2030 in Batteries, Hydrogen, 03 July 2023
[77] H2 Insight, POSCO to Invest $22bn in Clean Steel and Blue Hydrogen by 2030, 19 October 2024
[78] H2 Insight, POSCO to Invest $22bn in Clean Steel and Blue Hydrogen by 2030, 19 October 2024
[79] KED Global, Hyundai Steel Unveils Carbon Neutrality Roadmap, 26 April 2023
[80] Bloomberg, South Korea Finance Sector Pledges $313 Billion in Green Funding, 19 March 2024
[81] S&P Global, Korea to sharply reduce LNG's share in power mix by 2038, boost nuclear role, 31 May 2024

Opportunity to Partner with Asian Steelmakers

The energy transformation will result in a fundamental reshaping of global supply chains, most directly in global energy and commodity flows, plus a strategic realignment of refining and manufacturing. Given the continued rise in energy and electricity generation as a proportion of manufacturing and refining costs, and the growing range of policies to explicitly price in carbon emissions globally, heavy industries will see a shift away from co-locating with demand centres using historically lower-cost imported high-emission fossil fuels (i.e. coal, LNG, oil) to co-locating energy-intensive industries with regions with abundant low-cost, zero emissions renewable resources.

This scenario underpins a redirection of global financing flows, especially through export credit agencies and import-export banks, but also with a growing list of formal oil and gas financing exclusions, with 2 of the top 3 EU banks introducing new policies in May 2024.[82] [83] These add to the vast build-up of coal finance exclusions seen over the last five years.

Australia has a once-in-a-century opportunity to pivot and capture a greater share of value-add across energy and resource industries, leveraging public-private partnerships and inbound foreign direct investment from global sector leaders. The expansion of commodity refining and midstream production capacity onshore in strategic regions and industrial hubs provides the necessary diversification of energy load centres required for large-scale third-party investors in renewable energy generation and storage.

As WWF demonstrated in its recent green iron study, Australia can forge a ‘green iron key’ to help unlock global economic development and decarbonisation through green manufacturing, optimised to provide embedded decarbonisation in our resource exports to key trading partners that have committed to decarbonising the lion’s share of the steel value chain’s emissions.[84]

The decarbonisation of Australia’s resources industry is an imperative for Australia in order to maintain and expand its world-leading positions as a Tier 1 supplier of strategic metals and critical minerals that are vital to the global energy transition.

The embedding of decarbonisation in our resource industries critical to the growth of clean energy technologies is a vital component to the Federal Government’s Future Made in Australia, aligning economic incentives with broader national interest objectives.

As other key global exporters globally shift capital at speed and scale to develop green, value-added refining industries, Australia’s strategic metal exports, principally iron ore and aluminium, must move faster and larger.

[82] Reclaim Finance, BNP Paribas Says No to Bonds in the Oil and Gas Sector, 14 May 2024
[83] Reclaim Finance, Crédit Agricole: A Step Towards Ending Non-earmarked Bonds for the Oil and Gas Sector?, 23 May 2024
[84] WWF, Australia’s Green Iron Key, 01 August 2024

Section 6. EU Investments and Public Support

Section summary:

- The EU has long invested in public financial and policy support for industrial decarbonisation. The world-leading EU ETS provides the high and rising carbon pricing signal that industry and financing institutions require to deploy the necessary capital.
- The EU ETS is now supported by the phased introduction of protection from high emission imports via the progressive ratcheting up of the EU CBAM. The CBAM is **exactly the price signal other markets need to replicate** to facilitate the massive investment required to decarbonise their iron and steel value chains.
- The EU is leading the world in the development of low-emission iron and steel projects, with the world's first 100% green hydrogen based DRI plant soon to be completed by Stegra in Sweden.
- The EU Innovation Fund, which capitalises the EU Hydrogen Bank, is 100% funded by the EU ETS, demonstrating how to effectively use policy to shift headwinds to tailwinds for decarbonisation and electrification.
- However, despite more than EUR 12.8bn ($20.7bn) in subsidies and grants to low-emission iron and steel projects across the EU and the UK, projects are struggling to reach financial close given the high cost of green hydrogen, in part inflated by the trade barrier measures for access to production credits which limit the proportion of equipment from Chinese electrolyser OEMs. Multiple studies have identified electrolyser stacks produced in the EU are 3-4x the cost of that of Chinese manufacturers.

Implications for Australia:

- **Australia has a strong competitive advantage** over the EU in reducing the operational costs of a domestic green iron industry. Australia has world-class variable renewable energy resources, as well as access and **ability to partner with China's leading steelmakers and electrolyser OEMs** to minimise capex intensity, lowering the levelised cost of key inputs to the manufacturing process of green iron.
- However, even with Australia's natural endowments, we still massively risk losing out to markets prioritising the green iron transformation at the necessary speed and scale. The EU have made it clear they understand the scope and size of the opportunity, and have directed billions of strategic public capital to support iron and steel value chain R&D to unlock low-emission, cost-competitive steelmaking, in addition to supporting the massive capex challenges to building out the green iron supply chain.
- **Absent a carbon price in Australian trade**, we must prioritise demand-side incentives and provide support for mechanisms that will support price discovery and long-term offtake agreements of low-emission iron products.

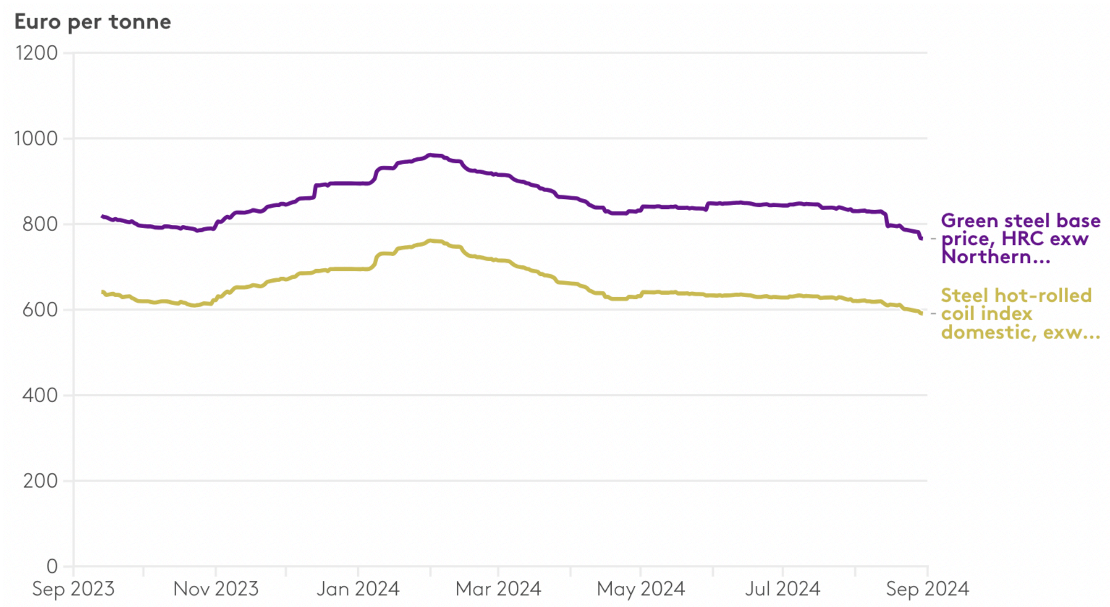
The EU's world leadership in carbon pricing and low-emissions taxonomy has resulted in significant public momentum and support for the accelerated decarbonisation of its steel industry. In the 10 months to October 2024, EU carbon permit prices have averaged €60-70/t CO_2.[85] As free allowances to industry are progressively phased-out from 2026 to 2034, and the implementation of the EU CBAM, the EU ETS price is expected to rise significantly. BloombergNEF forecasts EU ETS price to double to €150/t by 2030, underpinned by the EU's leadership on decarbonisation price signals and related taxonomy.[86]

[85] Trading Economics, EU Carbon Permits, October 2024

[86] BloombergNEF, EU ETS Market Outlook in 1H2024: Price Valley Before Rally, 01 May 2024

Given the world leadership of carbon pricing, the EU has demonstrated the ability for producers to attract a green premium, with steel products produced under the emissions intensity threshold maintaining a sustained higher realised price. Recent prices in the European steel market show, for steel produced with a Scope 1-3 emission intensity of less than 800 kg/tonne steel, producers are able to command a €100-150/tonne premium.[87]

Figure 6.1: Inferred Green Steel Price from HRC Index in Northern Europe



Source: Fastmarkets [88]

The domestic green steel market in the EU is from the utilisation of scrap steel in EAFs. For the Union to further displace its BF-BOF production capacity, largely situated in Germany, the EU Commission has significantly ramped up budgetary measures to support the deployment of hydrogen-ready DRI plants across the continent.

The **EU Innovation Fund** is one of the world's largest funding programmes for the deployment of net zero and innovative technologies, aimed at accelerating market solutions to decarbonise European industry whilst fostering global competitiveness. The Innovation Fund is a key pillar of delivering the EU's Net Zero Industry Act, the Green Deal Industrial Plan, the Hydrogen Bank, and the REPowerEU policies.

The EU Innovation Fund is 100% funded by the EU ETS. The EU has perfectly demonstrated how carbon taxes and emissions pricing mechanisms can generate huge tax revenues, which can then be directed into technologies, grants, auctions and subsidies to underpin the energy transition. From 2020 to 2030, the Innovation Fund is expected to be funded €40bn, assuming an average carbon price over the decade of €75/t.

The **EU Recovery and Resilience Facility (RRF)** is a temporary financing instrument that is the centrepiece of NextGenerationEU, a mechanism to provide grants and loans to support reforms and investments in EU member states that will make economies and industries more sustainable, resilient and lower-emission. Under the RRF, up to **€338bn of grants** will

[87] Fastmarkets, EU Steel Sector Committed to Decarbonisation Despite Ongoing Economic Woes, 02 October 2024

[88] ibid.

be financed through borrowing operations, with Member States also receiving an additional €17.3bn financed by the EU ETS. In addition, **€385bn in loans** are available to Member States, with €291bn of the RRF loan envelope already committed by the end of 2023.[89]

Fastmarkets estimates >50 Mtpa of new steelmaking capacity is expected to come online in 2025-27 across the EU, representing €100bn's worth of private investment, supported by significant strategic public capital, largely delivered by the EU RRF – see Figure 6.2.[90]

Figure 6.2: Capital Grants and Subsidies to Decarbonise European Steel Mills

Entity	Country	Site	Plant	Subsidy (EUR m)	AUD m
ArcelorMittal	Germany	Bremen And Eisenhuttenstadt	DRI, 3x EAFs	1,300	2,106
ArcelorMittal	France	Dunkirk	DRI, 2x EAFs	850	1,377
ArcelorMittal	Spain	Gijon	DRI, EAF	460	745
ArcelorMittal	Belgium	Ghent	DRI, 2x EAFs	280	454
ArcelorMittal	Germany	Hamburg	H_2-DRI pilot plant	55	89
Thyssenkrupp	Germany	Duisburg	DRI, 2x Smelters	2,000	3,240
Salzgitter	Germany	Salzgitter	DRI, EAF	1,000	1,620
Stahl-Holding-Saar (SHS)	Germany	Volklingen And Dilingen, Saarland	DRI, 2x EAFs	2,600	4,212
Tata Steel	Netherlands	Ijmuiden	DRI, EAF	3,000	4,860
Tata Steel	UK	Port Talbot	EAF	600	972
HYBRIT	Sweden	Luleå	Pilot DRI	143	232
HYBRIT	Sweden	Luleå	Demonstration DRI	270	437
Stegra	Sweden	Boden	DRI, EAF	265	429
Total				**12,823**	**20,773**

Note: Tata Steel Port Talbot grant is £500m (GBPEUR=1.2)

Source: Company Accounts, FT, GMK Center, Hydrogen Insight

In February 2024, EU's largest steelmaker, ArcelorMittal, announced it would still be uncompetitive to operate its planned European DRI plants using domestically-produced green hydrogen, despite multi-billion euro subsidies, due to the inability to source internationally cost competitive energy.[91] ArcelorMittal has shifted to prioritising methane gas in its European steel plants indefinitely, and will potentially delay construction of such subsidised DRI plants, favouring the import of green DRI from global markets.

To support first movers in green hydrogen production, the EU Commission's Innovation Fund expanded its support for the **European Hydrogen Bank**, awarding nearly €720m to seven renewable hydrogen projects selected via the region's first competitive hydrogen tender (IF23).[92] The tender was massively oversubscribed, receiving 132 bids from 17 countries, representing a cumulative value of the production tax credits 15x the tender's budget.

In September 2024, the Innovation Fund published the T&Cs for the second round of its renewable hydrogen production (IF24), with a budget of up to EUR 1.2bn. The auction will

[89] EU Commission, NextGenerationEU
[90] Fastmarkets, European Steel Sector Committed to Decarbonisation Despite Ongoing Economic Woes, 02 October 2024
[91] Hydrogen Insight, ArcelorMittal: Green Hydrogen is Too Expensive to Use in our EU Steel Mills, 21 February 2024
[92] EU Commission, European Hydrogen Bank Auction Provides EUR 720m for Renewable Hydrogen Production in Europe, 30 April 2024

open on 03 December, 2024.[93] However, a new limitation for the successful bidders is the limitation of hydrogen electrolyser technology sourced from Chinese OEMs. Under the IF24 Auction, no more than 25% of the MW-equivalent capacity of the project's electrolyser stack can be from Chinese OEMs.

As detailed in Section 4, Chinese electrolyser OEMs are the world-leaders in delivering low-cost alkaline electrolysers to market, with European OEMs on average producing electrolyser stacks at a 3-4x capex premium than that of China.

Australia has a strong competitive advantage over the EU in reducing the operational costs of a domestic green iron industry. Australia has world-class variable renewable energy resources, as well as access and ability to partner with China's leading steelmakers and electrolyser OEMs to minimise capex intensity, lowering the levelised cost of key inputs to the manufacturing process of green iron.

However, even with Australia's natural endowments, we still massively risk losing out on the once-in-a-century opportunity to markets prioritising the green iron transformation at the necessary speed and scale. The European Union have made it clear they understand the scope and size of the opportunity, and have directed billions of strategic public capital to support iron and steel value chain R&D to unlock low-emission, cost-competitive steelmaking, in addition to supporting the massive capex challenges to building out the green iron supply chain.

Sweden's Stegra and HYBRIT are leading the steel transition, building the world's first 100% renewable-powered hydrogen iron and steel projects on an industrial-scale. Australia must recognise that whilst there are still technical and economic hurdles to overcome, we cannot wait for the opportunity to come to us, we must move strategically and quickly to ensure we maintain our economic resilience and security of our no.1 future-facing export industry.

Stegra

Stegra (formerly H2 Green Steel) is developing the world's first industrial-scale, 100% green hydrogen DRI-EAF steel project in Boden, Sweden. Stegra partnered with MIDREX and Kobe Steel to construct a 2.1 Mtpa DRI facility that will feed into a Stage 1 2.5 Mtpa EAF, with construction provided by a consortium of MIDREX and SMS Group (via Paul Wurth).[94] The first-of-its-kind plant will be able to produce over 2 Mtpa of HBI with up to a 95% reduction in emissions compared to traditional blast furnaces.

In May 2023, Stegra announced a technical partnership with Thyssenkrupp Nucera, a leading western electrolyser OEM, to supply more than 700 MW of alkaline water electrolysers, comprising 20 MW Scalum electrolyser modules.[95]

Stegra has received overwhelming financial backing from global financial institutions, public financing agencies, and steel end users that have signed long-term supply agreements for green steel before the plant has even commenced production.

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[93] EU Commission, Second Renewable Hydrogen Auction: European Commission Publishes Terms and Conditions, 27 September 2024
[94] Stegra, H2GS Partners with MIDREX for Technology and Kobe Steel for Equity, 11 October 2022
[95] Stegra, Thyssenkrupp Nucera and H2GS Partner for huge Electrolysis Plant, 22 May 2023

- In May 2021, Stegra successfully closed its Series A equity financing of US$105m (€97m) for the Boden green steel plant.[96]
- In August 2022, Stegra completed its Series B equity round, securing €190m.[97]
- In October 2022, Stegra completed an additional €70m in Series B equity financing, bringing total Series B private placement to €260m.[98]
- In September 2023, Stegra raised €1.5bn in equity financing, the largest private placement in Europe in 2023.[99]
- In January 2024, Stegra signed definitive debt financing agreements for €4.2bn, as well as increased total equity funding amounts to date of €2.1bn.[100]
- In September 2024, Stegra was awarded €100m from the Industrial Leap fund of the Swedish Energy Agency, in addition to a further €265m grant available in part through the Recovery and Resilience Facility.[101]

Stegra has also locked in long-term, diversified high grade iron ore supply contracts from leading iron ore producers across North America, South America and South Africa.

In April 2023, Stegra formed an MoU with Anglo American to jointly study and trial the use of high-quality iron ore products from Anglo's Kumba mines in South Africa and Minas-Rio in Brazil as feedstock for its Boden green steel plant. The study aims to assess the possibility of using lump iron as complementary feedstock to iron ore pellets in the MIDREX DRI process, increasing the flexibility of the ironmaking process.[102]

The joint research partnership highlights the leadership of Anglo American's commitment to actively decarbonise its Scope 3 emissions, setting an ambitious target in 2021 to reduce its Scope 3 emissions by 50% by 2040.

In August 2023, Stegra signed an agreement with Rio Tinto for a multi-year supply deal of DR iron ore pellets from Rio Tinto's Iron Ore Company of Canada (with grades of 65% Fe and low impurities).[103] As part of the ramp up of steelmaking capacity at Boden, Rio Tinto has agreed to purchase and on-sell surplus HBI produced by the DRI plant.

In August 2023, Stegra and Vale, the world's largest producer of DR-grade pellets, formed a supply agreement for iron ore pellets to further diversify Stegra's supply chain for its Boden steel plant.[104] Vale has committed to a net Scope 3 emissions reduction of 15% by 2035, requiring the abatement of 80 Mtpa of CO_2-e, equivalent to the national emissions of New Zealand. Further strengthening Stegra and Vale's commitment to steel value chain decarbonisation, in September 2023, the partnership was expanded to study the development of green industrial hubs in Brazil and North America.[105]

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[96] Stegra, H2GS Completes Strong US$105m Initial Funding Round to Accelerate the Transition into Green Steelmaking, 23 May 2021
[97] Stegra, H2GS Completes EUR190m Funding Round, 29 August 2022
[98] Stegra, H2GS Completes EUR260m Equity Financing to Build World's First Large Scale Green Steel Plant, 19 October 2022
[99] Stegra, H2GS Raises EUR1.5bn in Equity to Build the World's First Green Steel Plant, 07 September 2023
[100] Stegra, H2GS Raises More than EUR4bn in Debt Financing, 22 January 2024
[101] Stegra, Stegra Granted State Aid from the Industrial Leap and Swedish Energy Agency, 19 September 2024
[102] Stegra, H2GS to Work with Anglo American on Low Carbon Steelmaking, 04 April 2023
[103] Stegra, H2GS Signs Agreement with Rio Tinto for DRI Ore Pellets and HBI, 09 August 2023
[104] Stegra, H2GS and Vale in Agreement for the Supply of DRI Ore Pellets, 10 August 2023
[105] Stegra, Vale and H2GS Sign Agreement to Study the Development of Green Industrial Hubs, 06 September 2023

Stegra, and other green iron projects in Sweden, have a significant advantage over other potential green iron hubs, with a decarbonised grid that is already producing surplus renewable energy.

In March 2023, Stegra formed a partnership with Sweden's Fortum for carbon-free electricity supply on both short and long-term basis, including a fixed rate 1 TWh pa PPA for up to 9 years (from 2027), and an index-based 1.3 TWh pa PPA (from 2026) with a five-year hedging horizon. The PPAs would contribute to powering the 700-800 MW of electrolyser capacity needed to power the 2.1 Mtpa DRI plant.[106]

In 2023, Northern Sweden generated 76 TWh of electricity from its hydropower and wind farms, and consumed just 33 TWh, leaving a 43 TWh surplus (equivalent to the annual electricity demand of countries like Hungary, Denmark or Ireland). Northern Sweden's green electricity surplus is largely trapped in the north as a result of poor transmission infrastructure to the South.[107] Stegra and HYBRIT (discussed directly below) estimate they would each require ~ 15 TWh per annum in full production.[108]

Stegra is planning further plants in Canada, Portugal and Brazil for green steel after Vattenfall, a Swedish state-owned utility, shifted Stegra behind the state-owned steelmaker SSAB in the queue for electricity supply.[109] October 2023 saw Bloomberg reports that Stegra was in talks with Governments in Canada to construct a green steel plant to supply customers in North America. The potential Quebec green steel project would be located in Sept-Iles, northeast of Montreal, requiring an investment of €3-6bn.[110]

HYBRIT

The Hydrogen Breakthrough Ironmaking Technology (HYBRIT) initiative was formed in 2016 as a joint venture of Swedish firms across the green steel value chain, including steelmaker SSAB, state-owned iron ore miner LKAB, and state-owned energy gentailer Vattenfall.

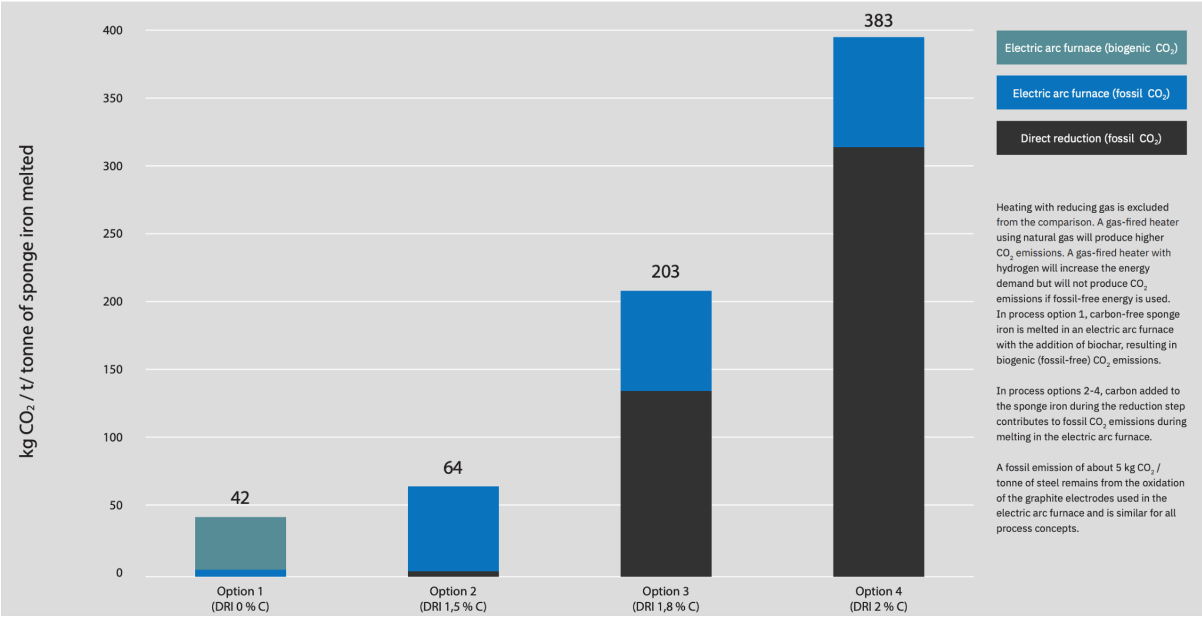
The venture conducted a feasibility study into the production of green steel in Sweden, using LKAB's high-grade, low-impurity magnetite resource and pellet plants, which would be charged into a DRI plant using 100% renewable hydrogen, and then refined in an EAF with biogenic CO_2 (meaning sourced from renewable biomass). LKAB developed a fossil-free pellet plant at its Malmberget site in 2020-21, replacing fossil fuels with bio-oil, which is 100% renewable.

The HYBRIT pilot plant for test production of sponge iron began operations in August 2020. In June 2021, the world's first pilot-scale production of hydrogen-reduced sponge iron was made by HYBRIT. Over the pilot plant's study across 2020-2024, HYBRIT has produced more than 5,000 tonnes of fossil-free sponge iron, achieving 98-99% metallisation and 0% carbon in the process. The pilot plant used alkaline electrolysers with a nominal capacity of 910 Nm^3/h (81.79 kg/h), corresponding to an output of ~ 4.5 MW. The alkaline electrolysers used in the pilot plant have an energy intensity of 55 kWh/kg-H_2.[111]

[106] Stegra, H2GS has Enters a Long-term Frame Agreement with Fortum for Electricity Supply, 03 March 2023
[107] FT, Can Sweden Deliver its Much Hyped Green Energy Boom, 13 August 2024
[108] FT, Can Sweden Deliver its Much Hyped Green Energy Boom, 13 August 2024
[109] FT, Can Sweden Deliver its Much Hyped Green Energy Boom, 13 August 2024
[110] Bloomberg, Swedish Industrialists Explore $6bn Green Steel Project in Canada, 09 October 2023
[111] HYBRIT, Fossil-free Steel Production Ready for Industrialisation, 27 August 2024

Using biogenic CO_2 in the EAF, HYBRIT was successfully produced green steel at 0.042t CO_2/t crude steel, a 98% reduction compared to BF-BOF production. Utilising fossil-based CO_2 in the EAF, coupled with added carbon in reduction to produce carbon steel, HYBRIT was successfully produced steel well below the IEA's green steel benchmark of 0.4t CO_2/t steel.

Figure 6.3: Emissions Intensity from HYBRIT Technology



Source: HYBRIT [112]

Over 2025-2035, the HYBRIT venture will focus on scaling operations to demonstration scale and subsequent industrialisation. The new facility is planned in Gallivare, Sweden, with a target to be operational in 2026, producing up to 1.2 Mtpa, 25% of Sweden's existing steel production. The demonstration plant will be supported by a 500 MW electrolyser. This will enable SSAB to replace two BFs with an EAF and DRI facility which, producing 1.2 Mtpa of fossil free crude steel, will abate 14.3 Mt CO_2-e over the first 10 years of production.[113]

In 2022, HYBRIT was awarded a €143m grant by the EU Innovation Fund to progress the demonstration plant.[114] In December 2023, the Swedish Energy Agency (Energimyndigheten) granted the HYBRIT initiative SEK 3.1bn (€272m) in state aid through the Industrial Leap, a fund to support technological advances that reduce GHG emissions from Sweden's industries, which currently account for a third of Sweden's fossil GHG emissions.[115]

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[112] HYBRIT, Fossil-free Steel Production Ready for Industrialisation, 27 August 2024

[113] HYBRIT, HYBRIT Demonstration Project

[114] EU Commission, HYBRIT Demonstration: Swedish Large-scale Steel Value Chain Demonstration of Hydrogen breakthrough Ironmaking Technology, April 2022

[115] Swedish Energy Agency, HYBRIT is Granted SEK 3.1 billion, updated 14 December 2023

Thyssenkrupp

Thyssenkrupp Steel operates Europe's largest integrated steel mill in Duisburg, Germany, with a production capacity of 11.5 Mtpa. In April 2024, Thyssenkrupp announced plans to reduce the size of the Duisburg plant capacity to 9-9.5 Mtpa, to bring capacity into line with the volume of production realised over the past 3 years.[116]

In September 2022, Thyssenkrupp announced plans to accelerate the decarbonisation of Europe's largest steel mill, constructing Germany's first DRI plant, tkH2Steel, a MIDREX furnace production capacity of 2.5 Mtpa, abating 3.5 Mtpa of CO_2-e.[117] In July 2023, The EU Commission approved German federal and state government funding for the tkH2Steel project, for up to €2bn, effectively funded by a portion of the tax revenues raised by the EU ETS.[118]

The tkH2Steel project is of global significance, with a technical partnership with MIDREX developer, SMS Group, to construct two 100 MW electric smelters that will further reduce and refine product from the DRI plant. This will be the first large-scale plant that will test the commerciality of hydrogen reduction via the DRI-ESF route.

In August 2024, Thyssenkrupp Steel and Australia's BlueScope Steel announced a cooperative agreement to develop carbon-neutral steel production pathways, with a focus on electric smelter technologies.[119] The joint study will provide critical learnings for BlueScope in its pilot study for DRI-ESF reduction of Australian hematite ores, in partnership with Rio Tinto and BHP, with BlueScope using the tkH2Steel project to enhance the group's understanding of process optimisation and plant management, although we note this proposal is still some three years away from reaching FID, and hasn't even finalised a site selection 18 months after the press release. This will build up on the successful operating smelter technologies using DRI made from iron sand at BlueScope's New Zealand Steel operations.

[116] Reuters, Thyssenkrupp to Reduce Duisburg Steel Production Capacity and Cut Jobs, 12 April 2024
[117] Thyssenkrupp, Decision Taken on the Construction of Germany's Largest DRI Plant, 08 September 2022
[118] Thyssenkrupp, EU-Commission Approves German Federal and State Government Funding for tkH2Steel, 20 July 2023
[119] Thyssenkrupp, Cooperation for Low-carbon Steel Production with International Partners, 19 August 2024

Section 7. World-leading Investment into Steelmaking in the Middle East

Section summary:

- The Middle East is rapidly emerging as a globally-significant intermediate production hub for the global seaborne steel value chain, and a key threat to Australia's potential in iron production.
- The Middle East is producing grey hydrogen at below US$1/kg, and will likely be one of lowest cost green hydrogen producers globally. The Middle East produces 20% of all grey hydrogen, and 14% of hydrogen from any source globally in 2023.
- The Middle East is already demonstrating it can be more competitive in renewable energy than Australia, despite Australia's oft-cited comparative advantage. In October 2024, a 3.7 GW solar tender delivered a record low US$13/MWh, less than half that of average wholesale solar prices in the NEM.
- The Middle East already has 16 GW of utility-scale solar, and is forecast to reach 23 GW by 2024, and surpass 100 GW by 2030.
- The Middle East has a significant investment pipeline of iron and steel projects from international partnerships, including with Chinese state-owned enterprises (SOEs).
- The Middle East is partnering with South American and emerging African iron ore producers to gain access to significant new seaborne iron ore supply.

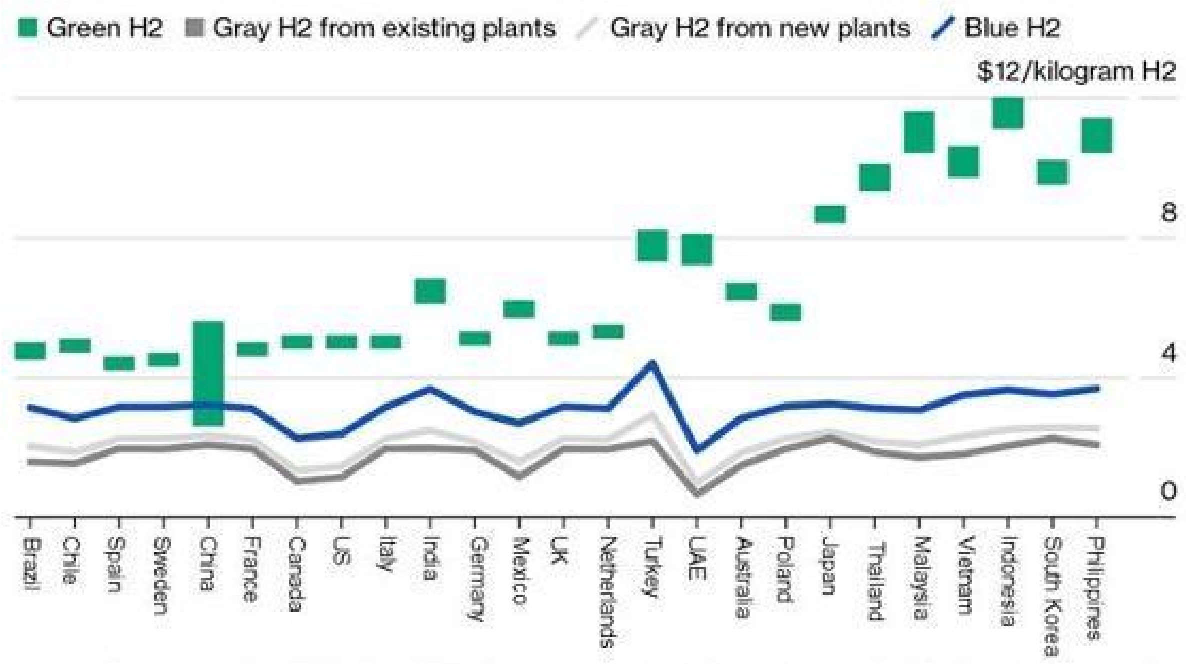
Implications for Australia:

- Australia **cannot compete with the Middle East** on a cost-competitive basis if we prioritise the development of a **methane gas-based iron value-add industry**. As a product of poor domestic policy and regulatory capture from the multinational methane gas cartel, Australia has domestic methane gas prices multiples of the price prevailing in the Middle East.
- The Middle East is moving faster than Australia in establishing itself as a world leader in iron production. With increasing co-investment by China's SOEs into the region, there is a massive risk for Australia as China diversifies and dilutes their exposure to Australia's resources, prioritising markets that can provide high quality iron products at cost competitive prices, as well as providing a platform to increase exports into the EU.
- Australia must recognise the strategic threat this has on displacing Australia's iron industry in the global market. To overcome this, **Australia must prioritise RD&D**, in collaboration with our Chinese customers, to unlock the technologies required to decarbonise Australia's hematite DSO.
- Concurrently, **Australia must address the approvals bottleneck** that is throttling investments into renewable energy in order to further lower the levelised cost of energy to ensure we remain competitive to the Middle East from a renewables and green hydrogen perspective.

Despite the Middle East having limited iron ore resources, low domestic demand for steel and comparably less manufacturing to that of nearby markets (i.e. the EU), the region is rapidly emerging as a globally-significant intermediate production hub for the global seaborne steel value chain market. The aggregation of world-class, low-cost renewable and methane gas energy resources, the intersection of global trade routes, and the abundant availability to land and water plus strong government policy support has seen major investment and capital flows to the Arabian Peninsula for intermediary steel product manufacturing.

A BloombergNEF analysis identified the average production cost of grey hydrogen, hydrogen produced from methane gas without emissions abatement, was US$2.13/kg, far below the average cost of GH_2 globally, US$6.40/kg – Figure 7.1. Given the abundance of methane gas for domestic use in the Middle East, Bloomberg identified the UAE as the lowest cost producer of grey hydrogen, at US$0.98/kg.[120] The analysis included grey hydrogen production from steam methane reformers (SMRs) and auto-thermal reformers (ATRs), the primary production methods used to produce gas-based reducing agents for DRI plants.

Figure 7.1: LCOH in 2023 by Market



Source: BloombergNEF

The study identified that beyond 2030, new GH_2 plants will likely be able to produce at a levelised cost similar to grey hydrogen, and cheaper than that of blue hydrogen plants, fossil-based plants internalising the cost of emissions by building CCS facilities that work.

The Middle East is the largest producer of hydrogen from unabated methane gas, producing 20% of global grey hydrogen globally, and 14% of global hydrogen from all sources in 2023.[121] In 2023, fossil fuels accounted for 93% of the Middle East's power generation, with renewables just 3%, and nuclear and hydro accounting for 2% each. 74% of the region's energy demand is derived from methane gas, with electricity making up 40% of overall methane gas demand in the region.[122]

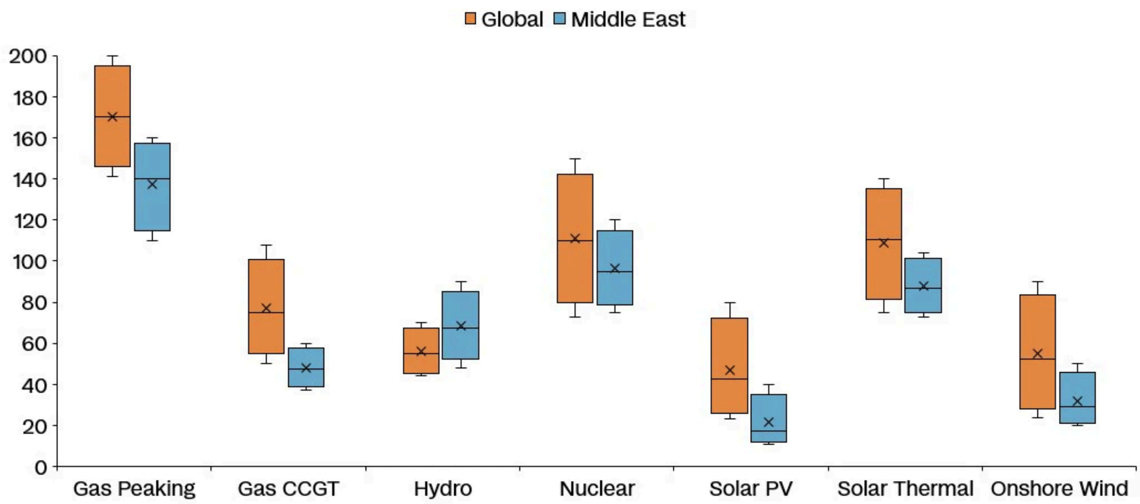
However, Rystad Energy forecasts renewable energy could account for some 30% of the region's power supply by 2030, with the potential to rise to 75% by 2050. Recent wind turbine and solar module manufacturing joint ventures with China and the Saudi sovereign

[120] BNEF, Green Hydrogen to Undercut Grey Sibling by End of Decade, 09 August 2023
[121] IEA, Global Hydrogen Review 2024, October 2024
[122] Rystad, Power Surge: Solar PV to Help Meet Soaring Middle East Power Demand and Reduce Reliance on Fossil Fuels, 28 May 2024

wealth fund PIF, [123] and associated battery and renewable energy project deployments, supports this forecast. As a result, methane gas' share of generation is anticipated to decline to 46% in 2040, and 22% by 2050.

Despite low renewable energy penetration, the Middle East has exceptional solar resources. In Saudi Arabia, the UAE and Oman, solar irradiation can exceed 2,000kWh/m^2 annually. As a result, Saudi Arabia hosts the world's lowest LCOE for solar PV, as low as $10.4/MWh - see Figure 7.2. The record-low LCOE is aided significantly by high energy output, but also low financing hurdle rates (minimum rate of return for an investor to be deemed acceptable), falling cost of hardware (i.e. solar modules), and low labour costs.

Figure 7.2: LCOE Range in the Middle East Compared to Global Average



Source: Rystad Energy [124]
Note: LCOE is based over the last five years on reported capacity above 100MW

Low renewable energy penetration in the Middle East is also a product of the region's rapidly increasing energy demand, largely driven by strong population growth (+60% since 2000). Current energy demand is ~ 1,200 TWh, with residential accounting for 40% of this, followed by commercial (26%), industrial (22%), and agriculture/transport (12%).

Total solar capacity as of 2023 exceeded 16 GW, and is expected to reach 23 GW in 2024, and is projected to surpass 100 GW by 2030. For comparison, Australia's current large-scale solar PV installed in the NEM is 8 GW.[125] In 2024, it is clear that large-scale renewable energy projects, the scale of projects required to underpin a green iron industry, are emerging across the Middle East.

The 2 GW Al Dhafra solar farm is the largest single-site solar project in the world, located 35km outside of Abu Dhabi, UAW. The project was developed by an international consortium including Abu Dhabi's TAQA (40%, UAE SOE Masdar (20%), France's EDF Renewables (20%)

[123] PIF Press Release, PIF strengthens renewable energy localization in Saudi Arabia with three new JV, 16 July 2024
[124] Rystad, Power Surge: Solar PV to Help Meet Soaring Middle East Power Demand and Reduce Reliance on Fossil Fuels, 28 May 2024
[125] OpenNEM, Facilities - NEM - Operating Solar, accessed September 2024

and China's Jinko (20%). Al Dhafra is underpinned by a long-term PPA signed in 2020 to supply power to EWEC at a then record-low tariff of US$13.2/MWh.[126]

In October 2024, the Saudi Power Procurement Company (SPPC) announced the bidders for its fifth round of the State's National Renewable Energy Program (NREP), including the 2 GW Al-Sadawi solar project, the 1 GW Al Masa'a solar project, the 400 MW Al Henakiyah 2 solar project, and the 300 MW Rabigh 2 solar project.[127]

A bid for the 2 GW Al-Sadawi project came from a consortium of UAE-based Masdar, and Korea Electric Power Corporation (KEPCO), offering a price of just US$12.90/MWh. A consortium of China-based Huanghe Hydropower Development Co. and France's EDF Renewables offered a price of US$13.10/MWh for the Al-Sadawi project.

The 3.7 GW tender received massive international buy-in, including multinationals of Japan's Itochu, Marubeni and Sumitomo Corporations, Korea's KEPCO and Samsung C&T Corporation, China's Power Construction Corporation (PowerChina), Jinko Solar, as well as large infrastructure and utility firms across the UAE and Saudi Arabia.

Also in Saudi Arabia is the world's largest GH_2 plant under development by NEOM Green Hydrogen, a US$8.4bn proposal due to start production in 2026. In Oman, ACME Group is poised to invest US$480m in a low-emission hydrogen project, set to come online in 2025.[128]

MENA now has a significant pipeline of value-added low-emission iron and steel initiatives.

Saudi Arabia

In May 2023, **China's Baosteel Group** (50%), in partnership with **Saudi Aramco** (25%), announced a 2.5 Mtpa DRI plant in Saudi Arabia, to produce hot metal feed for a 1.5 Mtpa EAF.[129] The DRI plant will be powered by methane gas, with the ability to blend in hydrogen without major modifications. The project is supported by a 25% equity stake from the Saudi sovereign wealth fund, **PIF**. In July 2024, Baosteel announced it would more than double its investment into the JV to US$1bn (up from US$437.5m in 2023).[130]

In June 2024, India's **Essar Group** reconfirmed a US$4bn proposal to construct a 4Mtpa DRI-EAF plant in Ras al-Khair, Saudi Arabia.[131] The project marks Essar's first steel investment outside of India. As part of the proposal, Essar plans to build port infrastructure exclusively for its steel project to supply domestic and international steel demand.[132]

In January 2024, Turkey's **Tosyali** announced an MoU with Saudi Arabia's National Industrial Development Centre (NIDC) to construct an integrated steel precinct, consisting of 2 DRI plants with a combined capacity of 2.7 Mtpa, as well as an EAFs to produce up to 4 Mtpa of HRC, as well as 1.6 Mtpa of CRC.[133]

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[126] Energy Institute, World's Largest Single-Site Solar Power Plant Inaugurated, 22 November 2023
[127] PV Magazine, Saudi Arabia's 3.7 GW Solar Tender Attracts Lowest Bid of $0.0129/kWh, 23 October 2024
[128] IEA, World Energy Investment 2024, June 2024
[129] Aramco, Aramco, Baosteel and PIF Sign Agreement to Establish First Integrated Steel Manufacturing Complex in Saudi Arabia, 01 May 2023
[130] Reuters, China's Baosteel to Boost Investment in Steel Plate in Saudi to $1bn, 26 July 2024
[131] GMK Centre, Essar Confirms Investment in Green Steel Production in Saudi Arabia, 17 June 2024
[132] Economic Times, Essar Awaits Final Approvals to Start on $4.5bn Steel Plant in Saudi Arabia, 24 June 2024
[133] Tosyali, Giant Investment Planned by Global Green Steel Producer Tosyali in Saudi Arabia, January 2024

Brazil's **Vale** also announced an MoU with the NIDC to construct a 4 Mtpa pellet plant in Ras Al-Khair, Saudi Arabia.[134]

UAE

An international consortium of Japanese trading house **Itochu**, Japan's **JFE Steel**, and the UAE's largest steelmaker, **Emirates Steel Arkan** (Emsteel), will develop a 2.5 Mtpa DRI-EAF plant in Abu Dhabi, UAE.[135] Itochu and JFE Steel have an equity stake in Brazilian iron ore miner, CSN Mineracao, alongside Kobe Steel. CSN Mineracao plans to construct a new pellet plant in Minas Gerais, Brazil, to export DR pellet feed to the DRI plant in the UAE.

In November 2023, **Masdar** and **Emsteel** announced the construction of a H_2-DRI pilot plant in the UAE to accelerate the decarbonisation of the region's rapidly growing steel industry.[136] Pilot plant production is expected in 2024, with electrolysers delivered in November 2023.[137] In October 2024, the JV announced the successful production of green steel.[138]

Oman

Vulcan Green Steel, a subsidiary of India's Jindal Group, will construct a 5 Mtpa DRI-EAF facility in Duqm, Oman. Phase 1 of the project will produce up to 3 Mtpa of flat steel products, using scrap steel and DRI from an integrated 2.5 Mtpa plant. In December 2023, Danieli announced it will supply the Oman project with the 2.5 Mtpa Energiron ZR platform, stating the plant will complete construction by 2026.[139] In June 2024, Volkswagen AG announced an MoU with Vulcan Green Steel to establish a low-carbon steel supply partnership, off taking flat steel products from the steel plant in Oman, a critically important endorsement providing some revenue offtake certainty.[140]

In April 2023, Japan's **Kobe Steel** and **Mitsui** signed an MoU to accelerate a feasibility study to construct a 5 Mtpa DRI plant in Duqm, Oman.[141] Kobe Steel, a subsidiary of Kobelco, is the technology owner of MIDREX. The project will use methane gas as the reducing agent, until replacement by blue hydrogen in combination with CCS is commercially viable.[142]

October 2024 saw Brazil's Vale and China's Jinnan Iron & Steel Group announce a joint investment of US$627m in an iron ore concentration plant in Oman. The facility will be located in Sohar, a port city 200 km north of the capital, Muscat. It will have the capacity to process 18 Mtpa of low-grade iron ore starting in 2027, aiming to produce 12.6 Mtpa of high-grade concentrate. Vale will invest $227m to connect the plant to its pelletizing facilities in the region. Jinnan will invest $400m to build and operate the plant, which it will own.[143]

North Africa

Turkey's **Tosyali** and **Libya United Steel Company for Iron and Steel Industry** (SULB) have signed an agreement to build the world's largest DRI complex in Benghazi, Libya. As part of

[134] GMK Centre, Vale to Build a Pellet Plant in Saudi Arabia, 01 November 2022
[135] Nikkei Asia, Japan's Itochu to Build Low-Carbon iron Supply Chain with Brazil, UAE, 23 June 2024
[136] Masdar, Masdar and Emsteel to Develop MENA Region's First Green Hydrogen-based Project to Decarbonise the UAE's hard-to-abate Steel Sector, 22 November 2023
[137] Hydrogen Insight, Electrolysers Delivered for UAE's First GH2-based Steel Project, 23 November 2023
[138] Hydrogen Insight, First Green Steel Produced from the Middle East, 28 October 2024
[139] Danieli, Vulcan Green Steel Orders DRI Plant from Danieli and Tenova, 05 December 2023
[140] Volkswagen, Volkswagen AG and Vulcan Green Steel Enter into Partnership, 12 June 2024
[141] Kobelco, Kobe Steel to Accelerate Feasibility Study in low-CO_2 Iron Metallics Project in Oman, 10 April 2023
[142] MIDREX, Kobe Steel & Mitsui Announce DRI Project in Oman, June 2023
[143] Mining.com, Vale, Jinnan invest $627m in iron ore plant in Oman, 28 October 2024

the project, Tosyali will construct a DRI plant with a capacity of 8.1Mtpa, using the MiDREX Flex technology, currently deployed in Tosyali's Algeria plant.[144] Phase one capacity is planned to be 2.7 Mtpa, supplying HBI to North Africa and Europe for green steel.

February 2024 saw Tosyali Algeria announce the development of a second DRI plant in the Bethia Industrial Zone, Algeria. The new MiDREX plant will produce 2.5 Mtpa Hot DRI (HDRI), feeding into Tosyali's 2.4 Mtpa EAF in Algeria.[145] May 2024 saw Tosyali commission its new 2.2 Mtpa flat-rolled steel plant in Algeria, using its existing EAFs in Algeria.[146]

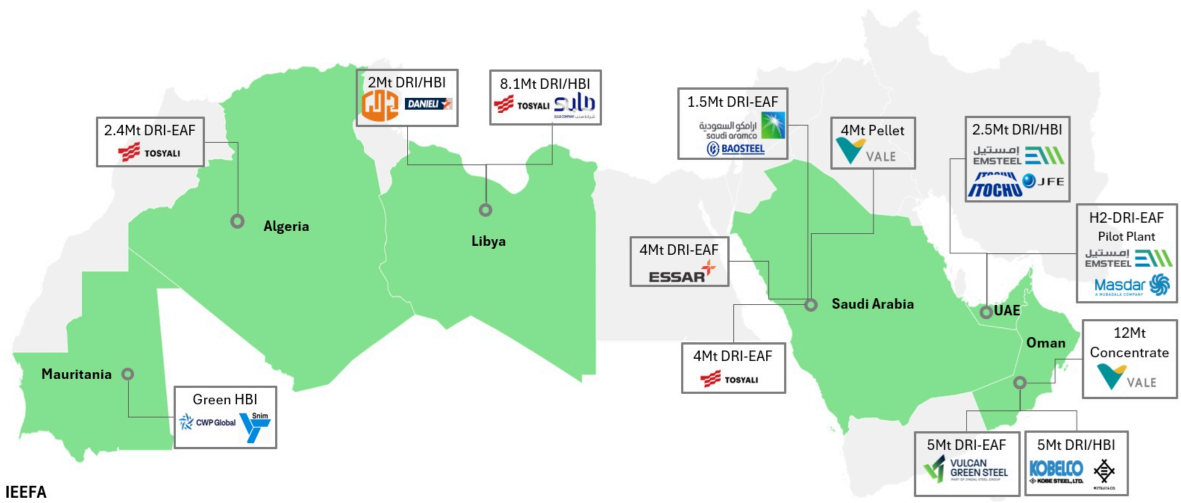
On 26 April 2024, state-owned **Libyan Iron and Steel Company** (LISCO) announced an MoU with Danieli and Tenova to construct a new 2 Mtpa DRI/HBI plant in Libya.[147] The plant would use Danieli's Energiron ZR platforms, using methane gas to produce metallic iron feed for Italian steelmakers' EAFs.

June 2024 saw **Societe Nationale Industrielle et Miniere** (SNIM) and **CWP Global** announce an MoU to collaborate on the decarbonisation of green iron production in Mauritania. CWP Global's large scale green hydrogen project in northwest Mauritania, AMAN, would feed the GH_2-based DRI plants to export low-emission DRI to the European steel industry.[148]

At full scale, the AMAN project could deploy 18GW of wind energy and 12GW of solar energy, with potential to produce up to 110TWh each year, producing 1.7Mtpa of green hydrogen for use in hydrogen derivatives in green ammonia and DRI/HBI. As part of the agreement, CWP Global will use Primetal Technologies' MIDREX platform for the HBI plant.

An excellent IEEFA summary of new iron and steel projects in MENA is shown in Figure 7.3.

Figure 7.3: New Iron & Steel Value-add Projects in MENA



Source: IEEFA [149]

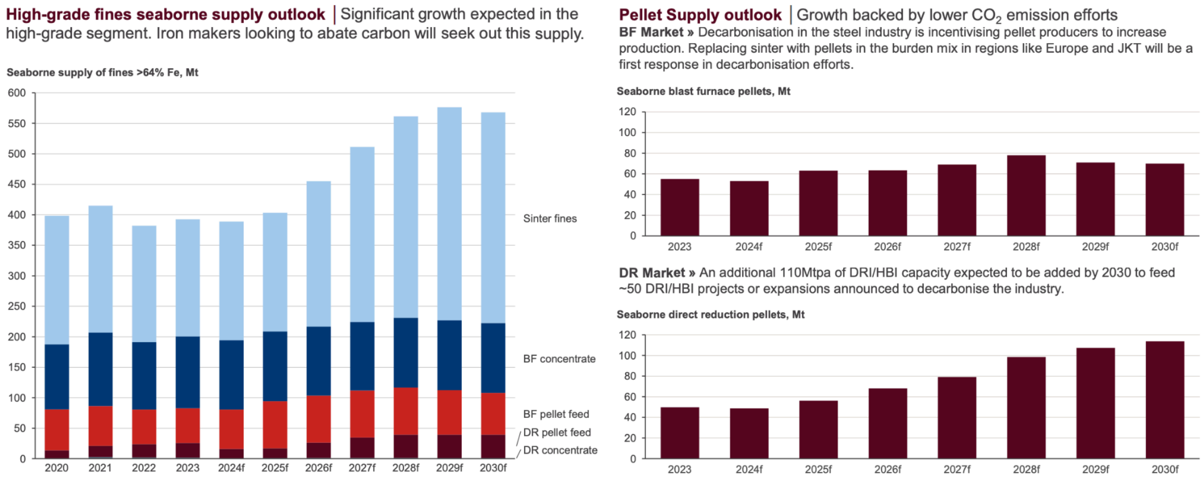
[144] Tosyali, Tosyali SULB Started Investment in World's Largest DRI Complex in Benghazi, Libya, 19 June 2024
[145] GMK Centre, Tosyali Algerie Launches Second DRI Production Unit, 21 February 2024
[146] GMK Centre, Tosyali Algeria Puts a New Flat-Rolled Steel Plant into Operation, 28 May 2024
[147] Danieli, Libyan Iron and Steel Company Signs an MoU with Danieli, 26 April 2024
[148] MIDREX, SNIM and CWP Global Agree to Explore Decarbonising Mauritania's Iron Ore Production, June 2024
[149] IEEFA, Practical Steps to Position MENA as a Green Steel Leader, 19 September 2024

Expanding High-grade Iron Ore Supply to the Middle East

Rio Tinto forecasts the supply of seaborne high-grade iron ore fines (+64% Fe) to exceed 550 Mtpa by 2028, a more than 150 Mtpa increase from 2023-24 supply. This will largely be due to the commissioning of Guinea's Simandou iron ore project (discussed below), which has the potential to displace legacy, low-quality seaborne iron ore volume from Australia, using the Middle East's gas and renewable energy resources to value-add iron before exporting to China, decreasing Australian iron ore exports to China.

Rio Tinto also forecasts an additional ~110 Mtpa of seaborne direct reduction pellet capacity will be added to the market by 2030, which will feed ~ 50 DRI/HBI projects and expansions globally (2.2 Mtpa/plant) - see Figure 7.4.[150]

Figure 7.4: High-grade Iron Ore Seaborne Supply Outlook



Source: Rio Tinto [151]

Simandou Iron Ore Project in Guinea

Guinea's 120 Mtpa Simandou iron ore project holds the world's largest reserve of high-grade iron ore, with this Chinese consortium placing a US$23bn investment, aiming to transform Guinea into the third largest iron ore exporter globally, behind Australia and Brazil.

As of December 2023, Simandou's Ore Reserves are estimated at 1,499 Mt at an Fe grade of 65.3%, with just 2.6% combined alumina and silica content. Given Rio Tinto's share in the project, Rio Tinto has access to 675 Mt of high quality, low-impurity iron ore.[152]

May 2024 saw SCMP report the Simandou project was 30-35% complete in infrastructure, with the mine slated to begin production by 2025.[153] Simandou is expected to produce 5 Mt in 2025,[154] before ramping up to 75 Mt in 2027, and 90 Mt in 2028.

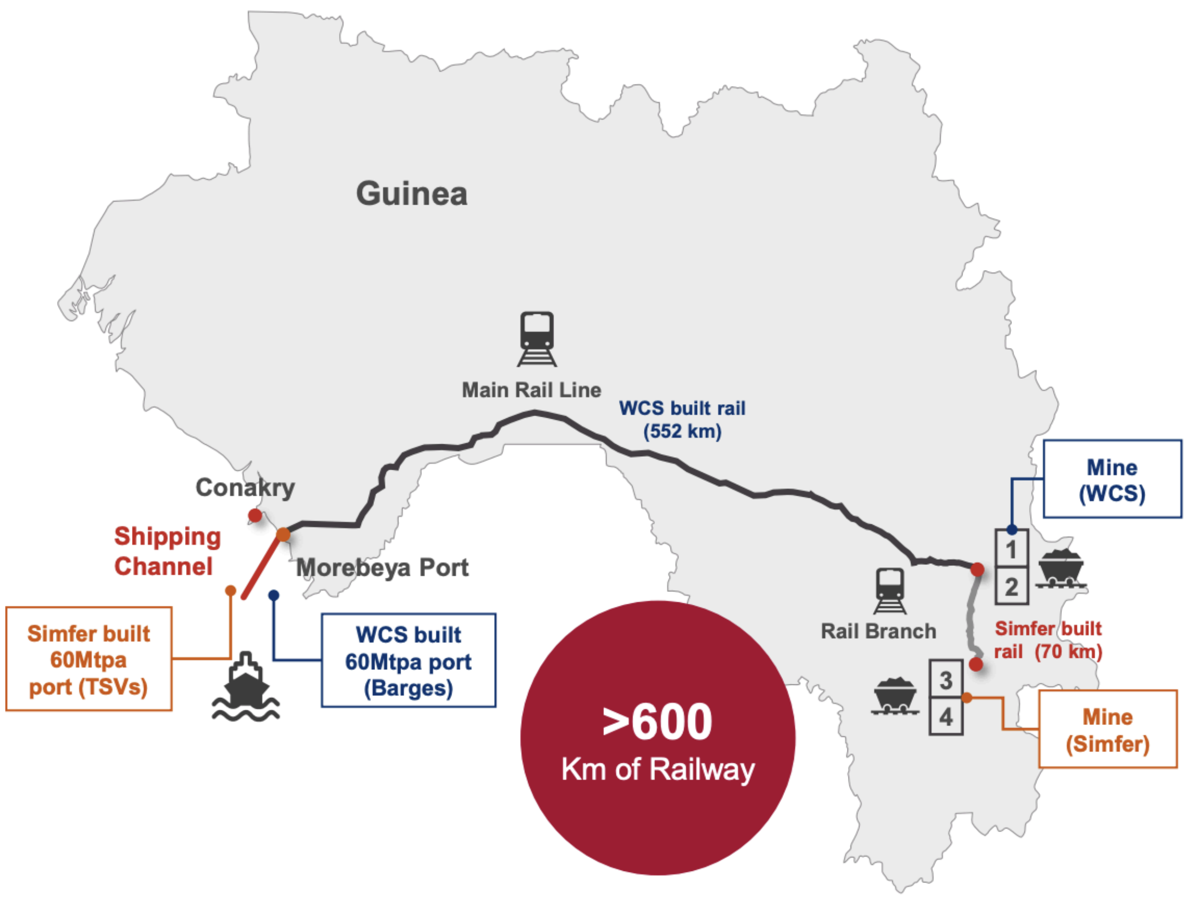
More than half of the Simandou iron ore extracted is to be exported to China. Given the far higher quality of iron ore from Simandou, and China's steel production is expected to have

[150] Rio Tinto, Financial Community Visit to North American Operations, 24 September 2024
[151] Rio Tinto, Financial Community Visit to North American Operations, 24 September 2024
[152] Rio Tinto, Release of Mineral Resource and Ore Reserve Estimates for Simandou, 06 December 2023
[153] SCMP, Mega Simandou Iron Ore Project in Guinea to Start Production by Next Year, 24 May 2024
[154] Reuters, Simandou to mine first cargo by end of 2025, 30 October 2024

already peaked, this product will directly displace lower quality iron ores from Australia's Pilbara, given the ability to reduce emissions intensities in BF using higher-grade ore. The remaining production from Simandou has the potential to be value-added in the Middle East, which has the potential to further displace Australia's future lower-emission iron production.

The Simandou project is divided into 2 main mining blocks, with Blocks 1 & 2 owned by the Government of Guinea (15%), Baowu Group (42.5%), and the Winning Consortium of Singapore (WCS), with capex funded by Baowu (49%) and WCS (51%). Blocks 3 & 4 will be owned by the Government of Guinea (15%), and the Simfer Consortium, of which Rio Tinto owns 53%. The enabling port and rail infrastructure will be funded 50:50 between the Simfer JV and WCS JV. Both Simfer and WCS mines will each produce 60 Mtpa of high-grade iron ore, leveraging common supporting infrastructure to export a total 120 Mtpa - Figure 7.5.

Figure 7.5: Simandou Iron Ore Project, Guinea



Source: Rio Tinto [155]

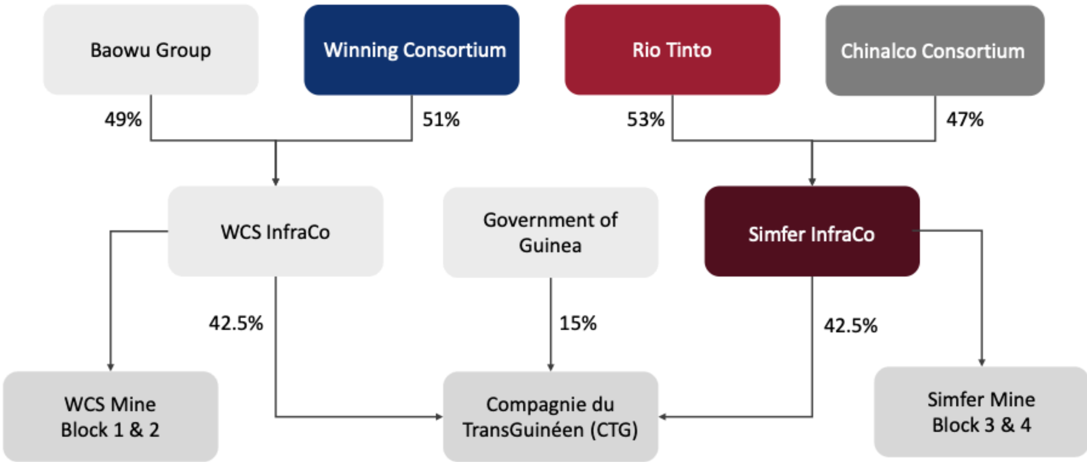
Primarily through Baowu Group, the world's largest steelmaker, and ChinalCo, a large diversified metals producer, both of which are 100% Chinese Government owned, China owns an effective share of 51.6% across the whole Simandou project. With the additional

[155] Rio Tinto, Copper and SImandou Investor Seminar 2023, 19 December 2023

equity stakes from China Rail Construction Company and China Harbour Engineering Company, the Chinese Government controls the entirety of the 51.6% share of the project.

Rio Tinto's effective stake is 22.5%, with the balance made up by the Government of Guinea, with a 15% stake, and Singapore International Group with 10.8% - Figure 7.6.

Figure 7.6: Corporate Structure of Simandou Iron Ore Project



Chinalco Consortium:
Chinalco (75%), Baowu Group (20%), China Rail Construction Corporation (2.5%), China Harbour Engineering Company (2.5%)
Winning Consortium:
Singapore International Group (50%), Weiqiao Aluminium (China Hongqiao Group) (50%), United Mining Supply Group (nominal)

Source: Rio Tinto [156]

Given seaborne trade routes from North Africa to China would likely go through the Suez Canal (connecting the Mediterranean and Red Seas), the case for a world-leading green iron production corridor along the Arabian Peninsula is massively supported, given further iron ore supply chains from North Africa, Canada, and Brazil.

As highlighted in CEF's recent report, 'Green Capital Tsunami', China as a > US$100bn outbound cleantech investment pipeline since 2023 alone, including the construction of solar and wind turbine manufacturing plants in Saudi Arabia, as well as multiple GWs of renewable energy and storage projects across Saudi Arabia, UAE, and Oman.[157]

Given China's increasing involvement in upstream cleantech manufacturing and renewable energy generation, there is real potential for China to leverage this world leadership by collaboratively establishing world-scale green iron hubs in the Middle East, in partnership with strategic, patient capital from the region's sovereign wealth funds, including Saudi Arabia's US$1.1 trillion PIF, and the aggregate US$2.1 trillion SWFs of the UAE.

Establishing an intermediate production hub in the Middle East provides further diversification for China, providing exposure to low-cost methane gas to increase DRI production, as well as incredibly low-cost renewable energy potential for green iron and steel, in which Chinese firms are already leveraging to increase their exports into the EU.

[156] Rio Tinto, 2023 Annual Results Slides, 21 February 2024
[157] CEF, Green Capital Tsunami: China's >$100bn Outbound Cleantech Investment since 2023, 02 October 2024

Australia needs to understand and counter this long term strategic economic threat to our largest export by volume and revenue. Australia needs to turn this risk into a massive investment opportunity by proactive public-private financing initiatives.

Vale Planned Growth in High-Grade Ore Supply

In November 2022, Brazil's Vale announced the joint feasibility studies, alongside local authorities, of the development of iron ore industrial processing hubs across Saudi Arabia, the UAE and Oman, with plans to build and operate a series of ore concentration, briquetting and pelleting plants.[158]

The 'Mega Hubs' currently include the potential for a 12 Mtpa iron ore concentration plant in Oman's Duqm Industrial Complex, and a 4 Mtpa pellet/briquetting plant in Ras Al Khair's industrial complex, Saudi Arabia.[159]

Vale is targeting a global production capacity of 100 Mtpa of agglomerates (iron ore briquettes and pellets) after 2030, but we note in the last financial year this output was only 43 Mt (37 Mt pellets + 6 Mt briquettes), leaving a massive investment gap needed to deliver on this aspiration. CEF notes that projects that have surpassed FID in Brazil for the production of DRI/HBI remain very limited, likely due to the limited availability of methane gas and access to abundant excess renewable energy potential.

In June 2023, Vale and Stegra announced the agreement to jointly study the feasibility of developing green industrial hubs in Brazil and North America. In such hubs, Vale would build and operate iron ore briquetting plants, which will feed DRI reactors for the production of HBI and other metallics.[160]

In October 2023, Stegra and Vale announced a multi-year supply agreement for iron ore pellets as material input for its world-leading green DRI plant in Boden, Sweden, albeit absent details of the timing of commencement of commercial scale deliveries.[161]

[158] Vale, Vale Signs Agreements to Develop Mega Hubs in the Middle East, 01 November 2022
[159] Vale, Vale Advances on Mega Hubs Project by Signing Offtake with Essar Group, 9 November 2023
[160] Vale, Vale and H2GS Sign Agreement to Study the Development of Green Industrial Hubs in Brazil and North America, 09 June 2023
[161] Stegra, H2GS and Vale in Agreement for the Supply of DRI Ore Pellets, 08 October 2023

Section 8. Australia's Green Iron Opportunity

Section summary:

- With a 56% export market share, Australia is by far the world's dominant iron ore supplier.
- However, BF-grade ore is set to decline 2.0-2.2% CAGR from 2023-2040 according to MineSpans and CRU, whereas DRI-grade iron ores are set to grow at 5.2-6.5% CAGR under the same forecasts
- Ore quality issues and a lack of long term strategic national interest planning, decarbonisation urgency and no Asian trade carbon price signal, all see an incumbent privileged industry complacent to the strategic risks, and the massive opportunities that are possible.
- Australia needs public-private collaboration and investment, in partnership with our key North Asian customers.
- Steel is an integral component of new energy technologies, buildings and infrastructure. As more industries reorient towards reductions in embedded emissions intensity in products, the decarbonisation of steel will become of paramount importance.

Implications for Australia:

- Forging Australia's green iron industry requires a complete restructure of the legacy dig-and-ship landscape that Australia's relied on for decades, and will require a new kind of intergenerational policy framing, forging green metal statecraft given the need for collaboration with our Asian trade partners.
- Without urgent, orchestrated RD&D between Australia's iron ore majors, world-leading steelmakers in Asia and the EU, as well as metallurgy process OEMs, supported by a joint international support system of patient strategic public capital, Australia risks progressively losing significant market share in the iron and steel value chain, as global markets shift to prioritising mature technologies with reduced emission intensities to that of blast furnaces
- For Australia to address the cost differential in green iron production, we must address the hurdles to accelerating renewable energy approvals to lower the cost of electricity, partner with world leading Chinese OEMs in the hydrogen supply chain to lower capex intensity, and support R&D initiatives for commercialising technologies specific to Australia's iron ore resources.

The global energy transformation is a major techno-economic paradigm shift, the kind that has characterised the evolutionary system of industrial capitalism since the 1800s. As economic theory tells us – and economic history confirms – in a capitalist system, all major techno-economic shifts involve a process of 'creative-destruction', with the energy transformation creating new green energy industries, and the progressive destruction of fossil fuel incumbencies.[162] As a result, this monumental energy transition is both a challenge of environmental policy and energy policy, and a challenge of techno-industrial policy: of new industry building and legacy industry adjustment and dismantling.[163]

With China representing some 54% of global steel production and 51% of global steel consumption in 2024, and importing 85% of all Australian iron ore exports, China will play a central role in the future of the steel industry. Whilst the US domestic steel industry is by

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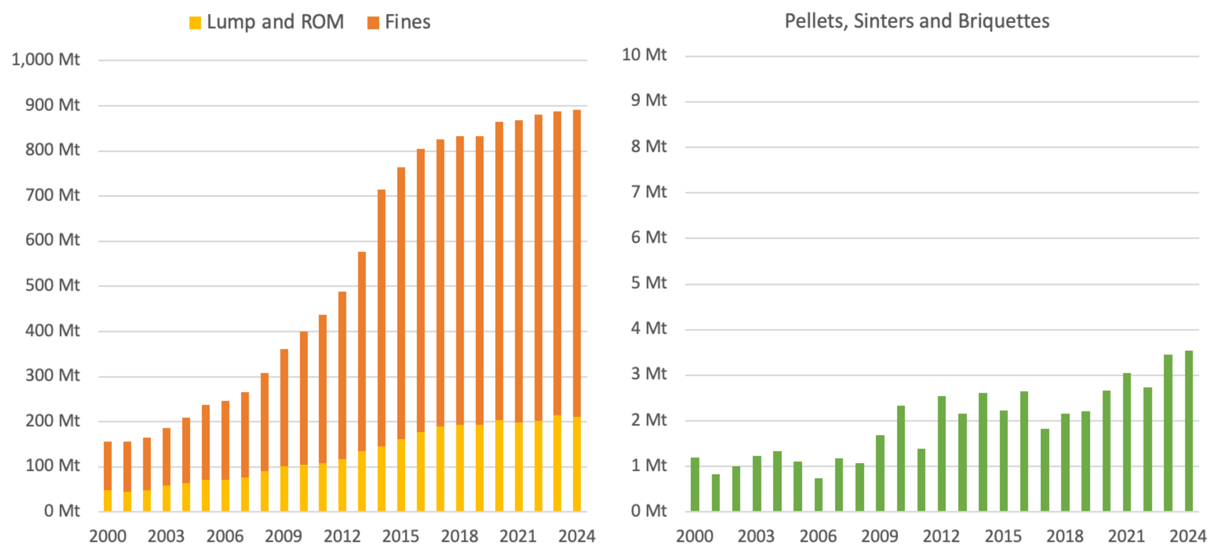
[162] Dr Elizabeth Thurbon, Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition, 02 May 2023

[163] Ibid.

comparison small, it is very advanced globally, with a very high(>70%) EAF share, and world leading scrap recycling rates.

In 2024, < 0.4% of Australian iron ore exports will be beneficiated, i.e., refined into products that command premiums in the global iron and steel market. In 2024, Australia will likely export 892 Mt of iron ore fines and lumps, of which 76% will be ore fines - Figure 8.1.[164]

Figure 8.1: Australia's Iron Ore Exports, DSO (LHS) and Value-add (RHS)



Source: Office of the Chief Economist (OCE) [165]
Note: 2024 is annualised 1H2024

Forging Australia's value-added green iron industry requires a complete restructure of the legacy dig-and-ship landscape that Australia's relied on for decades, and will require a new kind of intergenerational policy framing, forging green metal statecraft given the need for collaboration with our Asian trade partners.

In contrast, the total exports of iron ore sinters and briquettes (agglomerated iron ore) and pellets combined will only just exceed 3.5 Mt in 2024.[166] Since 1990, fines exports have grown at a 7.6% CAGR, from a significantly higher baseline to that of value-added products, whereas pellets, sinters and briquettes have grown at just 2.3% CAGR since 1990.

As mentioned in Section 1, the vast majority of Australia's iron ore exports are in the form of hematite direct shipped ore (DSO) - fines and lumps, which undergo basic processing onshore (e.g. crushing and screening) before being shipped to regions where all value-add of iron ore into iron and then steel occurs. The iron content, impurities and nature of Australia's DSO means they are processed in blast furnaces in North Asia.

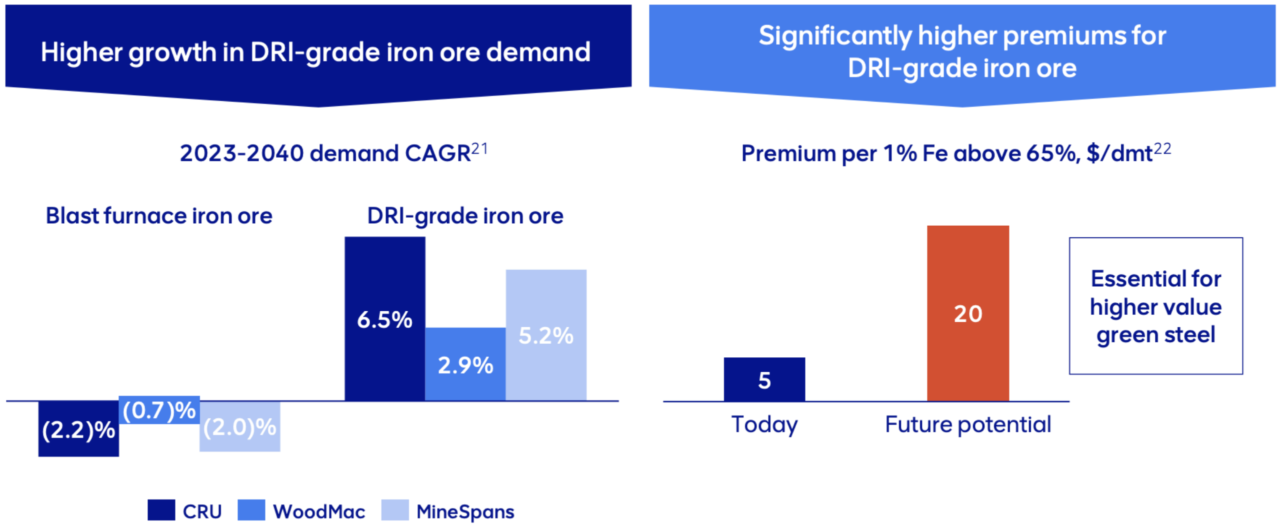
Without urgent, orchestrated RD&D between Australia's iron ore majors, world-leading steelmakers in Asia and the EU, as well as metallurgy process OEMs, supported by a joint international support system of patient strategic public capital, Australia risks progressively losing significant market share in the iron and steel value chain, as global markets shift to prioritising mature technologies with reduced emission intensities to that of blast furnaces.

[164] Note: Iron ore export values are annualised 2024 figures using 1H2024 data from the OCE
[165] OCE, Resources and Energy Quarterly: September 2024, 30 September 2024
[166] OCE, Resources and Energy Quarterly: September 2024, 30 September 2024

Magnetite ores, with more cost-effective beneficiation methods, will be prioritised globally for the initial decarbonisation shift, supplying first mover markets with carbon pricing and trade-adjusted carbon pricing mechanisms, e.g. the EU.

As per Figure 8.2, blast furnace grade ore is expected to decline 2.0-2.2% CAGR from 2023-2040 according to MineSpans and CRU, whereas DRI-grade iron ores are expected to grow at 5.2-6.5% CAGR under the same forecasts.[167] In addition, Anglo American, one of the largest diversified global miners, with investments in a diverse iron ore portfolio, expects the value-in-use premium to drastically increase from US$5/dmt per 1% Fe above 65%, to US$20/dmt.

Figure 8.2: Iron Ore Market Fundamentals: Anglo American



Source: Anglo American

The enthusiastic embrace of the energy transition in North East Asia has been catalysed by policymakers' growing realisation that their traditional 'fossil-fuelled' model of development is unsustainable economically, environmentally, and politically – in both the domestic and international geopolitical sense.

Developmentally-minded policymakers in Northeast Asia view local manufacturing capacity, technological autonomy, and export competitiveness as the essential foundations of domestic political legitimacy, national security, and international status, embracing the central role of Government in advancing such goals through strategic interventions in the market.[168]

East Asian policy makers appreciate that a successful energy transition is not just a challenge of de-growth in fossil fuel industries, but of massive growth in emerging industries enabled by renewable energies. Their acute awareness of the economic, energy and environmental security benefits associated with the energy transition has seen Easy Asian policymakers pour billions into green energy industry creation and establish by far the world's largest renewable energy system.

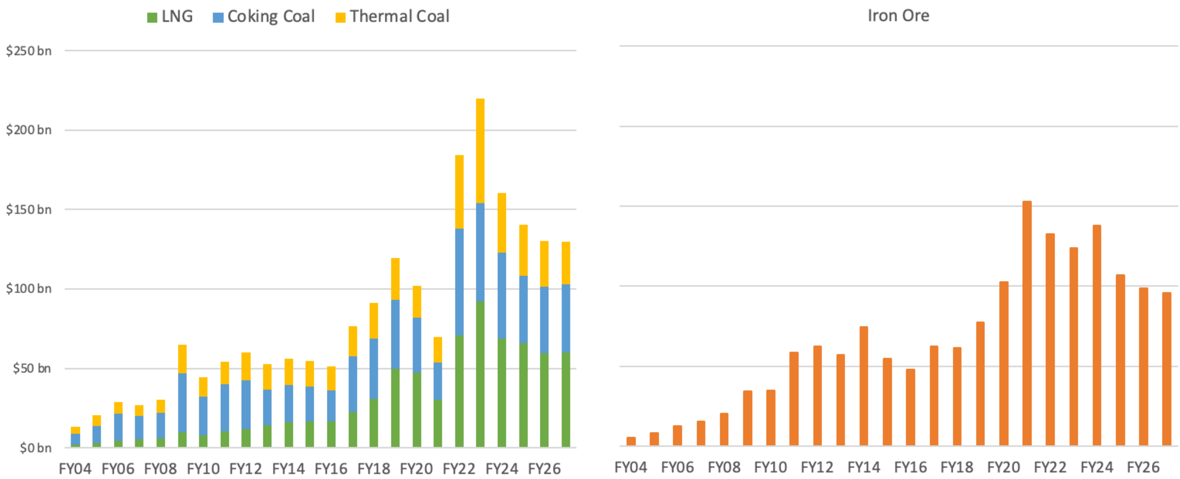
[167] Anglo American, Accelerating Value Delivery, 14 May 2024

[168] Dr Elizabeth Thurbon, Developmental Environmentalism: State Ambition and Creative Destruction in East Asia's Green Energy Transition, 02 May 2023

Australian policy makers have much to learn from Northeast Asia's approach to the energy transition, not least the ambition with which they pursue the massive economic opportunities on offer. The energy transition represents a massive economic and export growth opportunity for Australia - as well as a massive opportunity to boost national energy and environmental security. Specifically, it has the potential to simultaneously expand Australia's export base of future-facing commodities and value-added products with embedded decarbonisation, and phase-out Australia's exposure and overdependence to fossil fuel extraction and consumption.

Following the record exports of Australian fossil fuel producers of $220bn in FY2023, with windfall profits earned from the global energy supply deficit that emerged following Putin's invasion of Ukraine, fossil fuel export sales have fallen 27% to $160bn in FY2024. The Office of the Chief Economist forecasts fossil fuel export earnings to decline further, dropping to $130bn in FY2026.[169] Australia's iron ore sales are almost equal to that of Australia's combined LNG and coal exports, with the deficit in 2023-24 at $22bn.

Figure 8.3: Australian Fossil Fuel and Iron Export Earnings



Source: Office of the Chief Economist [170]
Note: 2024 is annualised 1H2024

As the world accelerates decarbonisation efforts and restructures their respective energy landscapes to align with the objectives of net zero by 2050, Australia's fossil fuel exports will enter a gradual, yet terminal decline (if we are to have a liveable planet, absent the development of CCS at a scale 100x current global levels, which in turn will require a price on carbon emissions of >>US$100/t (for now, US taxpayers are providing a massive subsidy for Exxon's CCS and CCUS developments, but other countries are unlikely to be able to afford such state capture)). For Australia to maintain its economic prosperity, stability, terms of trade, and employment levels, we must prioritise the value-add of our existing and emerging future-facing resources.

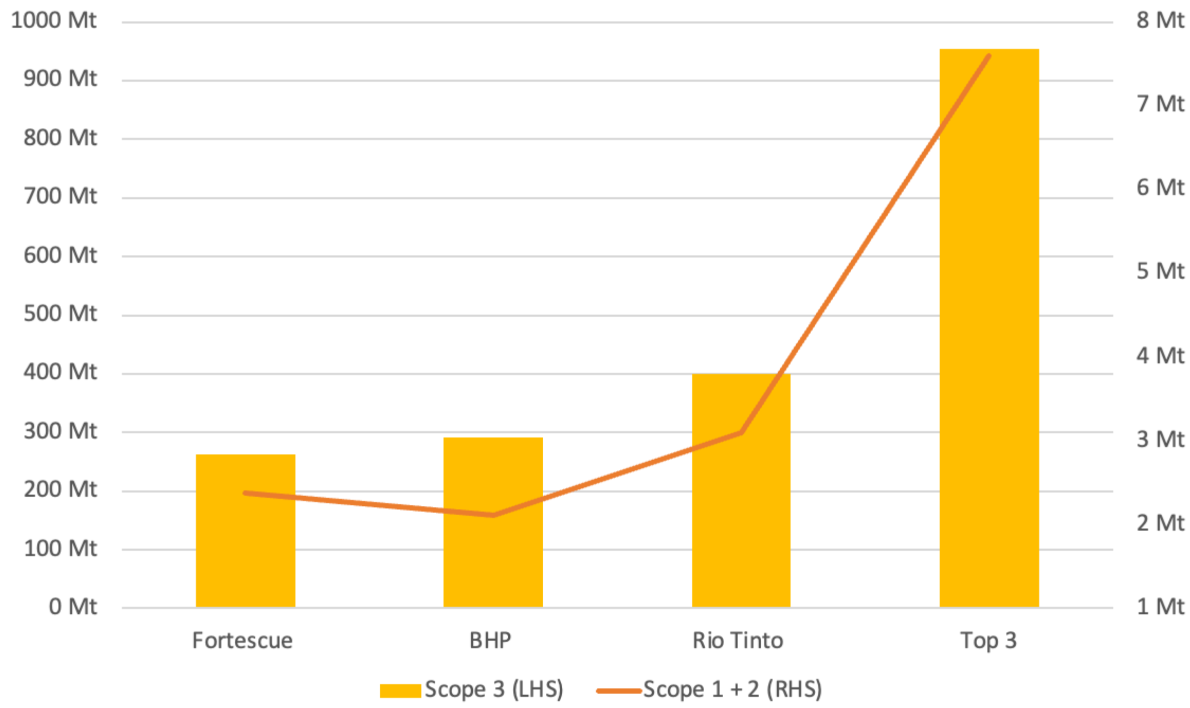
Steel is an integral component of new energy technologies, buildings and infrastructure. As more industries reorient towards reductions in embedded emissions intensity in products, the decarbonisation of steel will become of paramount importance.

[169] OCE, Resources and Energy Quarterly: September 2024, 30 September 2024
[170] OCE, Resources and Energy Quarterly: September 2024, 30 September 2024

We use the term green metal statecraft to capture the ambitious, long-term, visionary approach to policy making required to capture the enormous opportunities presented by the global transition away from fossil fuels and towards a green energy future. By embracing green metal statecraft, Australia can transition from a legacy petrostate into a renewables powered electrostate. The single largest opportunity for Australia this century is emerging, and has the potential for Australia to not just continue but extend its leadership as the top energy exporter to Asia, leveraging our renewable energy base to embed decarbonisation in our future facing industries pre-export.

Australia's largest iron ore producers, Rio Tinto, BHP and Fortescue, collectively emit 7.6 Mtpa CO_2-e from domestic Scope 1 and 2 emissions, primarily from the consumption of imported subsidised diesel to operate mobile mining equipment and rail fleets from inland Pilbara to Port Hedland and Karratha. In comparison, the three iron ore majors have exported (Scope 3) emissions of 954 Mtpa CO_2-e resulting from the processing of sold goods (i.e. iron ore into iron) alone. Scope 1 and 2 emissions account for less than 0.8% of the value chain emissions of Australia's iron ore industry - see Figure 8.4.

Figure 8.4: Domestic Emissions Compared to Exported Emissions in Australian Iron Ore



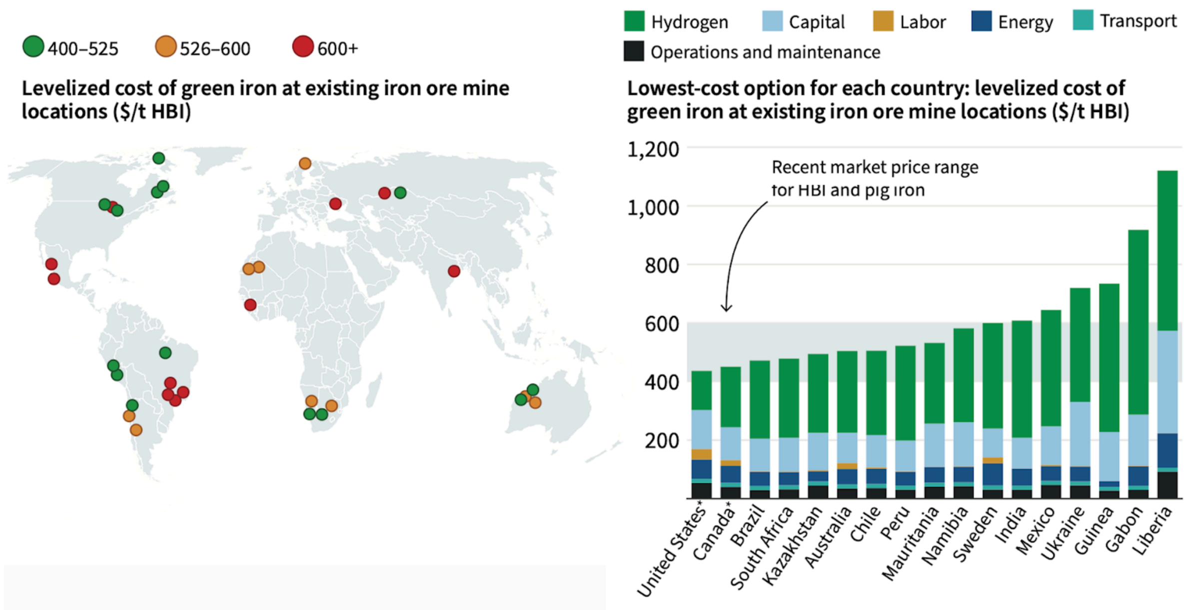
Source: Company Accounts Note: Fortescue and BHP are FY2024 data, Rio Tinto is CY2023 data, the latest publicly-available datasets.

Australia's role in the decarbonisation of the global iron and steel value chain lies in the potential for onshoring of ironmaking, which accounts up to 87% of this scope 1-3 emissions profile, to embed renewable energy in our exports by onshore refining.

The steelmaking industry, directly and indirectly, emits 3.6 billion tonnes of CO_2 annually, representing 6.7% of global emissions. The decarbonisation of just Australia's scope 3 emissions in iron ore processing would result in a 26.5% global reduction in iron and steel emissions.

Australia cannot compete globally in traditional fossil fuel-based iron and steelmaking, as well as the emerging MENA DRI market powered by its lowest-cost domestic methane gas supply. However, Australia is in the box seat to be a green iron superpower. RMI's recent study on green iron corridors identified Australia as one of the optimal jurisdictions for green iron production, alongside Brazil, Canada and the US.[171] The study identified Australia's lowest-cost scenario could produce iron at a levelised cost of ~ US$500/t - see Figure 8.5.

Figure 8.5: Levelised Cost of Green Iron and Lowest-cost Production in Key Regions



Source: RMI [172]

Australia's green export opportunity and comparative advantage in green metals refining is predicated on the expectation that abundant renewable energy resources will translate into low-cost renewable energy power, and thus low-cost derivatives such as green hydrogen.[173]

The commercial realisation of green metals and GH_2 presents a green premium hurdle (the cost difference between zero-emissions production and the benchmark conventional production cost).

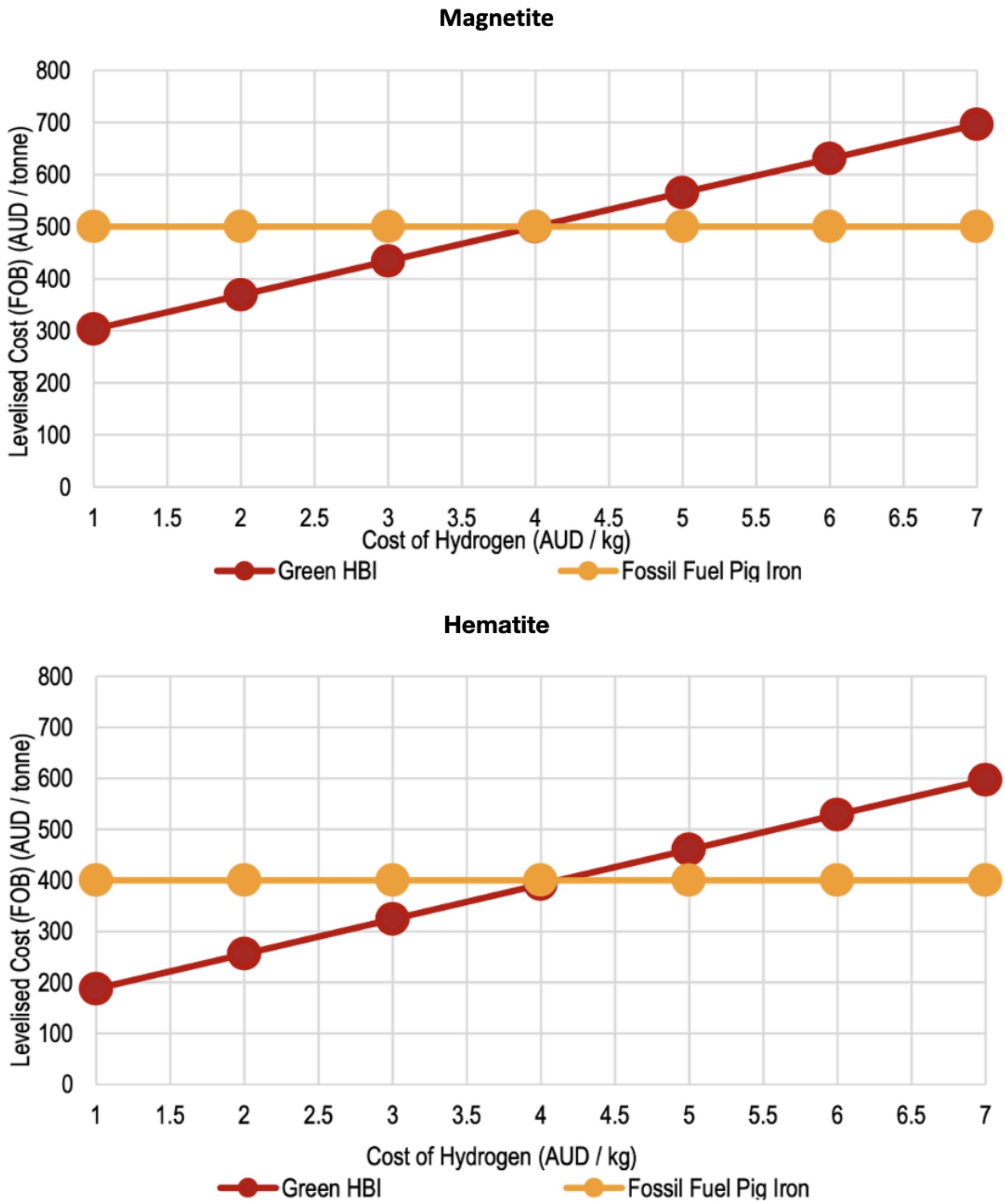
An analysis conducted by the Minerals Research Institute of Western Australia (MRIWA) examined the levelised cost of production of value-added iron and steel products in WA, comparing various input costs and scenarios between traditional fossil-fuel based pathways, and decarbonised pathways using renewable energy and green hydrogen.[174] The study identified, at a levelised cost of green hydrogen (LCOH) of A$7/kg (US$4.7/kg), green iron commands an approximate **$200/tonne premium** over the baseline cost of pig iron produced via a blast furnace, with coking coal as the reducing agent.

Pig iron produced via hematite in Australia is estimated to cost $408/tonne (US$272/tonne), with magnetite estimated at $514/tonne, largely due to the increase in beneficiation

[171] RMI, Green Iron Corridors: Transforming Steel Supply Chains for a Sustainable Future, September 2024
[172] RMI, Green Iron Corridors: Transforming Steel Supply Chains for a Sustainable Future, September 2024
[173] Calix, Calix Submission to the Australian Government Green metals Consultation, 12 July 2024
[174] MRIWA, WA Green Steel Opportunity, updated 06 November 2023

required to increase Fe content in magnetite ore from its in-situ grades. The study identified that price parity between that of fossil fuel pig iron and green iron in Australia can be achieved at an LCOH of $4/kg - see Figure 8.6. MRIWA's model forecasted Australia's green LCOH to be ~ $7/kg, which would result in a levelised cost of $612/tonne for hematite, and $712/tonne for magnetite.

Figure 8.6: Green HBI Price Sensitivity to LCOH Compared to Blast Furnace Pig Iron



Source: MRIWA

There are a number of pathways that can targeted concurrently to reduce long-term premiums, including policies and national interest objectives that provide:

Cheaper electricity. Value-adding and processing metals is energy-intensive, and will require significant renewable energy given the shift to electrification. Mechanisms and policies that can accelerate regulatory and environmental approvals processes, as well as leverage economies of scale through common user enabling electricity infrastructure will place downward pressure on renewable capex, lowering the levelised cost of energy.[175]

Reductions in capex in hydrogen supply chains. Electrolyser capex is falling at far slower than anticipated rates globally. Unlike other regions that are prioritising scaling green iron and steel value chains with restrictive domestic content requirements, Australia must partner with technology leaders in China, Japan and South Korea to realise significant capex savings. Electrolyser stacks manufactured in China are up to 75% cheaper than that of European OEMs.

Support for R&D into new technologies. Australia must actively and collaboratively prioritise capital and resources into RD&D to commercialise iron reduction technologies that will reduce the capex and opex of DRI plants in Australia. ARENA has made strong progress with its grant awards of $59m in April 2024,[176] but this should be only a first small down payment, and accelerated decision making and risk acceptance is critically needed at ARENA (as well as at CEFC and NRF), given the prize of a $100bn annual uplift in our iron export value, and the downside risk of not winning this race. As highlighted below, technical partnerships to unlock DRI-ESF pathways that can utilise low- to mid-grade iron ore fines provides significant savings through cost reductions via bypassing beneficiation and pelletisation.

Higher carbon prices. Scope 1 emissions of our metals industries are covered by the Safeguard mechanism, imposing a still too low carbon price to drive down emissions, however under current settings, this price is not likely to be sufficient to close the gap between production costs of current emissions-intensive pig iron and green iron prior to 2040.

[175] Reference your CEF CUI Pilbara report
[176] ARENA, Funding boost for hydrogen and low emissions iron & steel research, 10 April 2024

Section 8.1. Scoping Australia's Green Iron Opportunity

Section summary:

- Based on CEF's green iron analysis, hydrogen requirements for DRI will likely fall within the range of **54-76 kg/t-DRI**. It is important to note that 54 kg is the absolute minimum requirement stoichiometrically. The hydrogen demand is likely to be skewed towards the higher end of the range.
- To produce sufficient hydrogen, incorporating the intermittent nature of Australia's renewable energy resources, CEF estimates between **496-698 MW** of electrolyser capacity is needed per million tonnes of DRI.
- All in, CEF estimates the total energy demand for green iron production within the range of **4.1-5.3 TWh/Mt**.
- In FY2024, the NEM generated 213 TWh. Based on CEF's green iron analysis, producing 50 Mtpa of green iron (~ 25 facilities across Australia), would require 204-266 TWh of green electricity, which would translate to a doubling of the NEM's current annual generation.
- Value-adding ~ 40% of Australia's current iron ore exports could double the total iron and iron ore export revenues of Australia to more than double, **exceeding $250bn pa**.

Implications for Australia:

- Australia has benefited immensely from the high-margin revenues of direct shipped ore. However, Australia cannot rely on the continued prioritisation of volume over profitability from China's steel sector. As highlighted throughout this report, other jurisdictions are investing public and private capital at speed and scale to capture the value of the global restructuring of iron and steel value chains.
- Australia will not capture the export revenues required to fill the future deficit of our fossil fuel export commodities if left to the free market, as no other key established or emerging supply market has.
- Our key trading partners cannot achieve the transition on their own, but without Australia stepping up to the plate, other markets will.
- failure to overcome the technical and economic challenges of green iron, would mean Australia risks the reality that our iron exports could halve, as traditional importers restructure supply chains to regions of high-quality iron ore and low-cost ironmaking.

CEF has conducted analysis on the energy, water, and investment requirements in establishing a green iron industry in Australia. Green hydrogen production is the largest component of the levelised cost of green iron, consuming significant amounts of green electricity and water. A more detailed breakdown of key production factors for CEF's green iron opportunity analysis can be found in the Appendix G.

Under CEF's green iron methodology, we assume a hydrogen intensity range between **54-76 kg/t-DRI**, based off the minimum stoichiometric requirement to reduce hematite to metallic iron, and the minimum bound of MIDREX's total hydrogen demand for 100% green hydrogen-based DRI, which takes into account reaction inefficiencies and the endothermic nature of the process. CEF's model assumes an average electrolyser efficiency of 70% of the higher heating value (HHV) of 39.4 kWh/kg. This equates to a system efficiency of 56 kWh/kg. Based on CEF's hydrogen intensity range for DRI production, this would require between **3-4.3 TWh** of green electricity per million tonnes of DRI.

This is within the range of multiple other sources, including analysis by RMI, which estimated 160,000 tonnes of H_2 is required to operate a 2.5 Mtpa DRI plant (64 kg/t-DRI). This would require 8.3 TWh of renewable electricity to power the necessary scale of electrolysers, or 3.32 TWh/Mt-DRI for hydrogen energy demand alone.[177]

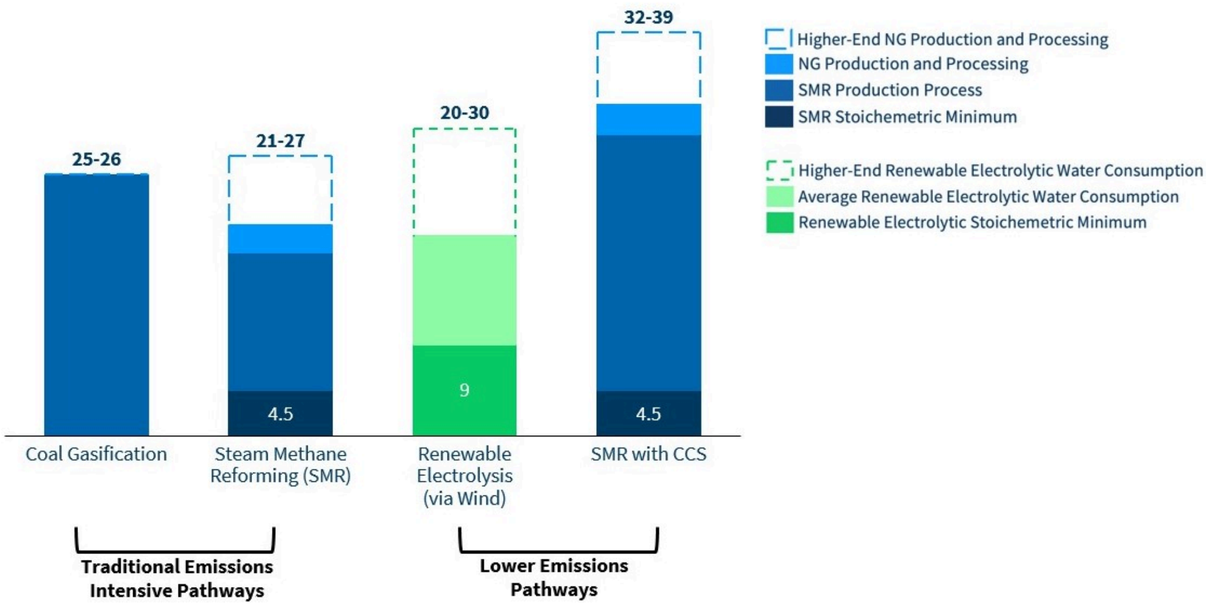
CEF also assumes a capacity utilisation factor for PEM electrolysers at a maximum of 70%, given the intermittent nature of Australia's renewable energy generation. Based on estimated system efficiencies, CEF's green iron model calculates between **496 - 698 MW** of electrolyser capacity is needed to produce the necessary green hydrogen for 1Mt of DRI.

RMI's green iron analysis identified the additional electricity requirements for heating and operating DRI plants.[178] Under RMI's model, DRI plants require 545 GWh/Mt of electricity in addition to green hydrogen production to produce DRI, with a further 10 GWh/Mt required for briquetting into HBI (555 GWh/Mt). RMI's analysis also estimates the electricity demand for operating a DRI-ESF plant would require an additional 480 GWh/Mt, bringing the aggregate electricity demand for HBI production of magnetite projects to 555 GWh/Mt, or 1,035 GWh/Mt for green iron via DRI-ESF.

Given Australia's iron ore industry is primarily hematite, CEF's model assumes a total energy demand for hydrogen production and DRI-ESF production of **4.1-5.3 TWh/Mt**.

Water is another significant component of green iron production. Average water consumption for renewably-powered electrolysis is between 20-30 litres/kg-H_2 (average 25L/kg).[179] However, it is important to highlight that the fossil-fuel intensive pathways of iron production also consume significant volumes of water. Steam methane reforming, the largest production method of grey hydrogen globally, consumes a very similar volume of water, at 21-27L/kg-H_2. In addition, coupling SMR facilities with CCS increases the average water consumption above that of electrolysis, averaging 32-39L/kg-H_2 - see Figure 8.7.

Figure 8.7: Water Consumption from Hydrogen Production Pathways (L/kg H_2)



Source: RMI [180]

[177] Canary Media, How Much Clean Energy Does it Take to Make Green Steel, 22 May 2024
[178] RMI, Green Iron Corridors: Transforming Steel Supply Chains for a Sustainable Future, September 2024
[179] RMI, Hydrogen Reality Check: Distilling Green Hydrogen's Water Consumption, 02 August 2023
[180] RMI, Hydrogen Reality Check: Distilling Green Hydrogen's Water Consumption, 02 August 2023

CEF's green iron analysis assumes a total water (for H_2) of **1.35-1.9 GL/Mt-DRI**. Traditional coking coal-based ironmaking also has significant embedded water consumption, given the high water intensity of metallurgical coal mining. BHP's BMA portfolio reports a water intensity of 667L/tonne of coal.[181] Given 770 kg of coal is used per tonne of hot metal, this assumes a water intensity of 514L/thm, or 0.51 GL/Mt-hm. Whilst GH_2's water intensity is higher than that of other fossil-based reducing agents, it is important to position such figures in a broader context.

As of January 2023, Australia's cotton industry had 672,247 hectares of cotton planted.[182] Australian cotton consumes a significant amount of water, averaging 6.5 megalitres per hectare annually.[183] Based on Australia's planted cotton, the industry would consume 4,370 GL of water every year. As highlighted in Figure 8.8, processing all of Australia's current iron ore exports into DRI would consume between 756 - 1,064 GL of water per annum, or just 17 - 24% of the water consumption of Australia's cotton industry, whilst generating a manyfold increase in export sales for Australia.

Figure 8.8 provides a summary of the key requirements of energy, electrolyser capacity, water, and investment needed for various scenarios. Accenture's Sunshot policy roadmap for global leadership in clean exports identified Australia could generate $96bn in export earnings from green iron and steel by 2040.[184] The Sunshot model assumes Australia could produce 258 Mtpa of green iron by 2040. The Superpower Institute identified Australia could export up to 560 Mtpa of green iron if we value-added 100% of current iron ore exports. Assuming average pricing of US$530/t, this could generate up to US$295bn in annual exports.[185]

Figure 8.8: Various Scenarios of Australia's Green Iron Opportunity

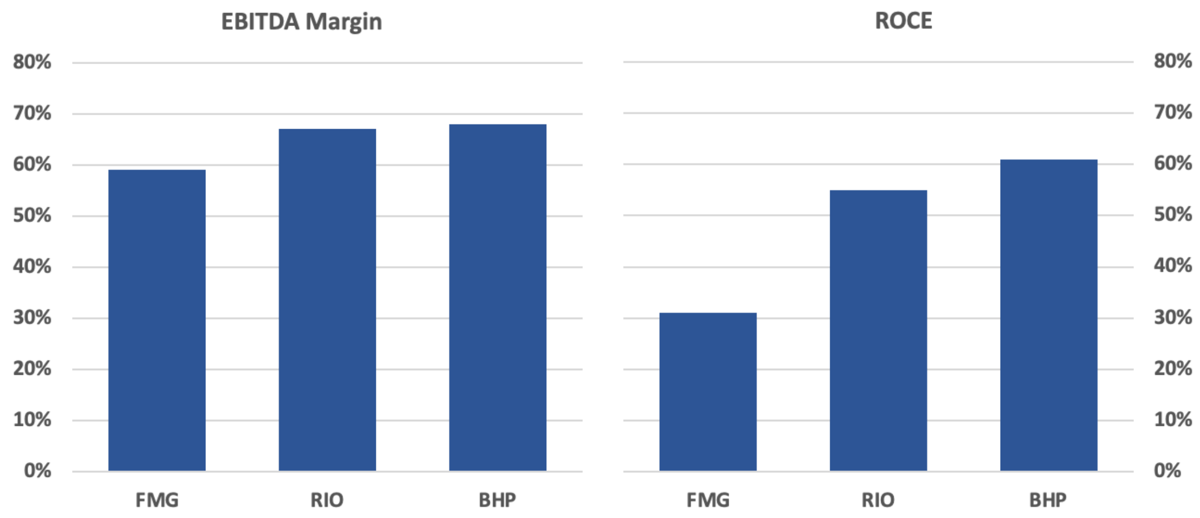
Scenario (Mtpa)	Energy (TWh)	Electrolyser (GW)	Water (GL)
1 - Baseline	4.1 - 5.3	0.5 - 0.7	1.4 - 1.9
2.5 - 1 Facility	10 - 13	1.2 - 1.7	3.4 - 4.8
10	41 - 53	5.0 - 7.0	14 - 19
50	204 - 266	25 - 35	68 - 95
100	407 - 531	50 - 70	135 - 190
110 - 10% Asian Pig Iron Production	448 - 584	55 - 77	148 - 209
258 - Sunshot	1,051 - 1,371	128 - 180	348 - 490
560 - TSI	2,282 - 2,975	278 - 391	756 - 1,064

[181] BHP, BMA Metallurgical Coal
[182] Cotton Australia, Statistics: Hectares of Cotton Planted, 01 January 2023
[183] Cotton Australia, Fact Sheet: Australian Cotton - Our Water Story
[184] Accenture, Sunshot: Achieving Global Leadership in Clean Exports, September 2023
[185] Superpower Institute, Submission: Unlocking Green metals Opportunities, July 2024

Section 8.2. Value-Adding Brings New Challenges

Australia has benefited immensely from the high-margin revenues of direct shipped ore, fuelled by China's rapid industrialisation and urbanisation, where national policies incentivised volume and capacity growth above short-term profits and economically sustainable models. In FY24, BHP, Rio Tinto and Fortescue have generated EBITDA margins of 68%, 67% and 59% respectively from their Pilbara iron ore operations, generating a massive 61%, 55%, and 31% return on capital employed (ROCE) over the same time frame.[186]

Figure 8.9: FY24 EBITA Margin and ROCE of Australian Iron Ore Majors



Source: Company Accounts

In comparison, China's steel industry has operated on significantly lower margins, with recent quarters continuing to generate losses across the sector. Even during the years of steady industry profits from 2017 to 2020, operating profit margins peaked at 7.5% in 2018 over the decade to 2020.[187]

However, Australia cannot rely on the continued prioritisation of volume over profitability from China's steel sector. As highlighted throughout this report, other jurisdictions are investing public and private capital at speed and scale to capture the value of the global restructuring of iron and steel value chains. Australia will not capture the export revenues required to fill the future deficit of our fossil fuel export commodities if left to the free market, as no other key established or emerging supply market has.

Developing a green iron industry in Australia must be led by a coordinated approach from government to reposition Australia from a global climate laggard and petrostate to a climate leader and electrostate that will export low-emission electricity through our resources. This will require coordinated, international, multigenerational investment structures, leveraging Asia's public financing institutions, including export credit agencies, development banks, as well as institutional and infrastructure investment partners to build out the necessary renewable energy infrastructure. Our key trading partners cannot achieve the transition on their own, but without Australia stepping up to the plate, other markets will.

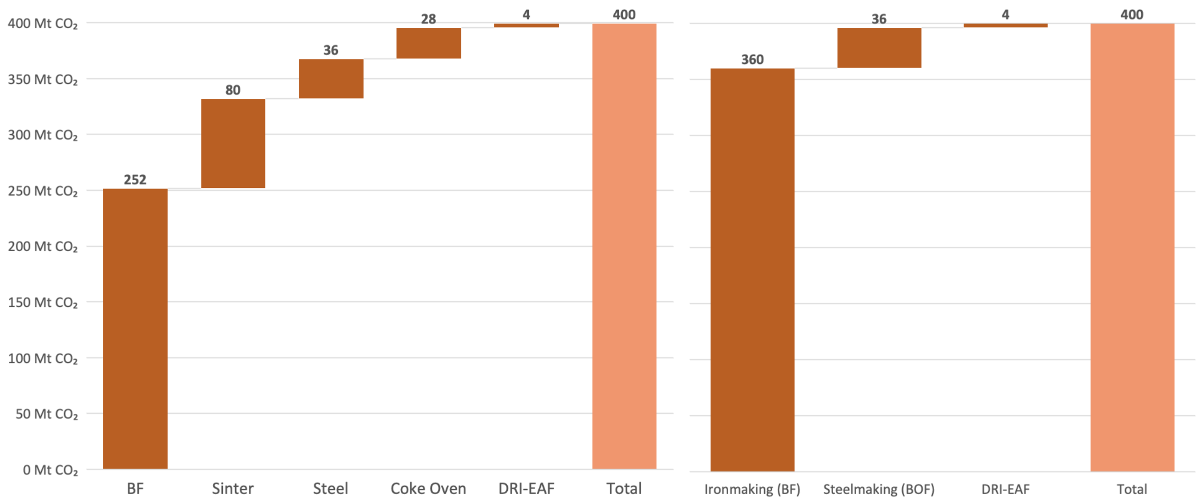
[186] Note: Rio Tinto financial ratios are 2HFY24 due to the company's reporting nature
[187] MRIWA, WA Green Steel Opportunity, updated 06 November 2023

Whilst the investment challenges are immense, the onshoring and decarbonisation of, what is currently, exported Scope 3 emissions of our commodities that are critical to low-emission technologies, as well as building and infrastructure, is the single largest opportunity to abate the largest sector of industrial emissions (i.e. iron and steel), and going further, the lion's share of the emissions breakdown.

Rio Tinto's Pilbara iron ore is the largest integrated portfolio of iron assets in the world, and is currently the largest producer globally. In 2023, Rio Tinto produced (on an equity basis) 290 Mt of iron ore (332 Mt on 100% basis). Scope 3 emissions from the processing of iron ore generated 400 Mt CO_2-e. The largest component is the processing of iron ore with coking coal in a blast furnace, generating 252 Mt CO_2-e (or 63%) - see Figure 8.10.

Adding in the emissions associated with sintering (which uses coal) to agglomerate the iron ore prior to charging in a blast furnace, as well as coke ovens to produce coke from metallurgical coal, the ironmaking stage emits 90% of Rio Tinto's Scope 3 emissions from the processing of its iron ore.

Figure 8.10: Scope 3 Emissions - Processing of Iron Ore, Rio Tinto Case Study



Source: Rio Tinto [188]

Based on average market prices, value-adding ~40% of Australia's iron ore exports could generate $174bn in export revenues from green iron. Coupled with additional iron ore export revenues of $77bn, this would translate to a doubling of export revenues from the iron export industry to $250bn. However, failure to overcome the technical and economic challenges of green iron, would mean Australia risks the reality that our iron exports could halve, as traditional importers restructure supply chains to regions of high-quality iron ore and low-cost ironmaking.

[188] Rio Tinto, Sustainability Factbook 2023, 21 February 2024

Section 8.3. Supporting Australian RD&D Programs

CEF recommends providing an additional **$500m over 10-years to the CSIRO of strategic support for RD&D into the commercialisation of technologies that will unlock and accelerate Australia's green iron industry.** The role of the CSIRO is to provide innovative scientific and technology solutions to national challenges and opportunities to benefit industry, the environment and the community, through scientific research and capability development, services and advice.

To secure the intergenerational value-add opportunity for Australia in scaling a green iron industry, it is imperative to support and foster research and development partnerships of Australia's existing iron ore miners with our research institutions, as well as international world leaders in steelmaking, to demonstrate the commerciality of hematite reduction.

To ensure Australia's centrality to the global iron and steel value chain, it is in Australia's national interest to deliver technical solutions that maintain and expand our nation's share of the value chain, in collaboration with our key trading partners.

The decarbonisation of iron and steel best represents the risks and opportunities for Australia in the global energy transition. Almost all of Australian ore currently exported (hematite/goethite) is low-grade, and not suitable for use in EAFs. Thus, ensuring the compatibility of Australian iron ore with future low-carbon steelmaking is a national priority, and imperative for Australia's economic security and resilience.

Calix Zero Emissions Steel TechnologY (ZESTY) Pilot

ASX listed Calix's Zero Emissions Steel Technology (ZESTY) is a renewable powered H_2-DRI technology for the production of green iron, and subsequent production of green steel. The ZESTY platform employs an indirect heating approach, replacing the inefficient combustion of hydrogen with precise, zero-emission electric heating. This is a key differentiator of Calix to other shaft furnace based green hydrogen platforms, ensuring hydrogen is separated from the heat source and used only within the chemical process of iron reduction.

Advantages of Calix's ZESTY platform include: [189]

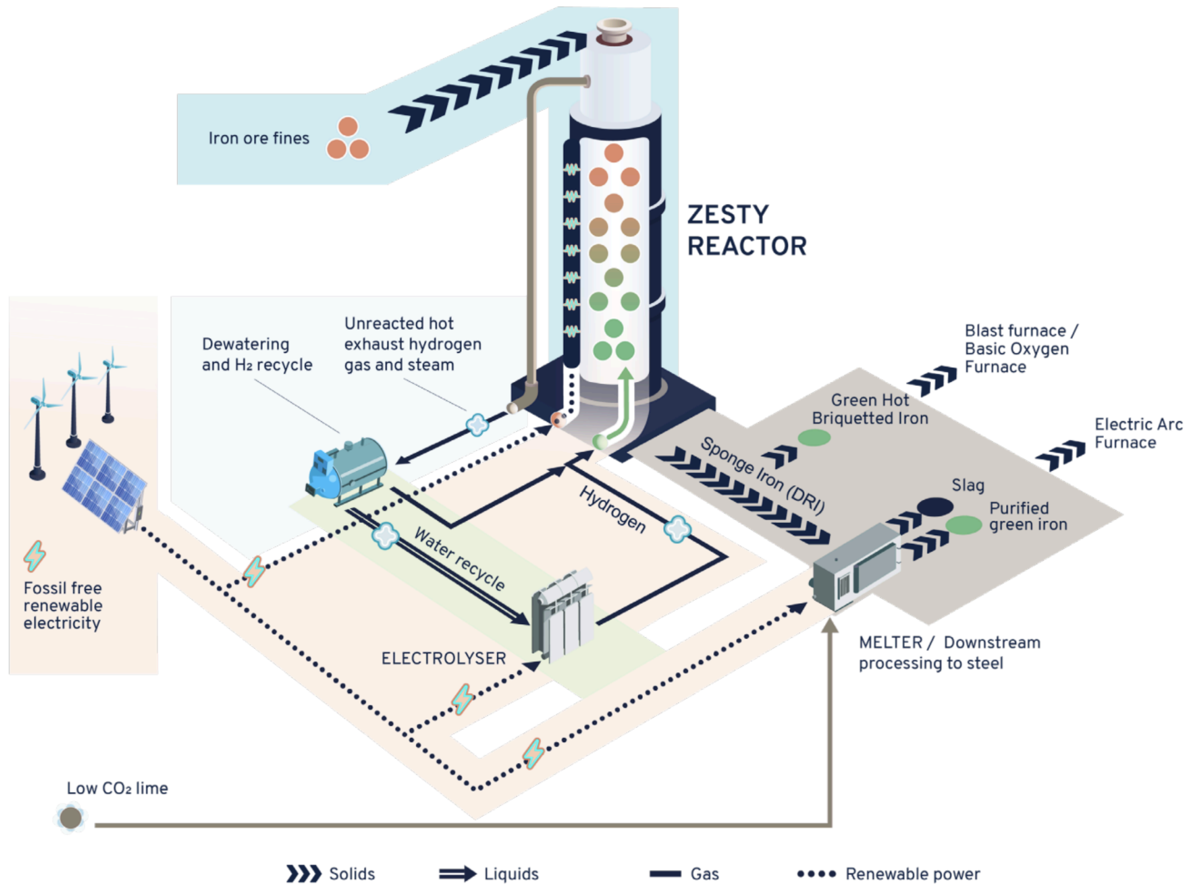
- **Reduced hydrogen consumption** - leveraging an indirect heating mechanism to ensure hydrogen is only used as a reducing agent in the processes, and thus also allowing for unreacted hydrogen to be recycled.
- **Charge fines and low-grade ores** - ZESTY is compatible with lower-grade ore fines, like those mined in the Pilbara, removing the need for sintering (agglomeration of iron ore fines into a larger product).
- **No pelletisation** - ZESTY removes the requirement of iron ore fines to be pelletised, eliminating processing prior to reduction, significantly reducing the capital cost, operating cost, and energy requirements of upstream processing
- **Flexible operability** - The ZESTY platform is compatible with intermittent and renewable electricity, with electric heating providing a high degree of temperature control with fast start-up and shut down, and highly flexible production rates. This

[189] Calix, Calix Submission to the Australian Government Green metals Consultation, 12 July 2024

allows ZESTY to potentially be employed as a load balancing/demand response tool to the energy grid.

In February 2024, Calix announced completion of its Front-End Engineering and Design (FEED) study for a 30,000 tpa ZESTY demonstration plant.[190]

Figure 8.11: Calix ZESTY Platform Process Flow



Source: Calix[191]

The total energy requirement of the process is expected to be 4.2-4.6 MWh/tonne HBI, inclusive of hydrogen production energy requirements. The plant's energy requirements excluding hydrogen is projected to be 0.9-1.3 MWh/tonne HBI.

Calix's ZESTY platform has demonstrated the production of HBI for $630-800/tonne (US$410-520/tonne), competitive to that of current carbon intensive methods, whilst reducing emissions by 80-85% compared to traditional BF-BOF routes.

RIO-BHP-BlueScope Pilot Plant

Rio Tinto, BHP and BlueScope will collaborate to develop a pilot plant to prove the commerciality of molten iron from a DRI-ESF combination using renewable power and green hydrogen to value-add the Pilbara's hematite ores.[192] Pre-feasibility works are expected to be

[190] Calix, Calix's ZESTY Study Finds High Potential for Economic Green Iron, 11 February 2024
[191] Calix, Zero Emissions Steel Technology Investor Briefing, 11 June 2024
[192] AFR, Push to Save Iron Ore Golden Goose, 09 February 2024

completed by the end of 2024, with the pilot plant, subject to approvals and financial close, could become operational as early as 2027.

BlueScope's $1.15bn relining of its BF at Port Kembla steelworks, locking in emissions-intensive steelmaking for another 20 years when it restarts operations in 2026. The relining is supported by a $137m government grant.

ARENA Low-Emission Iron & Steel Research

April 2024 saw ARENA grant $59m to 21 R&D proposals across and commercialisation activities covering renewable hydrogen and low emissions iron & steel.[193] CEF applauds the increased collaboration and joint research development of the grant winners. The challenges to commercialisation of decarbonised iron and steel technologies are a significant risk and hurdle that Australia must overcome to ensure we remain competitive in the global iron and steel value chain.

Among the projects that received funding are:

- **University of Wollongong**: The study of Australian Pilbara Iron Ores in an ESF Process
- **Australian National University**: De-risking large-scale Australian fine-ore hydrogen ironmaking.
- **University of Newcastle**: Electric Smelting of Australian Hematite-Goethite DRI
- **Fortescue Future Industries**: Low Temperature Direct Electrochemical Reduction for Zero Emissions Iron

A full list of projects ARENA is supporting is available in Appendix H.

HILT CRC: Iron & Steel Research

The Heavy Industry Low-Carbon Transition (HILT) Cooperative Research Centre (CRC) is an Australian collaborative venture between industry, academia and government to accelerate the global energy transition by addressing the key challenges and barriers to decarbonising heavy industries, including iron, steel, alumina, and cement.

HILT CRC operates 3 program streams:

- **Program 1**: accelerates decarbonisation in industrial processes with preferred emerging technologies, including the production of green iron from magnetite and Pilbara hematite ores, green alumina calcination, lime and cement. The program seeks to identify pathways to de-risking the necessary scale of investments required to transform current carbon-intensive industries through the development and demonstration of emerging technologies.
- **Program 2**: aims to identify multi-industry opportunities to share costs and reduce carbon intensities, developing novel technologies for economic decarbonisation of heat, fuels, oxidants and reductants.
- **Program 3**: assesses pathways to commercialisation of HILT CRC technologies, including techno-economic evaluations of specific technologies and how they incorporate into the larger systems in which they operate.

HILT CRC has, as of September 2024, completed 23 studies into decarbonising the global iron and steel industry with an Australian context, and are currently investigating another 6 projects. The list of all projects related to iron & steel by the HILT CRC is in the Appendix I.

[193] ARENA, Funding boost for hydrogen and low emissions iron & steel research, 10 April 2024

CEF recommends a proportion of the $500m over 100-years be deployed through CSIRO's partnerships in Australian cooperative research centres. An example for this is the Heavy Industry Low-Carbon Transition Cooperative Research Centre (HILT CRC), which supports R&D projects in iron and steel decarbonisation across industry and academic institutions, leveraging expertise and knowledge sharing across the global heavy industry value chain, with a key focus on overcoming the direct barriers and challenges for Australia.

Section 9. Western Australia's Green Iron Opportunities

Section summary:

- Whilst the Pilbara absolutely dominates Australia's current export supply of iron ore which brings massive scale potential, the remoteness brings a massive capex and opex cost premium that is a major hurdle, as are high methane prices, next to no renewables investment and investment approval inertia.
- Constructing just 1 Mtpa of gas-based DRI capacity in the Pilbara would require a 62% expansion of the current gas demand of the NWIS. WA's entire domestic gas demand forecast over 2024-2033 would equate to the gas demand of operating 41 Mtpa of DRI plants across the state.
- A methane gas-based DRI industry in WA would create a huge demand signal to expand gas supply, which would **cement the social license to operate for Australian gas producers** for decades, and ensure Australia **will not meet** its climate and emissions reduction targets.
- This would destroy any credibility of Australia being a renewable energy superpower on the global stage, undermining landmark policies like Future Made in Australia.

Implications for Australia:

- **Australia cannot afford to prioritise methane gas** in our value-added iron industry. The WA Government, having the greatest downside risk in Australia, must prioritise the acceleration of renewable energy and enabling infrastructure to lower the cost of energy, and thus lower the cost of hydrogen and iron products.
- To support the Pilbara, **common-user electricity infrastructure in the Pilbara** would enable multiple stakeholders to efficiently and cost-effectively electrify and decarbonise their operations. This is key to reducing the 'Pilbara premium' – i.e. the capital-intensive logistical barriers of remoteness, and associated materials, transport and labour costs – and ameliorate commercial disincentives to the shift to clean energy, accelerating investment into green exports.
- To support emerging projects in the Mid-West region of WA, CEF recommends the prioritisation of **developing common user electricity, port and water infrastructure at the Oakajee Strategic Industrial Area**, 23 km north of Geraldton. The Mid-West has greater complimentary wind and solar resources than the Pilbara, as well as significantly lower capex and opex given the premiums present in the Pilbara. In addition, the existing SWIS could be extended to Oakajee to support firming of renewable energy generation surrounding Oakajee.
- CEF recommends the expansion of WA's **Green Energy Approvals Initiative** to prioritise large-scale renewable projects that will support green metals projects in the state.

WA has underpinned Australia's economic strength for decades, the powerhouse of Australia's resource export industry, and the global leader in the export of iron ore.

To power the existing large resource industry, the Pilbara leans heavily on the import of high-emission, subsidised diesel to power mobile energy demand, and relies on methane gas to power its stationary energy demands, including port operations at Port Hedland and Karratha. CEF's report on the Pilbara's energy demand, 'Superpowering Up: Accelerating the

Electrification & Decarbonisation of the Pilbara',[194] identified the iron ore mining majors (RIO, BHP and FMG) consume a massive 2.4 billion litres of diesel annually. The electrification of the existing mining operations already poses a mammoth challenge to the Pilbara region, let alone the massive energy requirements of decarbonising iron production.

The current North West Interconnected System (NWIS) runs almost entirely on gas-fired power stations. In 2022-23 the NWIS, combined with the isolated, off-grid power stations operated by APA, BHP and Fortescue, consumed 17.5 petajoules (PJs) of gas, generating 4,868 GWh of electricity - see Figure 9.1.

Figure 9.1: NWIS Grid-connected Generation and Iron Ore Off-grid Facilities

Facility	Company	Fuel	Generation GJ	Generation MWh	Scope 1 Emissions tonnes CO2-e
Yurralyi Maya Power Station	Rio Tinto	Gas	2,382,821	661,895	388,022
Port Hedland Power Station	APA Energy Pilbara	Gas	1,660,858	461,349	352,397
Paraburdoo Power Station	Rio Tinto	Gas	1,948,865	541,351	270,649
South Hedland Power Station	TransAlta	Gas	1,996,427	554,563	270,158
West Angelas Power Station	Rio Tinto	Gas	1,442,442	400,678	211,291
Cape Lambert Power Station	Rio Tinto	Gas	840,097	233,360	141,935
Karratha Power Station	ATCO Australia	Gas	367,529	102,091	76,416
Total NWIS-Connected Generation			**10,639,039**	**2,955,287**	**1,710,868**
Newman Power Station	APA Energy Pilbara	Gas	2,874,237	798,399	379,196
Yarnima Power Station	BHP	Gas	2,815,536	782,093	336,179
Solomon Power Station	Fortescue	Gas	1,194,901	331,917	206,715
Total Off-Grid Generation from Power Stations			**6,884,674**	**1,912,409**	**922,090**
Total Gas-Fired Generation from NWIS and Off-grid Pilbara Iron Ore			**17,523,713**	**4,867,696**	**2,632,958**

Source: Clean Energy Regulator [195]

As highlighted in Figure 8.9, there are multiple iron proposals in the Pilbara, with the largest proposal in Australia, Port Hedland Green Steel, investigating up to 12 Mtpa of iron capacity in the Boodarie Industrial Hub.

WA has benefitted from lower-cost methane gas than Eastern states of Australia given domestic reservation requirements for gas producers, which has provided WA industrial users with significant discounts in long-term gas contract prices. From 2015 to 2023, WA users of methane gas have secured weighted average domestic contract prices of $4.7/GJ (US$3.1/GJ) - see Figure 9.2.[196] In comparison, methane gas prices in the east coast market are on average between $10-20/GJ, with prices hitting a peak of $49/GJ in August 2022.[197]

While WA methane gas prices are significantly lower than east coast markets, they remain multiple factors above comparable gas producing markets, notably the Middle East which is rapidly emerging as a global iron processing hub at direct competition with Australia. Australia cannot compete with the Middle East on a cost-competitive basis if Australia, and WA, prioritises gas-based DRI/HBI production.

[194] CEF, Superpowering Up: Accelerating the Electrification & Decarbonisation of the Pilbara, 13 August 2024
[195] CER, Electricity Sector Emissions and Generation Data 2022-23, 04 April 2024
[196] AEMO, 2023 WA GSOO, 14 December 2023
[197] ACCC, Gas Inquiry 2017-2030: December 2023 Interim Update, December 2023

In addition to gas prices, accessibility is also a key limiting factor to establishing a global-scale DRI/HBI industry. AEMO's WA Gas Statement of Opportunities (GSOO) 2023's expected supply-demand balance scenario estimates an average of 447 PJs per annum of domestic gas demand between 2024-2033. However, AEMO already forecasts a significant gas supply deficit, reaching a 27% difference by 2033.

Figure 9.2: WA Domestic Gas Prices (A$/GJ)

Source: AEMO [198]

The largest gas-based DRI platform operating in the world, MIDREX, consumes between 275-300 Nm^3/t-DRI. Based on bp's annual energy conversion factors, a 1 Mtpa DRI facility would consume **10.8 PJ of methane gas per annum**.[199] For context, constructing just 1 Mtpa of gas-based DRI capacity in the Pilbara would require a 62% expansion of the current gas demand of the NWIS. WA's entire domestic gas demand forecast over 2024-2033 would equate to the gas demand of operating 41 Mtpa of DRI plants across the state.

A methane gas-based DRI industry in WA would create a huge demand signal to expand gas supply, which would cement the social license to operate for Australian gas producers for decades, and ensure Australia **will not meet** its climate and emissions reduction targets.

Given the critical need to align with the climate science, and the commitment from all miners across WA to achieve net zero by 2050 or sooner, the accelerated electrification of diesel and diversification away from methane gas is required. APA currently operates the only large-scale renewable energy project in the Pilbara in FY23, the 60MW Chichester Solar Farm. Renewable energy accounts for just 2% of the Pilbara's energy supply, with fragmented corporate energy production and grid transmission structures undermining progress on comprehensive energy supply decarbonisation in the region.

[198] AEMO, 2023 WA GSOO, 14 December 2023
[199] bp, Statistical Review of World Energy: Approximate Conversion Factors

CEF's recent Superpowering Up report identified that in order for WA to build out the necessary renewable energy generation and storage capacity to support its domestic decarbonisation, as well as onshore green metals refining industries, a buildout of enabling **common-user infrastructure** and associated rapid deployment of world-scale firmed renewables projects in the Pilbara should be an urgent, top-tier strategic national-interest policy and investment priority for industry, government, regulatory and investment stakeholders.

Common-user electricity infrastructure in the Pilbara would enable multiple stakeholders to efficiently and cost-effectively electrify and decarbonise their operations. This is key to reducing the 'Pilbara premium' – i.e. the capital-intensive logistical barriers of remoteness, and associated materials, transport and labour costs – and ameliorate commercial disincentives to the shift to clean energy, accelerating investment into green exports.

Delivered effectively, common-user infrastructure will best support the future economic growth of the Pilbara in a net zero global economy: lowering the total capital investment required to power the region's industrial energy demand with green electricity, mitigating risk, minimising duplication of transmission networks, and integrating existing disaggregated grid and generation infrastructure 'islands' into a coordinated whole, while unlocking the development of green energy precincts to turbocharge regional decarbonisation.

To further accelerate the renewable buildout, CEF recommends that the Australian and the WA Governments reform approval processes and procedures if we are to achieve our national emissions reduction requirements under the Paris Agreement and renewable energy targets.

In December 2022, the WA State Government announced a $22.5m investment to reduce approval times for job-creating green energy projects, consisting of dedicated environmental assessment teams and dedicated major projects facilitation teams under the **Green Energy Approvals Initiative**.[200]

Building on the momentum of WA's Green Energy Approvals Initiative, CEF recommends the introduction of **Overriding Public Interest** principles into the environmental approvals processes for renewable energy, infrastructure, storage and green manufacturing projects, building on the merits of its use in the European Union.

In the EU, as in Australia, lengthy administrative permit-granting procedures are one of the key barriers to investment in renewable energy projects and their related infrastructure. Those barriers include the complexity of the applicable rules for site selection and administrative authorisations for such projects, the complexity and duration of the assessment of the environmental impact, and related energy networks, grid-connection problems, constraints on adapting technology specifications during the permit-granting procedure, and staffing problems of the permit-granting authorities. To accelerate the deployment of such projects, rules which simplify and shorten permit granting procedures are necessary, taking into account the broad public acceptance of renewable energy. This was highlighted in the EU following Russia's invasion of Ukraine.

After the unprecedented reduction of methane gas exports from the Russian Federation to EU Member States, and the former's weaponization of its fossil fuel supplies, the EU

[200] WA Gov, Green Energy Approvals Initiative, 07 May 2024

implemented an Emergency Regulation on Permitting, laying down a framework to accelerate the deployment of renewable energy to minimise Member States' exposure to high and volatile fossil fuel prices, which were causing economic and social hardship.[201]

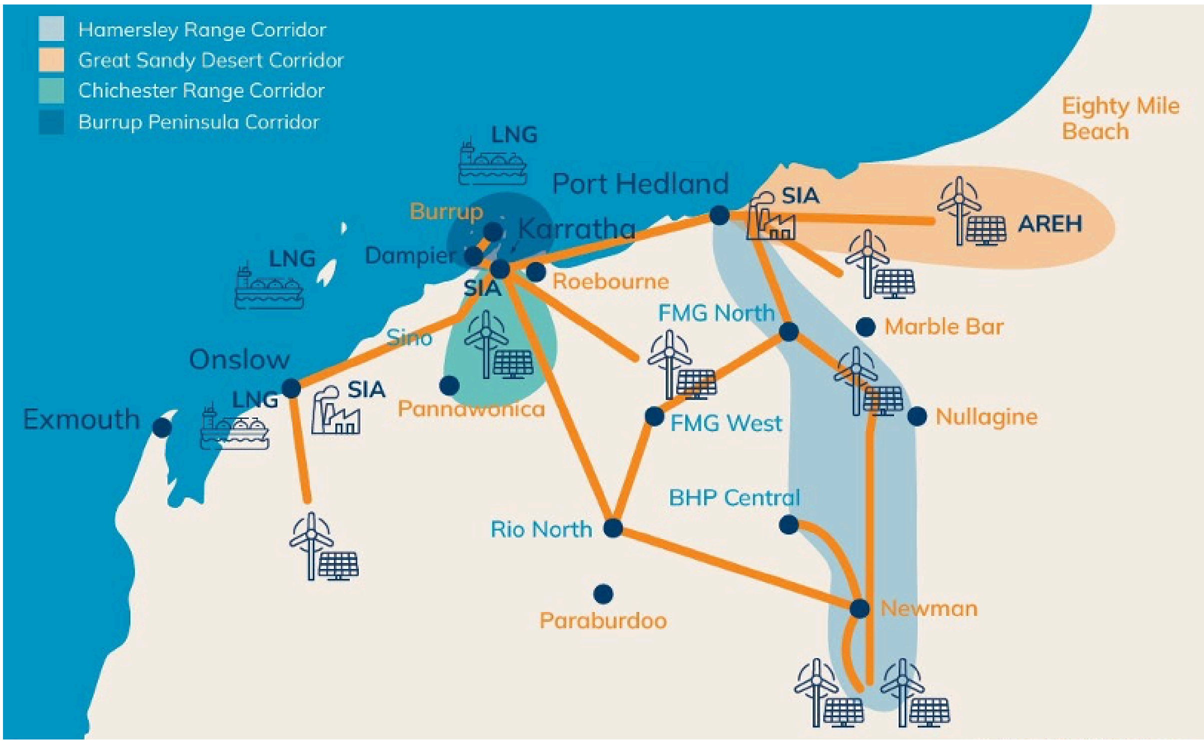
Following this streamlining, Germany permitted 7.5GW of new projects, 70% higher than in 2022, and significantly higher than the average 2GW of approvals in 2017-19. Spain permitted 3GW of new projects in 2023, also up 70% from 2022, and well above the previous years which were consistently below 1GW. Likewise, France and the United Kingdom, Greece and Belgium's approvals all increased from the year prior.[202]

Pilbara Energy Transition Plan

In a landmark for accelerating electrification and decarbonisation of the Pilbara, the WA Government's Pilbara Energy Transition (PET) Plan has announced the development of priority common user infrastructure (CUI) corridors in the region.[203]

The PET Plan identified four priority corridors for the accelerated, and coordinated development of high voltage common user electricity transmission infrastructure, that will connect existing energy-intensive industries in the Pilbara, of which is primarily powered by fossil fuels, to strategic regions of high renewable energy resources and land that can unlock future-facing industries and enable embedded decarbonisation in our exports.

Figure 9.3: Indicative Pilbara Energy Transition Plan Network Modelling



Source: WA Government

[201] EU Commission, Directive (EU) 2022/2577 Council Regulation, 22 December 2022
[202] Wind Europe, Wind Energy Permitting is Improving but Governments Still Have Work to Do, 08 February 2024
[203] WA Government, Pilbara Energy Transition Plan, updated 16 September 2024

The **Burrup (Murujuga) Corridor** will connect the Burrup Strategic Industrial Area (SIA), which houses large-scale gas liquefaction facilities (Pluto LNG and Karratha Gas Plant), and one of the world's largest ammonia production facilities in the world (Yara Pilbara Fertilisers), with the Maitland SIA, southwest of Karratha. This can enable significant electrification and decarbonisation of hydrogen production to manufacture green ammonia.

This would be further enabled by the **Chichester Range Corridor**, which will connect the Maitland SIA with a high-quality wind zone 50-100km to the south, infrastructure that will enable complementary wind capacity to the Pilbara to that of solar resources, currently the only renewable energy source operating in the region, and accounting for 2% of electricity demand in the Pilbara.

The **Hamersley Range Corridor** will connect the Boodarie SIA and Port Hedland with the Hamersley Range, where Australia's economic powerhouse of iron ore mining predominantly occurs. This Corridor will be critical to the electrification and decarbonisation of mobile mining equipment, the largest source of emissions in Australia's mining sector.

The **Great Sandy Desert Corridor** will connect Port Hedland with the western end of the Great Sandy Desert. This Corridor would then enable Australia's largest renewable energy proposal, the 26GW Australian Renewable Energy Hub (AREH) to connect to the existing NWIS. There are multiple green metals refining facilities proposed in the Boodarie SIA, which will demand significant renewable energy capacity and hydrogen production. This would also allow AREH to potentially contribute to the decarbonisation of the iron ore mining precincts via the Hamersley Range Corridor.

Port Hedland Green Steel

POSCO, South Korea's largest steelmaker (the 7th largest steelmaker globally), is developing the Port Hedland Green Steel (PHGS) proposal for a downstream, hot briquetted iron (HBI) processing facility in partnership with Taiwan's China Steel (24.5%) and Japan's Marubeni (24.5%). The PHGS proposed location is in the Boodarie Strategic Industrial Area (SIA), 10km south west of Port Hedland. A decision is understood to be deferred till 1HCY2025.

Stage 1 would consist of a magnetite pellet plant, processing Pilbara magnetite ore in a 2 Mtpa DRI furnace for export as HBI from Port Hedland, with excess pellets exported from Port Hedland as well. Stage 1 will require a pellet feedstock of 3-3.5 Mtpa.[204] POSCO will use MiDREX Flex DRI shaft furnaces for the reduction of magnetite, which allow for variations in the use of methane gas and GH_2 as reducing agents, increasing the proportion of GH_2 as a reductant as infrastructure and sufficient Pilbara renewables capacity is deployed.

POSCO plans a 4-stage development of the PHGS, culminating in 6 trains of MIDREX Flex HBI furnaces to produce a combined 12 Mtpa of value-added, low emissions iron. The 4 phases represent a total $27bn proposed investment into the plant alone, employing thousands of jobs during construction, and generating over 400 ongoing jobs in the Pilbara per train.[205]

POSCO plans to incorporate their HyREX technology into PHGS at various stages of scale-up, using fluidised bed technology developed from POSCO's FINEX process, providing a pathway to decarbonise low-grade hematite ores of the Pilbara.

POSCO estimates the unmitigated Scope 1 emissions of the project at 1,600 kt CO_2-e pa, with Scope 2 emissions of 331 kt CO_2-e pa, for a combined operational emissions profile of 1,931 kt CO_2-e pa. Producing up to 2 Mtpa of HBI, this would produce metallic iron at an emissions intensity of 0.97 t CO_2-e/t iron. Combined with value chain emissions from magnetite extraction, pelletisation, and further refining in an EAF, this is estimated to aggregate to an emissions intensity of 1.1 t CO_2-e/t steel, representing a 55% reduction in emissions from traditional coal-based steelmaking.[206]

There is significant opportunity to further reduce the emissions intensity of HBI from PHGS, as Stage 1 will begin operations with 1% green hydrogen, blended with 99% methane gas. The entire replacement of methane gas with green hydrogen in the HBI process could reduce emissions by 75% relative to the 2.2 t CO_2-e/t BF-BOF benchmark. ENGIE is working on the green hydrogen proposal.[207]

Located in the Boodarie SIA, the WA PET Plan provides a pathway for large-scale renewables generation to connect to the NWIS to provide the necessary green energy to facilitate the decarbonisation of PGHS, and decarbonise magnetite mining and midstream beneficiation and pelletisation to reduce the emissions intensity of HBI exported, which would lower the emissions intensity of under the 0.4 t/t threshold for low-carbon steel under the IEA.

October 2024 saw POSCO unveil US$88bn of emissions reduction capex plans by 2030, including US$22bn in cleaner steel initiatives.[208]

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[204] WA EPA, Port Hedland Green Steel - Stage 1, 15 September 2023
[205] ABC, Multi-billion-dollar South Korean Investment Could Make a Green Iron Centre, 16 December 2023
[206] WA EPA, Port Hedland Green Steel - Stage 1, 15 September 2023
[207] ENGIE and POSCO Holdings announce an important step towards a green steel industry, 16 October 2023
[208] Hydrogen Insight, Korean Posco to invest $22bn in clean steel and blue hydrogen by 2030, 19 October 2024

Element Zero

Element Zero is an early-stage green metals start-up based out of Perth, WA, founded by Michael Masterman, previously CFO of Fortescue Future Industries, and Bart Kolodziejczyk OAM, former Chief Scientist of Fortescue Metals Group.

Element Zero has developed a novel hydroxide electrolysis process that uses variable renewable energy to reduce iron directly, without the need for green hydrogen in the reduction process. The process uses a patented electrolyte that dissolves iron ore into a non-aqueous solution that is then reduced electrolytically.

Element Zero states their electroreduction technology is able to process low grade (30% Fe) to high grade (72% Fe) iron ore, producing a high-purity metallic iron product with up to 92% Fe content, whilst delivering a 30-40% lower energy intensity compared to traditional coal-based steelmaking.[209] The process proposes to operate at a range of 250-300ºC, which enables the plant to ramp up and down processing capacity depending on energy and material feedstock variations.

Given the company's technical ability to process low grade and high-grade ores, Element Zero expects to refine both hematite and magnetite ores into high grade briquettes for export. This is a critical step forward to realising the potential scale of Australia's green iron opportunity, commercialising technologies that can value-add Pilbara hematite ores.

In January 2024, Element Zero raised US$10m in seed funding, led by Playground Global, to expand R&D, engineering and employ project development teams to scale the development of a pilot plant. Element Zero has commissioned a green iron pilot plant in Perth capable of processing up to 100 kg/day of iron ore.[210]

May 2024 saw Element Zero acknowledged among the 17 'Top Innovators' in 'Enabling Technologies Steel Challenge' of the World Economic Forum's First Movers Coalition.[211]

Element Zero plans to undertake another capital raise in FY2025, targeting US$50-100m. Beyond this, Element Zero aims to construct a US$2.1bn ($3.2bn) world-scale green iron plant in the Pilbara prior to 2030, with pending approvals to situate the plant in the Boodarie SIA, Port Hedland.[212] The initial stage of the project would be capable of processing 5 Mtpa of iron ore feedstock into 2.7 Mtpa of green iron. Element Zero has aspirations to expand up to 20 Mtpa of iron processing, which is estimated to generate revenues of ~ US$9bn pa.[213]

The strategic location of Element Zero's planned green iron plant is its direct access to Pilbara iron ore in Port Hedland, the world's largest hematite port, but also access to significant planned renewable energy capacity from AREH, unlocked by the Great Sandy Desert Corridor for common user electricity infrastructure.

October 2024 saw the Federal Court dismiss attempts by Element Zero to have Fortescue's search-and-seizure tactics ruled invalid, in a court case that is a major hindrance and distraction for Element Zero.[214]

[209] Element Zero, Our Technology
[210] Business Wire, Element Zero US$10m Seed Funding led by Playground to Scale up Platform, 17 January 2024
[211] FMC, FMC Announced 17 Top Innovators from enabling technologies steel challenge, 24 May 2024
[212] SMH, The Iron Men with a $4bn Plan to Save the Planet, 15 April 2024
[213] Element Zero, Home
[214] AFR, Fortescue in court win over Element Zero, 4 October 2024

Fortescue

In May 2023, Fortescue announced it had built a lab-scale project capable of producing green iron without the use of hydrogen or coal via direct electrolysis, less than one year since it established its labs in Perth.[215] The Fortescue process claims to reduce iron ore at a significantly lower temperature compared to the mature shaft-based DRI technologies, operating at 100ºC, as opposed to 800-1,000ºC.

In August 2024, Fortescue announced it had begun construction of the $75m Christmas Creek Green Metal Project in the Pilbara. The facility is expected to start production in late 2025, with the pilot plant producing 1,500 tpa of green iron. The Green Metals Project forms an integral component to Fortescue's 'green pit to product' supply chain, using a green mining fleet and renewable energy to produce a high-purity pig iron (~95% Fe) product from Pilbara hematite ores with a decarbonised supply chain.[216] The facility will use green hydrogen to reduce the iron, and further refine in an electric smelting furnace.

Fortescue plans a follow-on step in creating a green iron industry to demonstrate the method at commercial scale via a 1-2 Mtpa green iron plant that will employ the same technology used in the Christmas Creek Green Metals Project. A full-scale green iron plant would require more than 2 GW of solar and wind generation, coupled with battery storage.

October 2024 saw Fortescue commit to invest US$700-900m in FY2025 on decarbonisation in the Pilbara, up from US$224m in FY2024. The Pilbara Energy Connect infrastructure aims to have all mines and renewable generation assets interconnected into a single network by 2028. Fortescue has commissioned the 100 MW North Star Junction Solar Farm near Iron Bridge, capable of producing more than 250 GWh pa (30% of FY2025 energy demand at Iron Bridge), and abating up to 125 kt CO_2-e annually from Fortescue's operations as decarbonisation remains a key priority for the group.[217]

Fortescue also announced a feasibility study for a 1 Mtpa green iron proposal in the Pilbara, flagged as potentially with a Chinese partner.[218] This is the first commercial-scale production facility that will begin Fortescue's vision to produce more than 100 Mtpa of green iron metal using ~ 200 Mtpa of green iron ore. CEF applauds the joint development of Australia's world leaders in iron mining with China's world leaders in steel production, fostering a fully integrated, decarbonised metals value chain between Australia and China, which is the key to Australia maintaining its position as a global leader in the iron ore market.

Fortescue's approach leverages the technical knowledge and existing infrastructure of both Australia and China, and allows Australia to benefit massively from the steelmaking expertise of traditional coal-based producers in China, as well as the world leading expertise and manufacturing capacity of renewable energy and cleantech products, and allows Chinese producers to leverage the natural renewable energy and mineral resources of WA, and Australia more broadly.

[215] AFR, Fortescue Lab Succeeds in Turning Iron Ore into Green Iron, 23 May 2023
[216] WAToday, Andrew Forrest isn't Giving up on his Green Iron Pilbara Dream, 16 August 2024
[217] Capital Brief, Fortescue exec sheds light on miner's high-stakes green gamble, 1 November 2024
[218] Fortescue, 1QFY2025 Investor Presentation, 24 October 2024

Iron Bridge Magnetite, Pilbara

Iron Bridge is Fortescue's first magnetite mining operation. Iron Bridge produces a wet, high-purity magnetite concentrate, transported via a 135km slurry pipeline into Port Hedland. Iron Bridge is a JV between Fortescue (69%), and Formosa Steel IB Pty Ltd (31%), a subsidiary of Vietnamese steelmaker Formosa Ha Tinh Steel Corporation.

Iron Bridge commenced operation in August 2023, with first shipment of high-grade 67% Fe magnetite in September 2023. The six months to September 2024 saw an average 65% grade. 13 Mt of ore was mined over FY2024, producing 2.1 Mt of dry concentrate, and shipped 1.2 Mt. At full capacity beyond FY2025, Iron Bridge aims to produce up to 22 Mtpa of high-grade, low-impurity concentrate. In comparison, Fortescue produced 190.4 Mt of hematite in FY2024.[219]

As of 30 June 2024, Fortescue's hematite Ore Reserves are 1,701 Mt, with an iron content of 57.4%, and a gangue content of 8.75% (5.98% silica, 2.77% alumina). In contrast, Fortescue's magnetite Ore Reserves are 832 Mt, with an iron content of 67.3%, and a gangue content of 5.7% (5.4% silica, 0.3% alumina).[220]

Oakajee Magnetite, Midwest WA

January 2022 saw Fortescue and the then Sinosteel (acquired by China Baowu in 2022) sign a MoU to assess of Sinosteel's Midwest Magnetite Project, with the assessment to include a rail and port development at Oakajee, citing the scale of resources, ore processing characteristics and high grade quality, but also in the huge renewable energy potential. After 12 months, Fortescue had the option to acquire up to 50% of the Midwest Magnetite Project and up to 100% of the proposed port and rail infrastructure proposal.[221] The plan was to build a new deepwater port at the Oakajee SIA, north of the city of Geraldton, and build a 500 km of railway to connect the port to numerous mines inland.[222]

October 2022 saw Fortescue allocated land in the WA Government's Oakajee Strategic Industrial Area, paving the way to progress its exploration of a proposal for the domestic and international export of green hydrogen and green ammonia from the MidWest.[223]

June 2023 saw Fortescue announce a MoU with China Baowu to work together on reducing emissions associated with iron and steel making, to explore lower emissions iron making technology at one of China Baowu's operations in China using Fortescue iron ore and GH_2.[224]

April 2024 saw reports Fortescue was still working on the study of this $10bn investment proposal.[225] CEF notes this study has not been referenced by Fortescue in recent investor communications, but we understand China Baowu remains very keen on developing this excellent DRI proposal, and the WA State government is advancing common user infrastructure development to enable progress.

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[219] FMG, FY24 Annual Report, 28 August 2024
[220] FMG, FY24 Annual Report, 28 August 2024
[221] Fortescue press release, Fortescue and Sinosteel to commence assessment of Sinosteel's midwest Magnetite and Infrastructure Project, 21 January 2022
[222] AFR, Fortescue breathes life into Oakajee dream, 21 January 2022
[223] Fortescue press release, FFI gets green light to explore potential Mid West hub, 18 October 2022
[224] Fortescue press release, Fortescue partners with Baowu to reduce iron making emissions, 14 June 2023
[225] Business News, Fortescue still working on Oakajee Port Study, 5 April 2024

Rio Tinto

October 2024 saw Rio Tinto announce it would launch a review of its global iron ore product strategy, having regard to customer requirements and available ore grades." This comes as Rio Tinto's 3QCY2024 SP10 volumes accounted for 19% of shipments in the third quarter, vs 17% in 1HCY2024, up from just 6.5% two years ago. The review will consider the global blending opportunities that Rio will have within 12 to 18 months when it's Simandou mine in Guinea starts production to complement Rio's existing iron ore supplies out of WA and Canada, but this review is also expected to take into account customer' increased priorities towards pursuing decarbonisation of steel.[226]

Simandou mine, Guinea

July 2024 saw Rio Tinto confirm its 25% share of the US$23bn investment in developing the new Simandou mine in Guinea. This includes developing 600 km of new multi-use trans-Guinean railway together with port facilities that will allow the export of up to 120 Mtpa of mined iron ore. Together, this will be the largest greenfield integrated mine and infrastructure investment in Africa.[227] Refer Section 7.

A key to this new investment is its Blast furnace feed or Direct Reduction Iron products (~65% Fe), with over 2Bn tonnes of >65% Fe content ore reserves.

Rio Tinto's share of capex will be US$6.2bn, almost half of which (US$2.7bn) will be the development of the 60 Mtpa Simfer mine (block 3 & 4), with the difference directed into port and rail infrastructure.[228]

Current Focus on Value-Adding Iron Ore

In October 2021, Rio Tinto announced an agreement with BlueScope to explore low-carbon steelmaking pathways from Rio's Pilbara iron ores, using green hydrogen to replace coking coal at BlueScope's Port Kembla Steelworks.[229] The R&D was directed into:

- **H_2-DRI and Smelting** - using GH_2 to power a DRI process of Rio's Pilbara ores, and the further reduction by an electric smelting furnace, also powered by renewable energy.
- **Enhancing existing processes** - reducing carbon emissions from existing iron ore processing technologies.[230]

As an alternative pathway for decarbonising Rio Tinto's Pilbara hematite iron ores, the firm has developed a new approach to reducing iron ore fines without coal or hydrogen reductants, **BioIron**. In the BioIron process, iron ore fines are mixed with raw biomass (e.g. agricultural waste) and heated using a combination of the gas released by the biomass and microwave furnace powered by renewable energy, replacing the traditional reducing agent of coking coal. Rio Tinto's modelling estimates the process has the potential to reduce CO_2 emissions by up to 95% compared with traditional steelmaking, as well as using less than a third of the electricity needed by iron reduction technologies that will utilise GH_2.[231]

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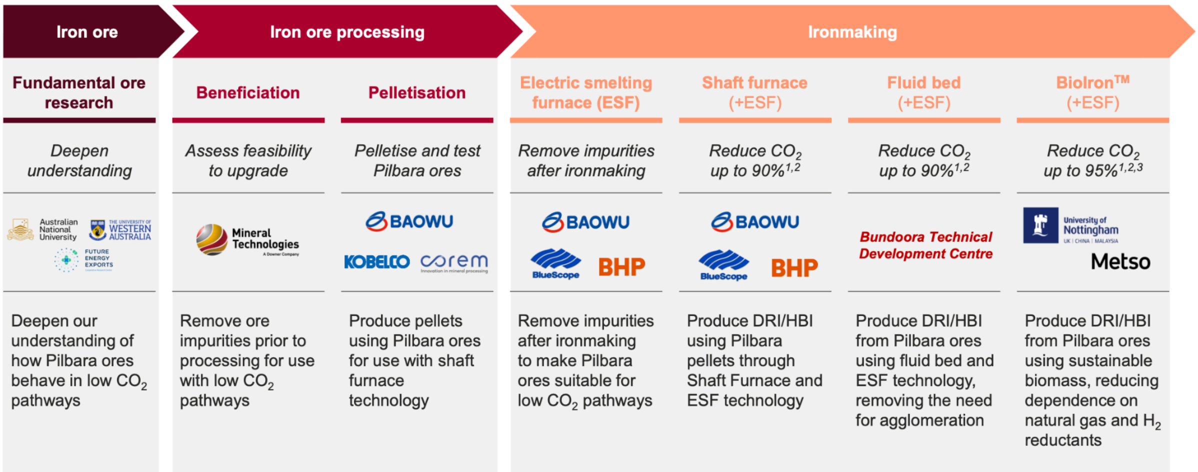
[226] AFR, Rio Tinto Considers Iron Ore Strategy Shift, 16 October 2024
[227] Rio Tinto press release, Conditions on Simandou investment now satisfied, 16 July 2024
[228] AFR, Rio Tinto's $34.3bn African Iron Ore Project Gets Green Light, 16 July 2024
[229] Rio Tinto, Rio Tinto and BlueScope to Explore Low-carbon Steelmaking, 29 October 2021
[230] BlueScope, BlueScope & Rio to Explore New Technologies for Low-emission Steelmaking, 29 October 2021
[231] Rio Tinto, A New Way to Decarbonise Steelmaking, 04 June 2024

In November 2022, Rio Tinto proved the effectiveness of its low-carbon ironmaking process, BioIron, in a small-scale pilot plant in Germany. The pilot plant was tested over 18 months, in collaboration with the University of Nottingham's Microwave Process Engineering Group, and technology provider Metso Outotec.[232]

In June 2024, Rio Tinto announced the $215m (US$143m) investment to develop a R&D facility in the Rockingham Strategic Industrial Area, WA to further assess the effectiveness of the BioIron process.[233] The new Australian R&D centre will be ten times bigger than the small-scale pilot plant in Germany, producing 1 tonne per hour (8,760 tpa).

The biomass will be supplied from agricultural by-products like wheat straw, barley straw, sugarcane bagasse, rice stalks, and canola straw. Rio Tinto has made clear the complexities on scaling a sustainable biomass supply chain, and has ruled out sources that support the logging of old growth and High Conservation Value forests.

Figure 9.4: Rio Tinto Partnerships for Value Chain Decarbonisation



Source: Rio Tinto [234]

HIsmelt

Rio Tinto has had previous value-added investments in Australia, developing the Kwinana HIsmelt plant in WA. The HIsmelt process was a direct smelting technology for the production of liquid iron using iron ore fines, using coal as the reducing agent (HIsmelt produces pig iron).

The Kwinana HIsmelt plant was developed by Rio Tinto (60%), US Nucor Corp (25%), Japan's Mitsubishi (10%) and China's Shougang Corp (5%), and was the result of a commitment by Rio Tinto to establish a downstream processing plant in return for the WA Government approval to mine its Yandicoogina iron ore deposit in the Pilbara.[235] In 2011, Rio Tinto axed its HIsmelt plant, waving off a $1bn investment.

[232] Rio Tinto, Rio's BioIron Proves Successful for Low-carbon Ironmaking, 23 November 2022
[233] Rio Tinto, Rio to Develop BioIron R&D Facility in Western Australia to Test Low-carbon Steelmaking, 04 June 2024
[234] Rio Tinto, Finding Better Ways to Progress Steel Decarbonisation, 07 May 2024
[235] The West Australian, Rio Terminates Kwinana HIsmelt Plant, 19 January 2024

Iron Ore Company of Canada

Rio Tinto's Iron Ore Company of Canada (IOC) is a 23 Mtpa, high-grade (+65% Fe), low-impurity, iron ore resource that provides Rio with an advantage in regards to asset diversification compared to its competitors. IOC produces high Fe content concentrates with very low phosphorus and alumina levels, as well as flexible product pellets, including standard acid pellets, low silica acid pellets, and direct reduction pellets than can be charged into blast furnaces (Europe and Japan) and direct reduction plants (MENA and Americas).

As of 2023, IOC produces 20% (3.3Mt) of its output in the form of DR pellets, however will significantly increase the proportion moving forward as BF pellet capacity to Europe will be transitioned to DR supply. Scope 3 emissions from IOC are currently ~ 1.9t CO_2-e/t steel (less than average BF-BOF emissions intensity given the diversity of IOC's product), but have set a target of a 50% reduction by 2035.[236]

Progressive Green Solutions

Progressive Green Solutions (PGS) is developing the Mid-West DRI project, located east of Geraldton, WA. Stage 1 of the MidWest DRI facility would consist of a magnetite pelletisation plant, using magnetite ore from the nearby Karara mine, located 200km southeast of Geraldton, WA. Karara Mining Ltd was formed in 2007 as an international JV between China's Ansteel Group (Anshan Iron and Steel Group Corporation, 52.16%) and previously ASX-listed Gindalbie Metals Ltd (GBG) (47.84%).[237] In July 2019, GBG was acquired by a Hong Kong-listed subsidiary of the Ansteel Group.[238] As part of PGS' green iron project, PGS will assist in the decarbonisation of Karara's beneficiation facility.

The Mid-West region of WA has over 5 billion tonnes of proven magnetite reserves, sufficient to support decades of high-grade green iron production, aided by a highly complementary/diurnal profile for wind and solar generation that can enable high capacity factors to improve the capex intensity of green iron production.

The Mid-West DRI Stage 1 consists of a pelletisation plant that would produce up to 7 Mtpa of green pellets for export, and hopes to reach FID in 2025, commencing operations in 2028. The initial plant capex is estimated at $1.5bn. This excludes the additional investments in renewable energy generation and storage required to produce decarbonised magnetite pellets. The project is supported by key partners across Australia, Germany, Japan and Korea, and has received strong support from local and regional stakeholders.

A Stage 2 expansion is being investigated to scale the plant up to 14 Mtpa of pellets, which would be charged into up to four trains of DRI shaft furnaces, producing up to 10 Mtpa of DRI. Mid-West DRI will use Danieli's Energiron DRI platforms, a 2.5 Mtpa shaft furnace direct reduction process capable of operating with any blend of methane gas and green hydrogen. The DRI plant will initially use methane gas as the reducing agent, with a phased transition to GH_2. At 100% hydrogen, each Energiron platform is expected to demand up to 140,000 tpa of green hydrogen. DRI will be compacted into HBI, and exported from the Port of Geraldton.

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[236] Rio Tinto, Financial Community Visit to North American Operations, 25 September 2024
[237] Green Steel WA, Mid West Hydrogen DRI Plant
[238] ASX, GBG Implementation of Acquisition and Demerger Schemes, 23 July 2019

Green Steel of WA

Green Steel of WA is a green steel recycling plant proposal in the southwest of WA, Collie Green Steel.[239] The Green Steel Mill will consist of an EAF facility to recycle scrap steel into long steel (rebar/rod) products for local and international markets. The Collie plant is expected to begin construction in 2HCY2024, with early operations commencing 1HCY26.

The Collie plant would be Australia's first new steel mill in over 30 years. With a proposed total investment of $400m, the mill will be located in the town of Collie, 220km south of Perth and would produce up to 400,000 tpa of long steel products, powered by renewable energy, utilising 500,000tpa of locally sourced steel scrap (that is currently exported) and employing a workforce of 200. Green Steel WA received a $2.7m grant from the WA Government's Collie Futures Fund to support the progression towards FID.

August 2024 saw this proposed Collie steel mill granted Works Approval by the Department of Water and Environmental Regulation, having been granted State Planning Approval in May 2024.[240]

Green Steel of WA also proposes a second $1.5bn 2.5Mtpa DRI facility to produce HBI from iron ore in the Mid-West of WA and powered by renewable energy. Initially to be powered by methane gas to reduce the emissions intensity of producing steel by >50%, the proposal is to progress at a future stage to using up to 150,000tpa of green hydrogen. Green Steel of WA has secured a technology partnership with global steelmaking leader Danieli. The proponent aims to take a final investment decision in late 2025 with operations beginning in 2028.

Hancock Prospecting

July 2023 saw reports Hancock Prospecting's Atlas Iron was investigating the Ridley Magnetite proposal, a mine located 60km east of Port Hedland with a grade of up to 36% iron content.[241] [242]

Stage 1 would consist of a magnetite concentrate plant with a nominal capacity of 3 Mtpa (dry), with scope for further staged expansion of up to 16.5 Mtpa (Stage 2). The product would be a high-grade 68% Fe concentrate, capable of being charged into a H_2-DRI shaft furnace and EAF for steelmaking.[243]

Hancock Prospecting's 70% owned Roy Hill reported iron ore shipments of 64Mt in FY2024, delivering revenues of A$9.4bn and net profit of $3.2bn, but has a short mine life, expiring early next decade absent major new investments.[244]

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[239] Green Steel WA, Home
[240] Green Steel WA, Works approval in hand, 29 August 2024
[241] The Australian, Gina Rinehart's Atlas Iron dusts off boom-era magnetite iron ore plans, 4 March 2022
[242] Business News, Paucity of new resources projects, July 2023
[243] WA EPA, Ridley Magnetite Project, updated 07 June 2023
[244] AFR, Fortescue breathes life into Oakajee dream, 21 January 2022

BHP

CEF notes that beyond a very lengthy BHP Climate Transition Action Plan (CTAP) 2024 committing to Net Zero Emissions (scope 1-3) by 2050, we see little evidence of any material decarbonisation progress in Australian mining this decade. BHP reported its global scope 1 emissions actually rose 1% yoy in FY2024, directionally opposite to the intended path. BHP has very little in the way of tangible investment in value-adding its $28bn pa of Australian iron ore exports (earning gross profits of US$19bn in FY2024), committing to undertake just ~US$75m funding by BHP for the next five years.[245]

CEF understands BHP's West Australian Iron Ore division delivered an underlying ROCE of 61% in FY2024 (53% in FY2023), and the board is hesitant to invest in downstream value-adding given:

a) BHP's experience with Boodarie Iron back in 1999-2000,[246] and
b) the very low returns on capital employed experienced by the steel industry in general (and in China, specifically - refer Figure 5.2).

However, CEF sees a massive long term structural shift in the global steel sector supply chain, and BHP, like Australia overall currently, is very exposed to progressively losing market share in its most important division.

October 2024 saw NBIM, manager of the US$1.7 trillion Norwegian sovereign wealth Fund, announce it was voting against the BHP Climate Transition Action Plan (CTAP) 2024 due to its lack of tangible time-bound interim measures.[247]

[245] BHP, Climate Transition Action Plan (CTAP) 2024
[246] BHP, Fact Sheet Boodarie Iron, 24 August 2005
[247] Responsible Investor, NBIM rejects BHP's transition plan, calls for more detail, 25 October 2024

Section 10. South Australia's Green Iron Opportunities

Section summary:

- Over FY24, variable renewables averaged just $38.93/MWh in the state. SA's established low-emission grid is already providing renewable energy at a wholesale electricity price that can enable a cost competitive green iron industry.
- South Australia has long promised a renewal of its ageing steel sector. But financial leverage and a failure to land credible private investment at scale leaves a dire current state.
- In June 2024, SA released its Green Iron and Steel Strategy, setting the state's vision to position itself as the partner of choice for decarbonised steelmaking.

Implications for Australia:

- Adversity at the Whyalla Steelworks could allow a recapitalisation in the hands of a strategically-minded, credible public-private-foreign investment coalition, freeing up monopoly port infrastructure and leveraging the strategic value of the state's magnetite resources, world-leading renewable energy position, and state leadership on building a commercial scale GH_2 base.
- CEF recommends Australia expand and build on the ambition and leadership of the SA by establishing a **National Green Iron and Steel Strategy**, Australia needs a well-designed strategy with measurable targets, **delivered by bold and deliberate statecraft**

The levers that have positioned SA to the forefront of Australia's green iron opportunity have been consistent, strategic progression in timely and ambitious policy, regulation and legislation, de-risking investment through offtake arrangements, direct investment and market participation, and meaningful public engagement with industry and communities.[248]

SA's consistent policies to crowd-in private capital into renewable energy, from the Rann Labor Government in 2004, which set a 15% renewable target by 2014, and 26% by 2020, has now attracted more than $6bn in large-scale renewable energy and storage projects, with a further $21bn in the investor pipeline.

Variable renewable energy represented a world leading 69% of the FY2024 total generation in SA, with this hitting a record 84% in the month of September 2024.[249] SA has regularly experienced 100% or more instantaneous VRE generation since October 2021.[250] The Federal Government's 9,500 GWh pa Mandatory Renewable Energy Target (MRET), and subsequent 33,000 GWh pa for large-scale generation certificates (RET) benefitted SA greatly given the state's wind resources.

SA was the first Australian region to develop a state-level hydrogen development plan, publishing its Hydrogen Roadmap for South Australia in 2017 to accelerate SA's "transition to an Asia-Pacific hub for the production, use, and export of hydrogen in a safe, clean and sustainable economy".[251]

[248] WWF, A Green Steel and Clean Energy Leadership Case Study South Australia, July 2024
[249] Open Electricity
[250] ElectraNet, 2023 Transmission Annual Planning Report, October 2023
[251] SA Government, A Hydrogen Roadmap for South Australia, 11 September 2017

South Australia is poised to be the first state to establish a low-emission iron value-added industry, providing urgent diversification and long-term planning to maintain and expand its existing fossil-fuel intensive iron and ageing steel industry.

October 2024 saw the South Australia government announce two proposed release areas designated for the development of large-scale renewable energy projects in the Whyalla and Gawler Ranges regions. The 5,200 square kilometre Upper Eyre Peninsula area of the Gawler Ranges East and the 6,500 square kilometre Upper Spencer Gulf region known as Whyalla West have been mapped for their solar and wind development potential, and proximity to transmission and utilities, providing the potentially massive scale of deployments needed to support green iron developments.[252]

As discussed in Section 8, the renewable energy requirements of establishing a green iron industry are immense. Thus, regions with an established, decarbonised electricity grid, coupled with a strategic vision for onshoring a green metals industry by the state government, have a clear first mover advantage.

South Australia's Green Paper on the Energy Transition (Green Paper) [253] has a target for the state to be a renewable energy superpower, powered by 100% renewables by 2027, a target that is absolutely on track - Figure 10.1. SA's energy generation is expected to grow from 15 TWh in 2024 to 38 TWh, powered by wind, solar and battery firming.

Renewable energy has consistently been the lowest cost wholesale electricity source in South Australia. In FY24, utility-scale solar and wind averaged a wholesale price of $33.92/MWh and $55.21/MWh respectively, far below the average gas price of $173.23/MWh (weighted average of GRE, OCGT and CCGT).[254] Over FY24, variable renewables averaged just $38.93/MWh. South Australia's established low-emission grid is already providing renewable energy at a wholesale electricity price that can enable a cost competitive green iron industry.

South Australia's Green Iron and Steel Strategy

In June 2024, SA released its Green Iron and Steel Strategy, setting the state's vision to position itself as the partner of choice for decarbonised steelmaking.[255] SA's strategy requires a long-term, coordinated strategy to transform the Whyalla Steelworks to that of a renewable hydrogen and low-carbon steelmaking industrial hub. The Green Iron and Steel Strategy is centred around the following objectives:

Objective 1: Enhance SA's comparative advantage by:

- Demonstrating the magnitude, quality, and development potential of SA's iron ore deposits,
- Confirming SA's green export viability through a Green Iron Supply Chain Study with the Port of Rotterdam, and

[252] PV Magazine, South Australia regions earmarked for large-scale renewable energy projects, 17 October 2024
[253] SA Government, South Australia's Green Paper on the Energy Transition, 29 June 2023
[254] Open Electricity, Energy: South Australia: FY24, accessed October 2024
[255] SA Government, Green Iron and Steel Strategy, June 2024

- Working with industry and the education sector to address technological and workforce challenges.

Objective 2: Establish local green steel industry foundations by:
- Partnering with the Federal Government to support the Whyalla Steelworks low-carbon transformation,
- Delivering a commercial de-risking study, in partnership with industry, to plan for development of a DRI plant and supporting value chain, and
- Supporting establishment of specialised industrial precincts and common user infrastructure corridors to de-risk and expedite projects across the value chain.

Objective 3: Ensure a sustainable, long-term industry and shared prosperity by:
- Finding solutions for First Nations advancement and community autonomy by sharing project benefits with communities, First Nations and Native Title holders,
- Phasing in the purchasing of Australian green steel for infrastructure projects as production capacity emerges, and
- Targeted support to facilitate the delivery of a new hydrogen-based green iron plan in SA by 2030, or earlier.

Unlocking South Australia's Braemar region is an important step to expanding the state's, and Australia's access to DR-grade magnetite iron ore. The Braemar Iron Formation can support the production of DRI for decades, providing diversification and growth to South Australia's existing, but small in comparison to WA, iron ore production. However, unlocking the region will require significant government support for the development of common user, enabling infrastructure, prioritising investments into:

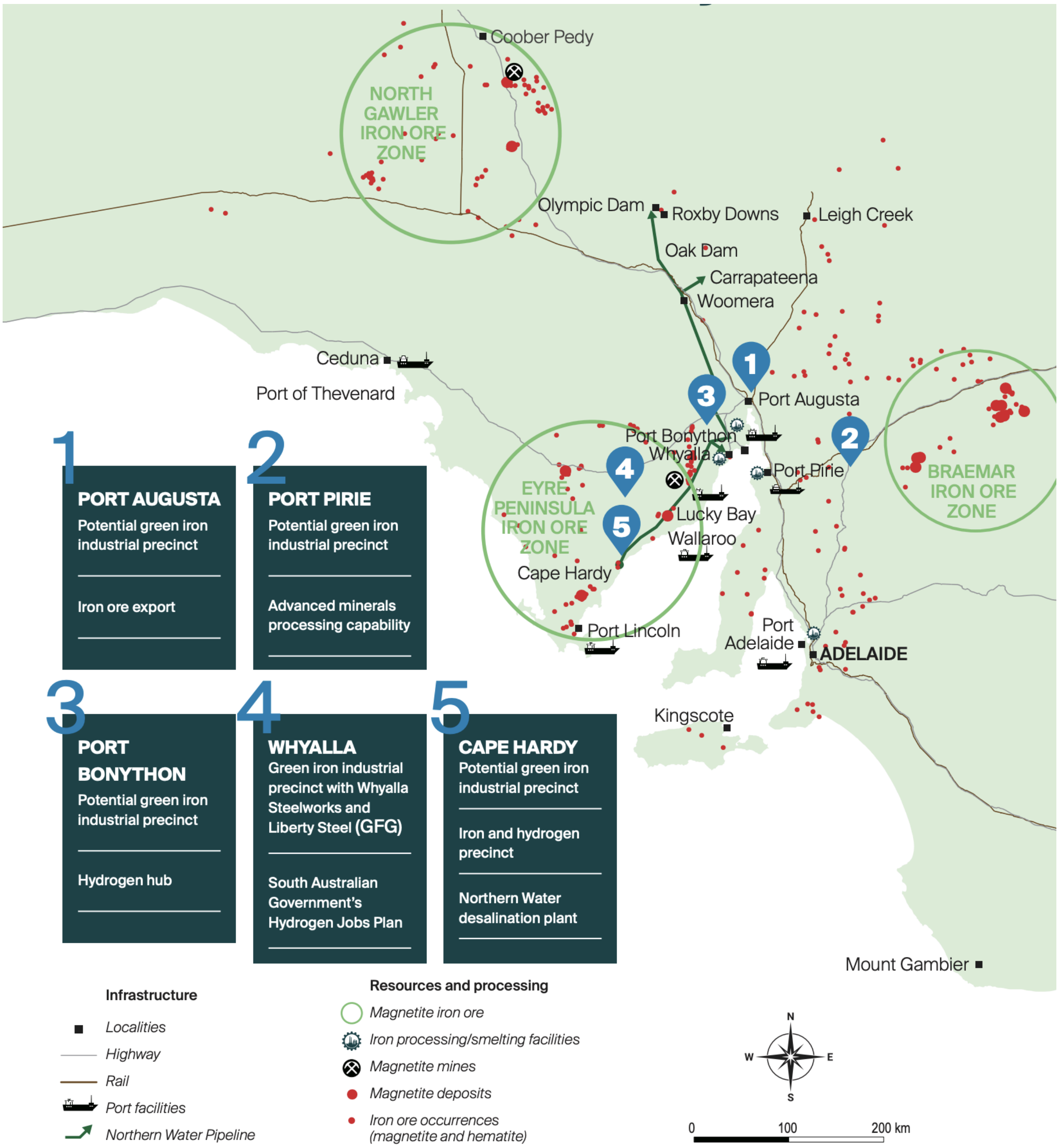
1. **Water supply** - given the production of magnetite concentrate is also water intensive, likely requiring a combination of coastal desalination and fresh water supply, potentially utilising latent capacity from the Adelaide Desalination Plant and the Northern Water project.
2. **High-voltage power supply**. While SA has leading penetration of renewable energy in its grid, the state's grid does not have high-voltage transmission networks that other regions like Queensland have access to. AEMO and ElectraNet have brought forward the Mid North Expansion (North) high-voltage transmission line to actionable project status.[256]
3. **Open access port bulk export capacity.** There is significant opportunity for the SA Government to invest in diversification from the privately-owned port of Whyalla (by the GFG Alliance), investing in green export industrial hubs in other port cities, including Port Pirie, commencing with open access port upgrades that can support iron ore transhipment to cape size vessels in the Upper Spencer Gulf.

In June 2024, the SA Government released an Expression of Interest (EOI) to de-risk the establishment of a new green iron plant in the Upper Spencer Gulf by 2030, through joint investigation and development across the entire value chain.[257] SA currently has 7.4 billion tonnes of economically demonstrated iron ore across 3 iron ore provinces, from a resource base of more than 18 billion tonnes of magnetite ore - see Figure 10.1. 94% of South

[256] ElectraNet, Green Energy Network to Power SA Energy Transition and Unlock State Prosperity, 26 June 2024
[257] SA Government, SA's Green Iron Opportunity Expression of Interest, June 2024

Australia's contained iron ore is in the form of magnetite, of which are low-impurity, coarser-grained and comparatively soft magnetite, which can be readily beneficiated to greater than 67% iron.

Figure 10.1: South Australia's Green Iron and Steel Ecosystem



Source: SA Green Iron and Steel Strategy

Leveraging its world-leading renewable and magnetite resources, South Australia has a strategic opportunity to establish a globally competitive green metals industry. A 2024 study by Monash University, commissioned by the SA Government's Department of Energy and Mining (DEM), modelled the economic feasibility of green iron production in SA, focussing specifically on HBI production scenarios across forecasted costs, plant configurations and temporal renewable energy availability.[258]

The study evaluated various scenarios from demonstration-scale (500,000 tpa) to commercial-scale (2.5 Mtpa). The preliminary analysis concluded that the abundant renewable energy resources of the state, coupled with efficiencies of integrated supply chains (i.e. on-site hydrogen production) demonstrate that the state could develop a competitive green metals industry.

Leveraging existing infrastructure will be key to developing green metal hubs in Australia, as well as the prioritisation of common user infrastructure to supply such hubs with key production inputs.

The South Australian Green Iron and Steel Strategy has identified the key role of strategic public capital in getting these critical projects up and running, and includes a number of key policies to support first movers in green iron, including:

- Government support for value-sharing and land access engagement with local and First Nations communities.
- Designing green infrastructure corridors including common user infrastructure such as roads, pipelines and electricity transmission.
- Industrial hubs, skilled workforce, existing port infrastructure. The SA State and Federal Government have committed $100m, and industry committed $40m, to develop common user infrastructure, including port upgrades, last mile pipelines, storage and access roads to Port Bonython.[259]
- Advanced government and private sector investigations for sustainable water supply for industrial off-take including the North Water project to supply developers.

In May 2022, the SA Government also launched its state Hydrogen Jobs Plan, with commitments to building 250 MWe of hydrogen electrolysers and a 200 MW hydrogen power station in the Whyalla area by December 2025.[260] The Jobs Plan also established an office of 'Hydrogen Power SA' to:

- Own and operate the hydrogen production and power plant as a government enterprise
- Rejuvenate manufacturing in SA by utilising hydrogen and the associated electricity generated to grow job-creating industries in SA, and
- Establish a world-leading hydrogen industry, including hydrogen export.

Magnetite Mines

ASX-listed Magnetite Mines (Market Capitalisation A$25m) is developing the Razorback Iron Ore Project, a pre-development magnetite proposal capable of producing high grade, low-impurity magnetite concentrate that can be charged into existing, mature DRI technologies, backed by 6 Billion tonnes in Resources, of which 2 Billion tonnes are Ore Reserves 50km by truck from an open-access railway line. Concentrate grades of up to 69.9% Fe and less than 2.0% silica + alumina have been attained.

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[258] Monash University, South Australian Green Iron Supply Chain Study, 19 January 2024
[259] SA Government, Office of Hydrogen Power SA 2022-23 Annual Report, 29 September 2023
[260] SA Government, Hydrogen Jobs Plan, May 2022

Stage 1 of the project would produce up to 5 Mtpa of DR-grade magnetite concentrate, that can be processed further to DR pellet feed before being processed in a DRI facility. A potential expansion option is also being evaluated, bringing concentrate production up to 10 Mtpa. Stage 1's pre-production capex is expected to be US$1-1.3bn.[261]

Estimated operating costs will be significantly higher than that of DSO hematite producers in the Pilbara, with an estimated US$87-96/tonne unit cost. However, the high-grade, low penalty element content of Razorback's concentrate product would command a US$41/tonne value-in-use premium above that of the standard 62% Fe index.

The proposal plans to send magnetite ore 180km to Port Pirie, to build it into a green iron hub for pelletising, downstream manufacturing and bulk export with an alignment with Aurizon Holdings, Flinders Port Holdings and GHD.[262]

July 2024 saw Magnetite Mines signed a Heads of Agreement with JFE Shoji Australia (subsidiary of JFE Holdings, parent company of Japan's second largest steelmaker, JFE Steel), which established a non-binding agreement to negotiate definitive feasibility study (DFS) funding, in exchange for the option of JFE to offtake 10% of Stage 1 production on commercial terms for 15 years.[263]

July 2024 saw Magnetite Mines sign an MoU with Australian renewables company, ZEN Energy, to investigate energy offtake agreements from ZEN's current renewable energy project pipelines, as well as the opportunities to partner, co-venture or offtake future renewable energy capacity for the Razorback project.

In Magnetite Mines call to the Federal Government's consultation on unlocking Australia's green iron opportunity, the company advocated for the funding and support of a CSIRO-led **Green Iron Centre of Excellence** in SA's Upper Spencer Gulf, designed to support research and demonstration of green iron technologies, using Australian iron ore and locally produced renewable energy and any necessary derivatives i.e. green hydrogen.[264]

As part of CEF's recommendations in this report, we have recommended the Federal Government increase budget support for the CSIRO to $500m over 10-years to accelerate the coordinated RD&D of green iron technologies, in partnership with Australian iron ore producers, Asian steelmakers, leveraging expertise across the iron and steel value chain.

In October 2024, Magnetite Mines announced the pioneering consortium of **Green Iron SA**, comprising Magnetite Mines, Aurizon Holdings, Flinders Port Holdings and GHD.[265] The consortium is leveraging the expertise of its members to address the logistical barriers to unlocking the Braemar Iron Region, including infrastructure in water, power and transport, and is working to transform the strategic location of Port Pirie into a green iron hub for the production of DR-grade pellets, and potential for further downstream value-add.

[261] Magnetite Mines, Premium Iron Ore for Steel Sector Decarbonisation, 03 September 2024
[262] Magnetite Mines, Green Iron SA Consortium Launches To Spearhead South Australia's Green Iron Revolution, 22 October 2024
[263] Magnetite Mines, Premium Iron Ore for Steel Sector Decarbonisation, 03 September 2024
[264] Magnetite Mines, Magnetite Mines Submission to the Australian Government, July 2024
[265] Magnetite Mines, Green Iron SA Consortium Launches to Spearhead SA Green Iron Revolution, 22 October 2024

Whyalla Steelworks

The SA steel sector currently relies solely on the Whyalla steelworks and associated iron ore mines, established by BHP in 1965, which has relied on coking coal ovens and blast furnaces for decades. In 2000, BHP spun off its Australian steel-producing assets. In 2016, the operating entity, Onesteel (by then known as Arrium), was placed into voluntary administration, and acquired by the British consortium, GFG Alliance, in 2017.

The South Australian Whyalla Steelworks are now operated by GFG Alliance's Liberty Steel, in addition to the separately operated steel distribution group, InfraBuild, formerly OneSteel, and the SIMEC Mining division, which extracts 2.0-2.3Mtpa of magnetite iron ore from the Iron Duchess mine for export from the Port of Whyalla.[266]

In 2023, the GFG-owned Liberty Steel Group announced a phase-out of coal-based steelmaking, beginning with a planned $485m investment into a low-carbon EAF to replace the existing carbon-intensive steelmaking infrastructure. In addition, GFG announced plans for a 1.8 Mtpa DRI plant to process magnetite ore from the Middleback Ranges.

In January 2024, the Federal Government, via the Powering the Regions Fund, awarded Liberty Steep Group $63m, alongside $50m from the SA Government, towards the purchase and commission of an EAF (total $113m).[267]

A white knight for the town and workforce of Whyalla in 2017, in which Sanjeev Gupta promised billions of dollars' worth of projects when GFG alliance bought the steelworks out of administration, has failed to deliver, and is hamstrung by declining global prices for steel, huge financial leverage along with an excessively close association with the collapsed Greensill financier and reports of fraud and bankruptcy proceedings in its sister operations across Europe.[268] [269]

Liberty Steel's global portfolio currently consists of idled plants in Wales and Scunthorpe, UK, as well as intermittent operations at its Dalzell plant in Scotland. In addition, Liberty's Ostrava steel mill in the Czech Republic has reportedly been forced into bankruptcy as its electricity supplier stopped selling the firm energy in December 2023, with similar issues affecting operations in Hungary and Poland.[270]

Over CY2024, Whyalla Steelworks had been shut down twice for more than four months with issues relating to blast furnace maintenance. As of October 2024, the blast furnace is closed again due to impurities entering the blast furnace. CEF would suggest under-investment in sustaining capex is a key factor.

In May 2024, the AFR reported InfraBuild was now paying 14.5% pa interest rates after refinancing in November 2023.[271]

In May 2024, the AFR reported the $500m EAF upgrade to the Whyalla Steelworks would be delayed a further two years, giving a timeline now stretched to 2027.[272]

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[266] AFR, Sanjeev Gupta steps up cost-cutting at iron ore mines, 24 October 2024
[267] Aus Government, $200m to Help Future-Proof Regional Steel Manufacturing, 31 January 2024
[268] AFR, The Town Bearing the Brunt of Sanjeev Gupta's Financial Nightmare, 15 October 2024
[269] AFR, Sanjeev Gupta's entire steelmaking empire is teetering on the brink, 18 October 2024
[270] AFR, Gupta's Steel Empire Restructures Global Boards as Troubles Mount, 15 October 2024
[271] AFR, Sanjeev Gupta Calls in Rival to Help Whyalla Steelworks Strife, 05 May 2024
[272] AFR, Gupta's $500m Whyalla Steelworks Upgrade Delayed by Two Years, 15 May 2024

May 2024 saw SA Energy Minister Tom Koutsantonis express a desire to meet with Danieli and Tenova to 'get a better understanding of exactly how far away the EAF is', after Liberty Steel announced in early 2023 it had ordered an EAF from Danieli, with the aim to commence operations by late 2025.

In September 2024, GFG Alliance announced the company would be cutting costs amid a global steel price glut, including sustaining capex critical for plant maintenance.[273]

In September 2024, it was reported the SA Government had sought advice from insolvency experts about the Whyalla Steelworks, acknowledging the possibility that GFG Alliance had fallen behind on royalty payments, and could go into administration.[274] Treasurer Stephen Mullighan told the SA parliament that the GFG Alliance situation represents a serious issue for the state.

In October 2024, the AFR reported new documents filed in the UK revealed GFG Alliance had made no headway in repaying US$587m in debts to Greensill Capital, the financier that underpinned Sanjeev Gupta's operations, despite having signed four agreements in two years.[275] As of October, InfraBuild's credit rating has been further downgraded, with ratings agency Moody's describing it as 'unsustainable' given its 'materially high debt costs which are expected to result in negative free cash flow over the next 12-18 months'.[276]

October 2024 saw Liberty Primary Steel CEO Tony Swiericzuk leave.[277]

Whyalla's need for recapitalisation to deliver on the massive potential opportunity is widely reported.[278] We would suggest the South Australian government remind ASIC to remind directors of the personal liability if trading while insolvent under Australian law.[279]

CEF sees any move into administration by the GFG assets in Australia could provide an excellent opportunity to bring in a credible, well capitalised consortium with Asian steel expertise and synergies, as well as patient public interest equity and debt capital from the National Reconstruction Fund and / or CEFC. This could well provide access to the existing steel mill and port infrastructure to facilitate a major investment in both the new EAF, a DRI or green iron processing plant, leveraging the South Australian government's green hydrogen initiatives. The offer of a strategic metals production tax credit in MYEFO in December 2024 tied to a credible decarbonisation and domestic value-add strategy could enhance the investment opportunities for South Australia dramatically.

[273] ABC, GFG Alliance Reduces Maintenance at Whyalla Steelworks to Save on Costs as Alarm Raised Over Safety Concerns at Aging Plant, 10 September 2024
[274] ABC, Whyalla Steelworks Behind in Royalty Payments as Government Seeks Insolvency Advice as Contingency Plan, 25 September 2024
[275] AFR, Gupta's Steel Empire Restructures Global Boards as Troubles Mount, 15 October 2024
[276] AFR, Gupta's Steel Empire Restructures Global Boards as Troubles Mount, 15 October 2024
[277] AFR, Whyalla steelworks boss exits in Sanjeev Gupta shake-up, 31 October 2024
[278] The Washington Post, Australia, The Land of Iron Ore Exports, Faces a Green Reckoning, 26 October 2024
[279] AFR, Gupta 'has reached the end of the road' on $300m debt, court told, 06 November 2024

Section 11. Queensland's Green Iron Opportunity

Section summary:

- Queensland's Energy and Jobs Plan has put the state on an inevitable path to electricity sector growth, decarbonisation and renewal at a scale that promises to underpin a shift away from the strategic over-reliance on coking coal exports, a sector in a slow but structural decline as the world belatedly aligns with the climate science.
- Limited iron ore resources means although Queensland can become a large green hydrogen producer, it is unlikely the state will play a major role in green iron exports.
- However, Queensland will still be a key component to Australia's green metals industry through critical minerals, alumina and aluminium production.

In September 2022, the QLD Government announced the **QLD Energy and Jobs Plan** and SuperGrid blueprint to turbocharge the deployment of low-cost zero emissions renewable energy. The Energy and Jobs Plan aimed to deploy $62bn in public and private capital to achieve 70% renewable energy penetration by 2032, 80% by 2035, with 25 GW of new and existing zero emission generation.[280]

In June 2024, the Miles Government delivered the largest state investment package for renewable energy to-date in Australia, providing the critical impetus to crowd-in the necessary capital at speed and scale to establish the state as a world-scale renewable energy producer, and accelerate the development of emerging low-emission industries to safeguard and urgently diversity the state's economic and employment future away from fossil fuels.[281]

The budget included an allocation to the Energy and Jobs Plan of $26bn in public investment over 4-years into new, zero-emissions publicly-owned renewable energy, storage and enabling infrastructure projects, including $16.5bn for renewable energy, $8.5bn for transmission infrastructure, including CopperString 2032, SuperGrid and renewable energy zone development, as well as $500m for distributed energy storage.

Whilst Queensland has been an emissions reduction laggard in comparison to other Eastern states, the state government has shifted gears in recent years to massively accelerate the development of the supporting and enabling renewable infrastructure to establish a green iron industry, which has the potential to produce sufficiently low-cost green hydrogen to power a cost competitive value-added iron industry, especially given the state's investments into storage assets.

In FY24, Queensland's energy grid generated 28.5% of its electricity from renewable energy, producing over 18 TWh from solar and wind. As observed in South Australia, renewable energy prices continue to fall. In FY24, renewable energy average wholesale prices were $45.51/MWh, compared to weighted average fossil fuel prices of $107.01/MWh over the same period.

AEMO's Step Change Scenario of the 2024 ISP forecasts QLD to produce 146 TWh from renewable energy, predominantly wind and utility-scale solar, with methane gas playing a

[280] CEF, Queensland's Energy Transformation: From Coal Colossus to Renewable Energy Superpower, 21 February 2024
[281] CEF, Queensland Budget 2024-25: A Win for Renewable Energy, Jobs, Investment and a Win for Queenslanders, 11 June 2024

small firming role. Under the scenario, renewables would be more than 98% of generation.[282]

A key limitation to the green iron industry is providing sufficiently low-cost zero-emissions firming capacity to produce green hydrogen at a high enough capacity factor to lower the levelised cost of green hydrogen to be cost competitive against grey hydrogen, which currently dominates the global hydrogen landscape.

The QLD Government has committed to developing a renewable hydrogen industry, given the state's advantages including proximity to Asian offtakers, established port infrastructure, manufacturing capabilities and significant renewable energy potential. The Queensland Hydrogen Industry Strategy initiatives include:[283]

- **Supporting private sector investment** through targeted technical- and commercial-study and development approval support with the $35m Hydrogen Industry Development Fund and the Queensland Hydrogen Investor Toolkit, as well as the $4.5bn Renewable Energy and Hydrogen Jobs Fund that enables GOCs to partner with private enterprise for domestic production and use and for large-scale export projects.
- **Strategic planning for infrastructure** in public-private partnership, including the $15m Supercharging Hydrogen Hubs program, the $8.5m Abbot Point Activation Initiative and an $8m desalination detailed business case for Gladstone.
- **Investing in skills and training** with the state's Hydrogen Industry Workforce Development Roadmap 2022–2032, the first dedicated workforce development for Australia's hydrogen industry.

QIP Gladstone Green Iron Project

May 2024 saw Quinbrook Infrastructure Partners (QIP) announce the development of a possible $3.5bn Queensland Green Iron Project in Gladstone. QIP has partnered with Central Queensland Metals (CQM) to conduct detailed evaluation and testing of the Eulogie deposit, the largest known magnetite resource in Queensland.[284]

The Gladstone Green Iron Project would involve the extraction and concentration of magnetite ore on-site at Eulogie, then transported to the Gladstone State Development Zone, with the option to use green hydrogen to process into DRI-ready pellets and then into green iron (HBI) for export. The project represents a capital investment of up to $3.5bn on current estimates. Previous testing estimated the Ore Resources up to 465 Mt.

QIP has secured exclusive rights over the land adjacent to the Central Queensland Hydrogen Project CQ-H2 (short-listed in December 2023 for the Hydrogen Headstart program) being developed by Stanwell Corporation and consortium members Iwatani Corporation and Marubeni Corporation of Japan and Keppel Limited of Singapore.[285] QIP is in discussions with Stanwell Corporation for the supply of green hydrogen, as well as the delivery of firmed renewable power to support the needs of the Gladstone value-added processes.

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[282] Open Electricity, Scenario Explorer, AEMO 2024 ISP Step Change (CDP14), October 2024
[283] QLD Government, Hydrogen Industry Development, updated 16 July 2024
[284] QIP, Quinbrook Sponsors Development of Green Iron Project in Gladstone Queensland, 20 May 2024
[285] Stanwell Corporation, Hydrogen Headstart Program Shortlist, 21 December 2023

Section 12. Green Metals Statecraft to Catalyse Australia's Green Iron Industry

Section summary:

- Whilst longer term a credibly high price is needed on carbon emissions in international trade in Asia, like in the EU, Australia will miss the boat if we don't start investing now in preparation for the inevitable, massive Asian steel supply chain realignment.
- Both policy ambition and strategic public financial support at scale is needed to de-risk onshore investment in iron ore value-adding.
- A shift in ambition and understanding of the strategic role government and policymakers can play in developing a green iron industry in Australia. The value of Australian iron ore exports could double if we successfully overcome the challenges, but failure could see our exports halve.
- As outlined in previous sections, Australia already has a pipeline of projects that would be transformative for Australia.
- Australia as the institutional architecture it needs to provide and expand supply-side support, what is critically needed are mechanisms to support demand creation.

Ambitious Green Metal Statecraft to Secure Australia's Green Iron Opportunity:

1. National Green Iron and Steel Strategy with Clear, Measurable Targets.

2. Demand-Side Policies and Incentives, including:

- Trilateral Clean Commodities Trading Company (Australia, South Korea & Japan)
- Australasian Green Iron Corporation JV between Australia & key trade partners.
- Public procurement for green metals to create a national demand signal.
- 'Contracts for difference' to bridge the gap between pricing & production costs.

3. Supply-Side Policies and Incentives, including:

- $20bn Future Fund mandate for renewables-powered green metals processing.
- Production tax incentives for green metal refining.
- Exclusion of state investment in fossil fuel-powered onshore strategic metals refining; capping of Fuel Tax Credit Scheme to incentivise mine-to-product decarbonisation.

4. Policies to Address Technical Challenges:

- $500m over 10-yrs to the CSIRO for RD&D into commercialisation of green iron tech.

5. Foreign Policy & International Collaboration, including:

- DFAT & Austrade mandate to build collaboration on an Asian Carbon Border Adjustment Mechanism, creating a premium price signal for green iron.
- Australian/Asian steel supply chain decarbonisation collaboration pre-COP31.

6. Accelerated Renewables Deployment, including:

- Overriding Public Interest Test to speed renewable energy project approvals.
- Renewables investment conditional on community benefit/First Nations benefit sharing
- Accelerated development of Renewable Energy Industrial Precincts.
- Industrial demand response mechanisms to optimise renewables supply/demand.

Section 12.1. National Green Iron and Steel Strategy

CEF recommends the establishment of a **National Green Iron and Steel Strategy** in partnership with the state governments. Australia needs a well-designed strategy with measurable targets, delivered by bold and deliberate statecraft, to ensure Australia maintains its relevance across the iron and steel value chain.

It is clear Australia's key trading partners, as well as jurisdictions that are rapidly emerging as suppliers of decarbonised iron and steel products, are acting with strategic, intergenerational planning and policy, acknowledging the opportunity a global reorientation of supply chains can have for sustained economic and employment growth.

The Federal Government should expand on the ambition and state leadership of the SA Government, the first state to introduce a Green Iron and Steel Strategy. The Strategy also leveraged the previous work and progress of the state's Hydrogen Strategy.

In September 2024, the Federal Government released its updated **National Hydrogen Strategy**. The 2024 National Hydrogen Strategy will establish 5-yearly production milestones out to 2050, targeting the production of at least 15 Mtpa of hydrogen, with a potential to produce up to 30 Mtpa by 2050.[286] CEF recommends the Federal Government utilise and expand on the incentives introduced in the updated Hydrogen Strategy.

As part of the strategy, the Federal Government highlighted a number of supply-side and demand-side incentives for hydrogen producers and industrial users to accelerate investments into Australia's green hydrogen industry. These incentives are critical to building out the green hydrogen industry that will support the decarbonisation of green metals refining and value-add in Australia.

CEF also sees the expansion of the **Guarantee of Origin** (GO) scheme as critical to achieving green premiums in the global export market, verifying the embedded emissions content in Australian value-added critical minerals and strategic minerals The GO Scheme is an internationally aligned scheme to measure and verify emissions intensities of the production of hydrogen. The GO Scheme is both scalable and expandible, enabling similar verification of products produced from hydrogen including green metals and low carbon liquid fuels.[287]

CEF recommends as part of a National Green Iron and Steel Strategy, the introduction of a **Green Metals Standard for Australia**, a certification scheme that is complementary to standards implemented in key export market economies.

The Product GO (PGO) provides certification for renewable energy derivatives, including hydrogen and ammonia, incorporating the Renewable Energy GO (ReGO). As value-adding green iron uses different technologies and pathways, CEF recommends a Green Metals GO (GMGO) that builds on both the ReGO and PGO for different stages of refining.

[286] DCCEEW, 2024 National Hydrogen Strategy, 13 September 2024
[287] DCCEEW, 2024 National Hydrogen Strategy, 13 September 2024

Section 12.2. Demand-Side Policies and Incentives

First mover producers and buyers will require greater policy and price support to bridge the green premium gap, absent a sufficiently large carbon price to incentivise global buy-in and price parity with fossil-based steelmaking, both from coal-based BF-BOF and majority methane gas-based DRI-EAF.

To address this challenge, CEF recommends establishing a **Trilateral Clean Commodity Trading Company** (CCTC), jointly owned by Australia, South Korea, and Japan to accelerate the development of decarbonised, value-added industries in Australia, initially green iron. The CCTC's mandate would be to contract, purchase, and trade commodities produced via low-carbon pathways, while optimising the economic, political, environmental, and geostrategic benefits for the parties, and minimising government financial support by operating with a commercial mindset, while understanding governments' enabling role.

Globally, the largest obstacle to private sector investment into commodity decarbonisation is the lack of ***long term contacts for clean commodities*** **at a predictable price**.

The absence of willing and creditworthy contracting counterparties is now throttling investment in clean commodity projects. The CCTC's participation in the market will aid in accelerating price discovery in the emerging low-emission global iron market, especially in countries without a price on carbon.

The offtake contracts created by the CCTC could allow for the 'clean' nature of the value-added iron to be stripped from the iron product, and retained by the CCTC in the form of a clean commodity carbon credit. This would allow for the CCTC to separately sell the credits generated from the lower-emission iron production, replicating established mechanisms like in Australia's power markets, in which the green nature of the electricity is routinely traded separately from the energy itself, and is a similar design to carbon markets and trading systems introduced globally.

The formation of a CCTC will enable the Federal Government to share in the costs and benefits of industry creation, as the CCTC will be jointly capitalised by Australia, South Korea and Japan, reducing the risk profile to each country, as well as collectively share the costs and benefits of demand creation and trading of both the commodities and clean commodity credits generated from the production of such commodities.

Prioritising demand-side incentives to secure long-term offtake agreements allows the established financing institutions of Australia to further support projects and secure the necessary capital to construct the enabling renewable energy infrastructure to support green iron facilities.

Australia has an excellent portfolio of public financing institutions with mandates, either partially or wholly focussed, on Australia's decarbonisation, with independent boards, skilled executives, effective oversight and a requirement for transparency. EFA has demonstrated its key role in supporting large-scale projects with trade finance, in collaboration with our strategic trading partners' respective export credit agencies, in addition to NAIF providing strategic debt to the North of Australia, including the Pilbara. In addition, CEF sees the $15bn NRF as playing a critical role in enabling economy-wide re-industrialisation and skills growth.

In grants and debt markets respectively, ARENA and CEFC are well established. CEFC's deployment of the $20bn Rewiring the Nation Fund is critically important to develop the enabling common user electricity infrastructure in the Pilbara and Mid-West that will enable green value-adding in the region.

Section 12.3. Supply-Side Policies and Incentives

Production Tax Incentives for Green Metals

CEF recommends as part of the supply-side incentives implemented in a National Green Iron and Steel Strategy, the Federal Government establish **Production Tax Incentives** for green metal refining, expanding on the Critical Minerals Production Tax Incentive introduced in the Federal Government's 2024-25 Budget to cover strategic metals imperative to Australia's economic resilience and security, and to the global transition to net zero.

A green metal production credit would complement the Hydrogen Production Tax Incentive to lower the cost-differential for first movers in embedding decarbonisation, as well as aid the expansion of the GO Scheme to cover metals that consume products covered under the ReGO and PGO schemes.

CEF recommends Australia prioritise the capitalisation of demand-side incentives to support market creation across Asia, as Australia's iron ore market has almost entirely serviced. However, stackable production tax incentives provide diversification of Australia's public capital support to Australia's green iron opportunity.

A time-limited production tax incentive will help support producers between now, where Australia lacks a carbon price in international trade, and the inevitable policy response of international carbon price. This ensures Australia's green iron industry gets moving, and helps align the trajectory of Australia's resource sector with the acceleration of policy responses to climate change.

Expanding the Mandate of the Future Fund

CEF recommends the Federal Government enhance the mandates of the Future Fund to leverage its patient, strategic public-interest capital, standing, capacity and expertise to accelerate investments into Australia's green metals industry. As developing a green metals industry in Australia will require long-term, large-scale investments into enabling energy and infrastructure, CEF sees the $272bn sovereign wealth fund of Australia as a valuable co-investor alongside established private capital partners to catalyse the more than $500bn of energy transition and future-facing industry investments required.

Beyond the core SWF, the Future Fund has specific mandates for the Medical Research Future Fund ($22bn), the DisabilityCare Australia Fund ($16bn), the Aboriginal and Torres Strait Islander Land and Sea Future Fund ($2bn), the Future Drought Fund ($5bn) and the Disaster Ready Fund ($4bn). The Future Fund has delivered a 10-year 8.3% CAGR, exceeding its annual 6.9% return target of CPI +4-5% pa, demonstrating its ability to generate a sustained positive return on capital for Australia.[288]

[288] Future Fund FY2024 Year in Review

CEF calls for the introduction of a **$20bn Clean Technology Futures Fund Mandate** to crowd-in private capital, catalysing Australia's re-industrialisation, jobs and skills-building in decarbonised value-added industries, primarily the refining of critical minerals and strategic metals using low-emission energy sources.

The Future Fund can provide the informed discussion and framing of strategic, patient capital deployment into value-adding our future-facing commodities onshore that can enable the massive $3.6 trillion in Australia's superannuation industry, as well as the $4 trillion of collective Assets under Management (AuM) of Australia's commercial banks to jointly de-risk and fund the development of world leading, decarbonised industries of the future, exported resources embedded with zero-emission energy that enables Australia to export our world-leading renewable energy resources.

As part of CEF's recommendation, we propose the implementation of a US$100/tonne shadow price on emissions across the Future Fund's portfolio, which will provide a strong market signal for Australia's financial sector of the clear, and accelerating direction of travel towards the inevitable global decarbonisation.

Section 12.4. Technical Policies and Incentives

To address technical challenges of iron and steel decarbonisation, CEF recommends the Federal Government provide an additional $500m over 10-years to the CSIRO of strategic support for RD&D into the commercialisation of technologies that will unlock and accelerate Australia's green iron industry. The role of the CSIRO is to provide innovative scientific and technology solutions to national challenges and opportunities to benefit industry, the environment and the community, through scientific research and capability development, services and advice.

Section 12.5. International Collaboration and Working Towards Carbon Pricing in Asian Trade

Across the globe, economies are shifting energy and industry policy to those which factors in a price on carbon, both implicitly and explicitly. The two largest emissions trading schemes (ETS) are in China and the EU.

Carbon prices are needed to capture and price in the negative externalities associated with carbon emissions, i.e. the burden placed upon the public from diminishing crop yields, health care costs, and the rapidly rising monetary impacts of climate change and the increasing severity and frequency of heat waves, droughts, flooding and sea level rise. The IEA models in its Net Zero Emissions scenario the developed world having comprehensive carbon prices of US$250/t by 2050, with major developing countries having a carbon price of ~US$200/t. While carbon markets globally are expanding with each year, there is a long way to go.

CEF are strong advocates for the introduction and progressive rise of a carbon price across the whole economy as a clear indication of policy direction both domestically and internationally. This would act as the most effective mechanism to align private investment in clean energy technologies and production methods with that of national emissions reduction objectives.

Putting a price on carbon shifts the burden back onto the entity, and their supply chain, that is responsible for carbon emissions. Emissions do not respect international borders. The burden of climate change is placed onto the shoulders of everyone, with those least responsible suffering the largest burden. A credible global price on carbon eliminates the ability for fossil fuel producers to ship emissions offshore free of charge, externalising their cost of doing business, a massive ongoing subsidy that continues to undermine the Federal Government's Climate Change (net zero future) Act 2023 and the economic competitiveness of zero emissions alternatives.

Currently, there are three main carbon pricing mechanisms: Emission Trading Systems (ETS); direct carbon taxes; and Carbon Border Adjustment Mechanisms (CBAM).

Emission Trading Systems (ETS)

ETS introduces a cap to the level of GHG emissions and allows industries with low emissions to sell additional allowances to larger emitters. The ETS creates a supply and demand market dynamic, with higher demand for allowances driving up the prices the entity must pay to emit. The most effective and significant scheme is the European Union (EU) ETS, which has been in place for several decades, and is progressively expanding beyond the electricity sector to heavy industry, and has credible prices currently averaging €60-100/t and a ratcheting-up over time capacity.

Carbon Taxes

An explicit price on carbon with a defined tax rate on GHG emissions or carbon content of fossil fuels. Unlike the dynamic market of an ETS, a carbon price is pre-defined, and often has a legislated ratchet-up profile over time e.g. Singapore (S$25/t), Canada (C$80/t) and New Zealand (NZ$50/t).

Carbon Border Adjustment Mechanisms (CBAM)

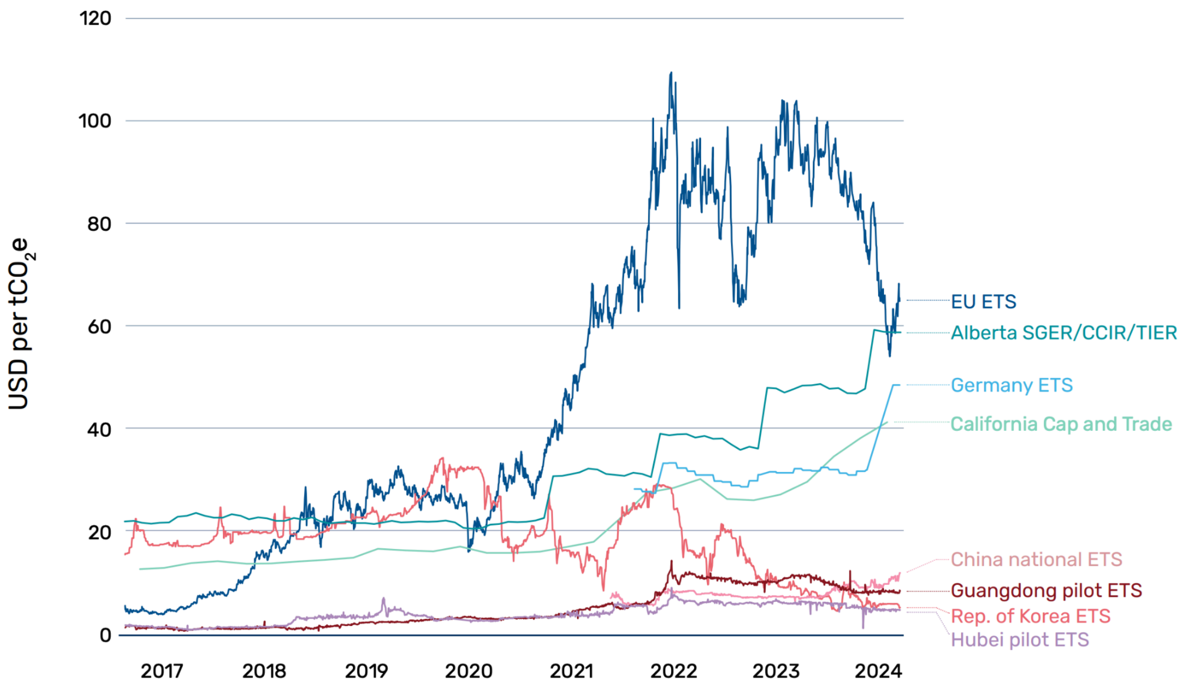
October 2023 saw the EU introduce its transitional CBAM to ensure that the imposition of the carbon price on EU industry doesn't create an unfair advantage for high emissions import alternatives, covering critical industries including iron/steel, aluminium, cement, fertilisers, hydrogen and electricity.

As of April 2024, there are 75 carbon taxes and ETSs in operation globally, an increase of two carbon pricing instruments from 2023, the reformed Australian Safeguard Mechanism into an intensity-based ETS, and Hungary's new carbon tax.[289] Carbon pricing mechanisms now cover ~ 24% of global GHG emissions, almost 13 gigatons of CO_2-e annually.

There are now 7 carbon pricing mechanisms that are within or exceed the High-Level Commission on Carbon Prices recommended US$63-127/t range to limit temperature rise to below 2ºC, all of which are carbon taxes. The highest ETS price remains the EU ETS, which dropped below the threshold in 2024 - see Figure 12.1.

[289] World Bank, State and Trends of Carbon Pricing, 21 May 2024

Figure 12.1 Price Evolutions of Largest Emissions Trading Systems Globally



Source: World Bank [290]

On 28 May 2024, The EU and Australia signed a Memorandum of Understanding (MoU) for a bilateral partnership to cooperate on sustainable critical and strategic minerals. The MoU is designed to provide a framework to build secure value chains between the economies that support the clean energy and digital transition. The scope of the MoU includes, but is not limited to, the:

- Cooperation and integration of sustainable material value chains, including networking, joint facilitation (i.e. joint ventures), and promotion of trade and investment linkages,
- Development of open, fair and competitive markets for critical raw and processed minerals, developing Australia's domestic sector to enable the EU to diversify its suppliers necessary to achieve the green transition,
- Cooperation on ESG standards and assessments that align international mineral pricing with high ESG standards.

This MoU marks a significant moment for international development of high environmental, social and governance (ESG) standards for mining supply chains, a major opportunity to leverage and extend the EU Battery Passport. CEF views this as a good first step towards developing decarbonised commodity trade and the reshaping of supply chains to regions of high renewable energy resources. As global leaders export more technologies and resources critical to the net zero transformation, exporters are beginning to reshape and enhance carbon pricing and emissions reduction mechanisms to align their industries with the EU.

In September 2024, China's Ministry of Ecology and Environment (MEE) sought public feedback on a plan to include cement, steel and aluminium production in its carbon ETS by

[290] World Bank, State and Trends of Carbon Pricing, 21 May 2024

the end of 2024. Doing so would increase the GHG emissions covered under the ETS to 60% of China's annual emissions, more than the annual emissions of the US.[291]

China will expand the ETS over two stages, familiarising participants with its processes between 2024 and 2026, and improving management and quality of emissions data and reducing quota allocations to firms from 2027.

Australian Carbon Leakage Review

In November 2024, the second consultation paper on the Federal Government's Carbon Leakage Review (the Review) was released, led by Professor Frank Jotzo.[292] The Review noted that "a border carbon adjustment applied to imports could be an appropriate policy measure for selected Safeguard-covered commodities with high carbon leakage risk from imports."

Critically, the Review places importance on the international rules-based trading system and on maintaining open and liberal trade relationships, especially in the region and "including any potential border carbon adjustment, respect international trade rules and obligations, facilitate trade that is consistent with climate change policy objectives, and could be collaboratively implemented with Australia's trade partners." CEF agrees entirely with this approach.

Working towards an Asian CBAM

As per **recommendation 5.1**, CEF views an Asian CBAM as a key development to provide the right price signal for Australian mining majors to accelerate the deployment of capital to build embodied decarbonisation into our critical mineral and strategic metal exports, which in turn will pivot from our massive over-exposure to fossil fuel exports of old.

A multilateral Asian CBAM with Australia's largest trading partners would critically provide the necessary and clear price signal needed for Australia's iron majors, BHP and Rio Tinto, to accelerate and scale their investment timeline to embed decarbonisation in mining operations and establish domestic, green value-added capacity onshore.

CEF expects the carbon price in China to progressively rise. Our discussions with government officials suggest a price ambition of as high as RMB 2,000-3,000/t (US$275-413/t) by 2060, which is higher than even the IEA models (US$250/t for developed countries by 2050).

China Baowu Group, the largest steelmaker globally, is moving to explore options for a path to decarbonisation, but unfortunately, they are still officially working towards a 2060 NZE target. This target needs to be accelerated a decade to 2050 to drive technology and investment innovation. The Chinese steel industry has already likely peaked emissions, given Chinese domestic steel demand likely permanently peaked in 2022 (aided by the rapid property sector decline in 2023-24), and growing access to steel scrap means a progressive rise in the use of EAF and circularity, progressively reducing China's need for Australian iron ore and coking coal.

This would also work to send the right policy signal to shift Chinese investment from new blast furnaces to electric arc furnaces. This then ties decarbonising the steel industry to the accelerating decarbonisation of the electricity sector.

[291] Reuters, China Plans to Include Steel, Cement, and Aluminium in its Carbon Market in 2024, 09 September 2024
[292] Australian Government DCCEEW, Carbon Leakage Review, November 2024

As to the path towards establishing an Asian CBAM, China has the advantage over Korea and Japan of an existing national ETS. CEF understands Japan's METI is considering a national ETS by 2028, which would be an excellent precursor to an Asian CBAM.

As per **Recommendation 5.1**, CEF recommends giving DFAT and Austrade a clear new mandate to build international collaboration and consensus to work towards an **Asian Carbon Border Adjustment Mechanism (CBAM)** to extend and reinforce the merits of the EU CBAM introduced in October 2023. Enhancing the value of Australia's key resource exports by onshore value-adding, powered by firmed renewable energy means the addition of embodied decarbonisation is a $100-200bn annual trade value uplift opportunity, but only if there is the right price signal incorporated in Asian trade.

Foreign Minister Penny Wong and Trade Minister Don Farrell need to step up internationally and support the onshore decarbonisation efforts of Ministers Chris Bowen, Ed Husic and Jenny McAllister and leverage the domestic progress made with the Safeguard Mechanism and the ambitious 82% Renewables by 2030 target.

As per **Recommendation 5.2**, CEF urges the Federal Government to prioritise a focus on Australian/Asian collaboration in iron and steel decarbonisation for the prospective Australia/Pacific-hosted **COP31**. The scale of the challenge to build a world-scale green metals industry in Australia, to enable global decarbonisation, will require strategic and coordinated international public finance, knowledge sharing, trade and investment. Enhanced globalisation and diversification of value chains is critical to achieving globally significant industrial emissions reduction.

Section 12.6. Policies to Accelerate Renewable Energy Deployment

Slow and complicated development approval processes for renewable energy and enabling infrastructure are a critical barrier that must be overcome for Australia to deploy the capex at speed and scale to unlock Australia's green iron and other green metals and critical minerals industries.

CEF supports the recommendations made by the **Climate Change Authority's Sector Pathways** to prioritise approvals processes for net zero transition projects, fast-tracking development of renewably-powered industrial hubs. In addition, the expertise of the Net Zero Economy Authority should be utilised to support and coordinate local, state and federal governments to expedite approvals for firmed, off-grid renewable projects that will support the production of green metals.

To minimise the extensive investments required in grid transmission infrastructure if all green metals projects were grid-connected, we also recommend the establishment of a dedicated **Renewable Energy Approvals Initiative** for distributed behind-the-metre generation and storage projects that will power hydrogen production and electricity demand for value-added projects critical to underpinning the Federal Government's Future Made in Australia initiatives and its Net Zero Transformation Stream (projects that make significant contributions to the global net zero transition) and Economic Resilience and Security Stream (to maintain and expand Australia's position in the global iron and steel value chain).

Given the scale of the task to accelerate firmed renewables infrastructure deployment rates, CEF recommends the introduction of an **Overriding Public Interest** (OPI) test, like in the EU, to streamline approvals process and expedite deployments.

As part of any approvals reforms, CEF urges the Federal Government to introduce clear **community benefit principles** and First Nations capacity building and benefit sharing as part of the approvals process. Onshoring a green iron industry will require investment into renewable energy, enabling infrastructure, and zero-emission firming capacity at an unprecedented speed and scale. This has the potential to negatively impact surrounding communities and First Nations lands if equitable and sustainable community principles are not a critical component to the approvals process, but also presents immense opportunities for benefits to flow to host communities.

For grid-connected green metals projects, CEF recommends the priority development of low-emission, Renewable Energy Industrial Precincts,[293] leveraging economies of scale for energy transmission and hydrogen pipelines with common user infrastructure, industrial heat and workforce skills development. This will also reduce planning approval duplication, as well as minimise the development footprint, as larger renewable energy projects are able to provide power to multiple offtakers.

To minimise the impacts of large-scale green metal facilities on grid capacity building, CEF recommends the Federal Government and AEMO support the integration of industrial **demand response mechanisms** (DRM) into Australia's existing and future grid-connected, energy-intensive value-added refineries, starting with aluminium smelters.

The electrification and scaling of Australia's onshore capacity in green metals refining will spur significant new renewable electricity demand. Leveraging DRM during periods of peak power demand and renewable energy droughts will significantly lower the need for additional renewable energy generation, long-duration storage projects and transmission infrastructure, and reduce overcapacity / gold-plating of the NEM during the energy transition.

[293] BZE Economic Analysis: Renewable Energy Industrial Precincts, July 2021

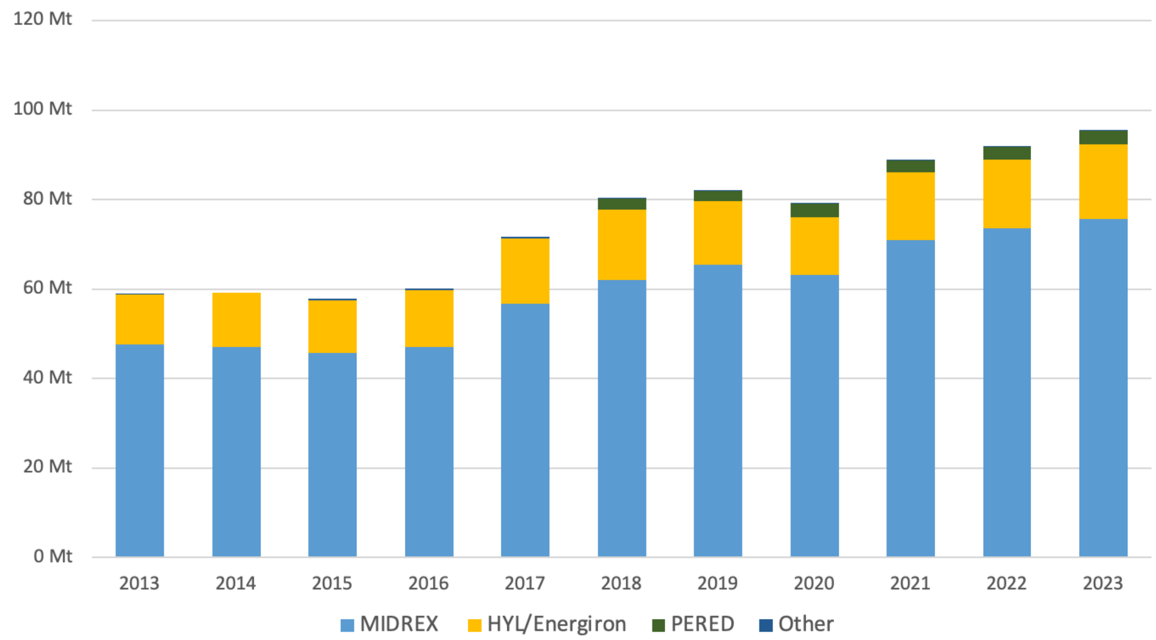
Additional Information: Current Iron and Steel Decarbonisation Technologies

MIDREX

The MIDREX shaft furnace DRI process is owned by Japan's Kobe Steel (a subsidiary of Kobelco). MIDREX plants are the largest supplier of DRI, accounting for ~ 80% of global DRI production in 2023 (excluding thermal coal based rotary kilns) - see Figure 2.1.[294]

MIDREX plants have been operating since the 1970s, with plants operating at ~400,000tpa capacity. Over time, MIDREX shaft furnaces have increased their operational capacity, with plants commissioned over the past decade, and plants currently under construction, reaching a maximum of 2.5 Mtpa.

Figure 2.1: Global DRI Production from Gas/Hydrogen Technologies



Source: MIDREX [295]

As of the end of 2023, there are 64 operating MIDREX plants globally, with the majority built in the Middle East and North Africa. There are currently 7 MIDREX plants under construction, with a combined capacity of 11.55 Mtpa, 5 of which are in Iran, the largest producer globally of gas/hydrogen-based DRI, and 1 plant in Algeria (Tosyali), and the world's first full-scale 100% H_2-DRI MIDREX plant in Boden, Sweden, under construction by Stegra (formerly H2 Green Steel). Refer Appendix A for a schematic of the MIDREX process.

The main plant design is MIDREX Flex, which can flexibly operate at different ratios of methane gas and hydrogen blends to produce DRI/HBI. Compared to traditional ironmaking, a MIDREX Flex plant operating on 100% methane gas can reduce emissions by 50%, with

[294] MIDREX, 2023 World Direct Reduction Statistics, 2024
[295] MIDREX, 2023 World Direct Reduction Statistics, 2024

direct emissions intensity of 0.5t CO_2/t-DRI. This process will typically consume between 275-300 normal cubic metres per tonne of DRI (Nm^3/t-DRI) during operations.

For a 2.5 Mtpa plant, this requires 25-27 PJ pa of methane gas (termed NG in Figure 2.2) supply just for the reduction of iron ore, excluding the necessary energy to pelletise the magnetite feedstock - see Figure 2.2. Hydrogen replacement of up to 30% of methane gas requires no changes to the major processing equipment including the shaft furnace and the methane reformer in MIDREX plants, which translates to a further 30% reduction in emissions relative to 100% methane gas, and giving a ~ 65% reduction relative to BFs.[296]

Figure 2.2: MIDREX Energy Consumption and Emissions from Decarbonisation

		NG Displacement by H_2			
	NG	30%	50%	80%	100%
NG Consumption (Nm^3/t)	275-300	190-215	140-165	50-80	0
H2 Consumption (Nm^3/t)	0	250-300	450-500	700-750	850-900
H_2 / CO	1.6	2.8	4.5	10.5	-
Direct CO_2 Emissions (kg CO_2/t-DRI)	500	350	250	100	0

Source: MIDREX [297]

MIDREX plants have been commercially proven at scale (2.5 Mtpa) operating at 55-75% hydrogen as the reducing agent. To achieve greater decarbonisation, MIDREX is collaboratively working with operators to develop the MIDREX H_2 platform, which can be powered by up to 100% green hydrogen.

Using 100% hydrogen, MIDREX H_2 requires 650 Nm^3/t-DRI (58 kg H_2/t-DRI) as a reducing agent. However, due to the inefficiencies of using hydrogen as a reductant, and the endothermic nature of the chemical reaction between iron and hydrogen, the total hydrogen demand for MIDREX Flex is between 850-900 Nm^3/t-DRI (76-80 kg H_2/t-DRI) - see Figure 2.2. For a 2.5 Mtpa plant, the annual hydrogen demand for producing DRI from magnetite pellets is 190-200,000tpa of green hydrogen.

MIDREX plants can only be constructed by a small number of firms globally, including Japan's Kobelco (incl. subsidiary Kobe Steel Group), Germany's SMS Group (incl. Subsidiary Paul Wurth S.A), and Primetals Technologies.[298]

July 2024 saw Nordic steel startup Blastr Green Steel sign a contract with Primetals Technologies for the supply of a new 2 Mtpa MIDREX DRI plant to be located in Inkoo, Finland, to supply its proposed adjacent 90% lower than average emissions steel plant.[299]

October 2024 saw German steel producer Dillinger and ROGESA sign a contract with Primetals Technologies for the supply of a new production complex, including a 2 Mtpa MIDREX DRI plant and an EAF. This is an ambitious green steel transformation project to

[296] MIDREX, Fuelling the Future of Ironmaking: MIDREX Flex, March 2024
[297] MIDREX, Fuelling the Future of Ironmaking: MIDREX Flex, March 2024
[298] MIDREX, Project Development
[299] MIDREX, MIDREX H2 Plant to Produce 2.0 Million Tons of DRI Per Year, 09 July 2024

replace its current BFs in Dillingen. It will operate on methane gas, but 'hydrogen-ready.' Funding support is coming from the German Government and the state of Saarland.[300]

Energiron

The Energiron gas/hydrogen shaft-furnace process was developed by Danieli and Tenova, both firms based in Italy. The Energiron platform converts methane gas into carbon monoxide (CO) and hydrogen to reduce iron ore into metallic DRI/HBI. Energiron platforms have been in operation since the 1980s. A flowsheet is available in Appendix B.

The latest iteration, Energiron ZR (Zero Reformer) forms reducing gases by in-situ reforming within the reduction reactor, with the Fe contained in the feedstock acting as the continuous catalyst for the reforming of methane gas into CO and H_2.

As of the end of 2023, there are 15 operating Energiron plants, which produced 16.61 Mtpa of DRI products in 2023, the second largest global production process for gas/hydrogen DRI plants.[301] There are currently four Energiron plants under construction as of the end of 2023, the largest of which is Salzgitter AG's 2.1 Mtpa HDRI project in Germany.

In March 2024, Tenova announced a research and development (R&D) partnership with Japan's Nippon Steel to jointly develop an Energiron DRI platform operating on 100% hydrogen, reportedly to be equipped with carbon capture and storage (CCS), in Nippon's Hasaki R&D centre (CEF notes Japan has no operational CCS capacity, nor probably ever will given earthquakes).[302] The project will be supported by a consortium of Nippon Steel, JFE Corporation, and the Japan Research and Development Centre for Metals.

Primetals Technologies

HYFOR Process

Primetals Technologies was founded in 2015 by Siemens VAI, Mitsubishi Heavy Industries, and partners. In 2023, Mitsubishi Heavy Industries obtained full ownership of Primetal Technologies. Primetals is a technology provider for the global metals industry, providing turnkey systems, as well as upgrades, engineering, construction and metallurgical services to other technology OEMs and end users.

Primetals' Hydrogen-based Fine Ore Reduction (HYFOR) is a low-temperature fluidised bed technology, capable of reducing iron ore concentrates without agglomeration, allowing the processing of hematite, magnetite, and limonite.

In June 2021, Primetals announced the first successful tests of the HYFOR system at a pilot plant in Donawitz, Austria, at Voestalpine's Stahl Donawitz steel mill.[303] The pilot plant uses 100% hydrogen as a reducing agent, lowering the DRI emissions intensity to near zero.

HYFOR consists of a preheating-oxidation unit, in which fine ore concentrate is heated to 900ºC before being charged into the reduction unit. The reducing agent is supplied over the fence from a hydrogen supplier. Hot DRI (HDRI) is produced at a temperature of ~ 600ºC before cooling and discharged as Cold DRI (CDRI).

[300] MIDREX, Dillinger & ROGESA selects Midrex & Primetals for Major Decarbonization Project, 11 October 2024
[301] MIDREX, 2023 World Direct Reduction Statistics, 2024
[302] Tenova, Energiron for Experimental DRI Plant in Japan, 18 March 2024
[303] Primetals, HYFOR Pilot Plant Under Operation, 24 June 2021

Primetals is investigating an industrial-scale (intermediate stage between pilot and commercial) plant with a production capacity of 5-15t/hour of continuous operation. Depending on the ore quality, between 550-600 Nm^3/t DRI (49-54 kg/t-DRI) of hydrogen is required (depending on iron metallisation between 94-100%), used solely as a reductant, with the HYFOR process using alternative energy sources for ore and gas heating.[304] A schematic of the HYFOR process is available in Appendix C.

FINMET Process

Primetals' co-founder, Siemens VAI, developed the FINEX and FINMET processes in the 1990s, the former in partnership with POSCO, and the latter in partnership with Orinoco Iron of Venezuela.[305] Both processes utilise fluidised bed technology, using methane gas as a reducing agent of iron ore fines. FINMET is a four-stage, bubbling reactor system where iron ore is reduced in a counter-current flow, with fossil reducing gas produced via coal gasification or methane gas reforming.

The FINMET process was used in BHP's Boodarie Iron plant in Port Hedland, WA, which began construction in 1996, began production in 1999, and halted production in 2004 following a fatal explosion. The plant was permanently closed in August 2005.[306] The Boodarie Iron plant was designed to produce up to 2.3 Mtpa of HBI, with a 67% Fe content iron feedstock producing granules with over 90% metallisation. Over its life, BHP's HBI plant produced 5.7 Mt using the FINMET process. A schematic flowsheet of the FINMET process is available in Appendix D.

BHP was three decades ahead of its time. At the time, the global steel industry, and the world, had no focus on the massive externalised cost of carbon emissions, and hence the value of emissions reduction capacities (hence why CEF is focussed on a clear, high, well regulated market price signal via an Asian CBAM – refer Section 14.1), BHP failed to get customer buy-in for the plant, in addition to the far greater than anticipated growth of China's steel demand which resulted in consumers prioritising more cost-effective steel production methods (i.e. BF-BOF using comparatively cheaper metallurgical coal), in addition to the difficulties associated with the beneficiation of Pilbara iron ore qualities when processed in the selected technologies.

BHP remains scarred by this failure, and associated $2bn write-off, to this day, and retains a fixation with dig-and-ship strategies that, in CEF's view, severely undermine the ambition and direction of FMIA. BHP's experience of Indonesia's nickel global market share grab over the last few years, supported heavily by investment and workforce support from China's largest battery material producers, has unfortunately reinforced this view, and is central to why CEF advocates for a clear price signal in international markets for either an Asian CBAM or ideally (and harder to implement) green premium price signal (along the lines of the EU Battery Passport).

[304] Mitsubishi Heavy Industries, HYFOR - Hydrogen-based Fine ore Reduction, June 2022
[305] SaiMM, Fluidised-bed Technology for the Production of Iron Products for Steelmaking, 04 March 2009
[306] BHP, Boodarie Iron Fact Sheet, 24 August 2005

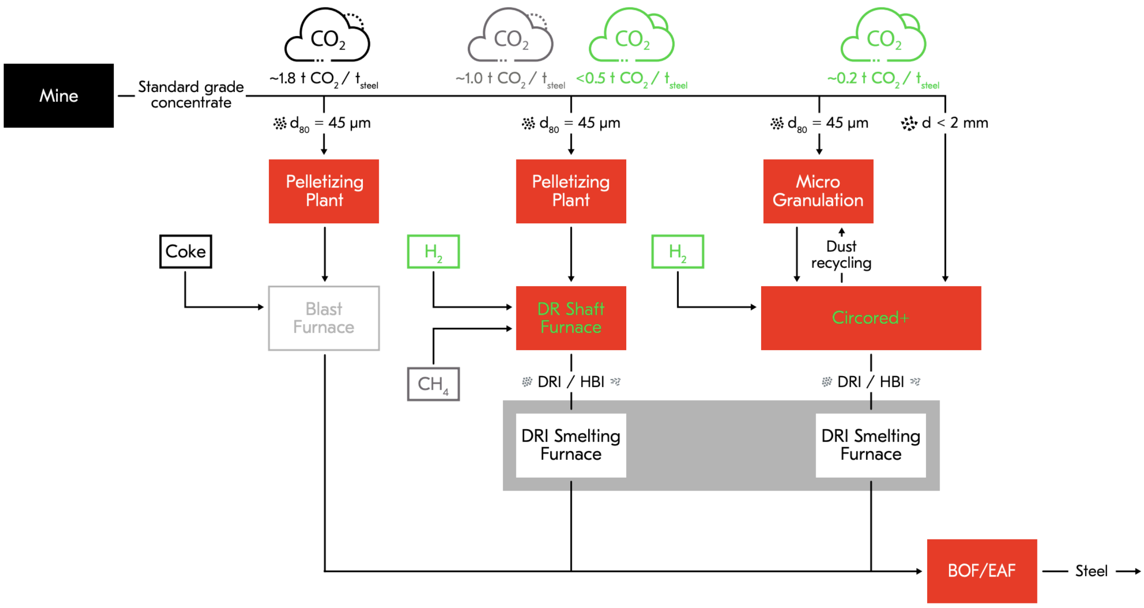
Metso Outotec

DRI-Smelting Furnace Process

Finland's Metso Outotec has designed a pilot electric smelter furnace (ESF) to combine with direct reduction plants that can enable the decarbonisation of the global steel industry by replacing traditional blast furnaces. Metso's ESF is modelled off proven smelting technology for refining non-ferrous elements like copper and nickel. The current pilot ESF is equipped with a 2.5 MVA transformer allowing the demonstration of DRI-smelting of ~ 1 tonne/hour.

In January 2024, Metso announced it began the process of developing a €8m hot metal DRI-Smelter pilot plant to further demonstrate the technology's efficacy at scale, constructing a customer-specific pilot plant in Pori, Finland, in one of the firm's major R&D centres.[307] The DRI-Smelter route allows for the use of blast furnace grade iron ore fines to be processed in a decarbonised, electric steelmaking round.

Figure 2.3: Emissions Intensity of Metso's Technologies



Source: Metso [308]

The DRI-Smelting Furnace could produce iron for under 0.5t CO_2-e/t steel when the DR process is powered by renewable energy and/or green hydrogen, and ~ 1t CO_2-e/t steel if grey hydrogen derived from methane gas is used - see Figure 2.3. With the BF proportion of emissions estimated at 1.8t CO_2-e/t steel, this would result in a 72% and 44% emissions reduction in the ironmaking stage respectively.

Circored Fluidised Bed Process

Metso Outotec developed **Circored**, a process which uses iron ore fines to produce highly metallised DRI or HBI that can be fed directly into an EAF. Circored is the only 100% hydrogen-based iron ore reduction process that has proven its functionality and performance in an industrial-scale plant, operating in Trinidad since 1999.

[307] Metso, Supporting Decarbonisation of the Iron and Steel Industry, 17 January 2024
[308] Metso, Metso DRI Smelting Furnace

Circored's use of iron ore fines eliminate the need to agglomerate into sinter, required in BF-BOF steelmaking, or pellets, used in shaft-based DRI technologies. This provides significant energy and cost savings to the beneficiation of iron ore.

Circored utilises a two-stage reaction process with a circulating fluidised bed (CFB), followed by a bubbling fluidised bed (FB) downstream, with a single module up to 1.25 Mtpa. Multiple lines can be combined using joint facilities to expand the production capacity and leverage economies of scale through joint facilities.[309]

The iron ore fines are preheating up to 900ºC before being charged into the CFB, achieving a fast pre-reduction of up to 80% metallisation. The final reduction in the FB can achieve total iron reduction in excess of 95%. The processes operate in temperatures below 700ºC, which avoids iron particles sticking in the reduction processes. Circored can produce HBI for export, as well as HDRI for direct hot feeding of the metallic iron into an EAF.

As illustrated in Figure 2.3, using hydrogen produced from renewable energy, the Circored process can lower the ironmaking proportion of steel emissions intensities to ~ 0.2t CO_2-e/t steel, which would fall well below the IEA's definition of green steel with an EAF powered by renewable energy.

The only operating Circored plant is in Point Lisas, Trinidad & Tobago, owned and operated by ArcelorMittal. The plant was commissioned in 1999, with a capacity of 0.5 Mtpa.[310]

The plant was decommissioned in 2006 after several campaigns of production. Although technically successful, the plant operated on very high grade Brazilian iron ore and struggled commercially, selling HBI into the USA. In comparison, other fluidised bed technologies are far more efficient and less complex, including HyFOR, HyREX, Finored and Finmet.

POSCO

FINEX and HyREX Fluidised Bed Processes

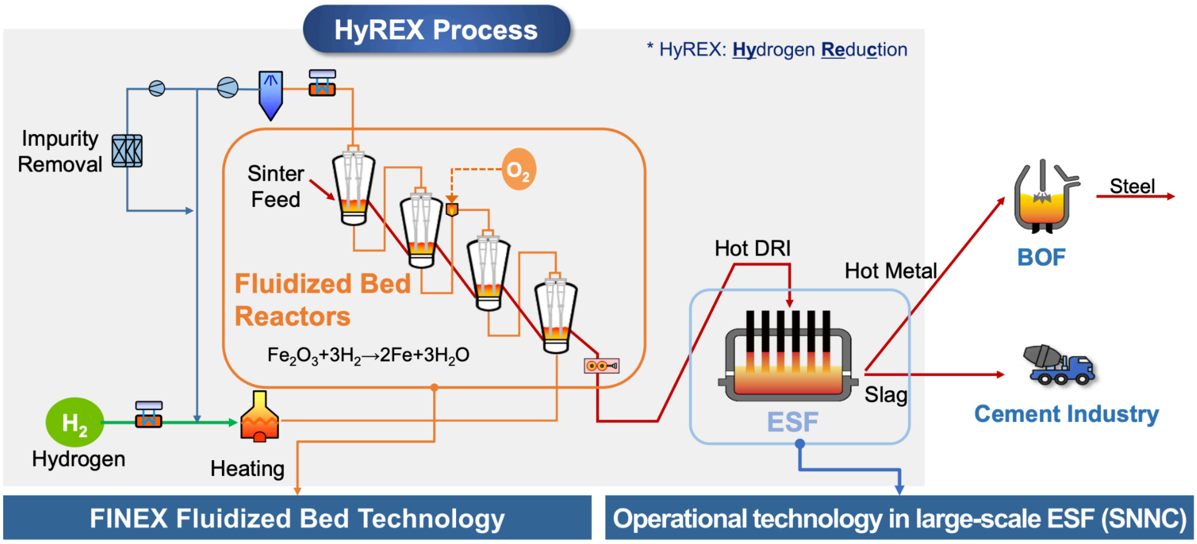
The **FINEX** fluidised bed process was jointly developed by POSCO and Primetals Technologies, using iron ore fines and non-coking coal. The FINEX process has an advantage over blast furnaces in its ability to utilise low-cost raw materials, with no requirement for iron ore sintering, and the use of typically lower-cost thermal coal instead of coking coal, eliminating the need for a coke oven. According to Primetals, a 1.5 Mtpa FINEX plant can more economically produce hot metal than a modern 3 Mtpa BF, with capex per unit of output of a FINEX plant ~ 20% lower, and opex ~ 15% lower compared to blast furnaces.[311]

The joint venture between POSCO and Primetals (then Siemens VAI) in 1992, with initial laboratory-, bench-, and pilot-scale plants before the 2,000t/day demonstration plant was built in Pohang, Korea, began operations in 2003. The commercial-scale FINEX 1.5 Mtpa plant began production in 2007. Following successful operations, POSCO expanded the plant to 2 Mtpa, commencing production in January 2014. The FINEX process has surpassed POSCO's blast furnaces, which are considered among the most modern and economic BFs in the world.[312] In 2017, POSCO announced it had produced a cumulative 20Mt of hot metal (liquid iron) using the FINEX process.

[309] Metso, Circored Process
[310] MIDREX, 2023 World Direct Reduction Statistics, 2024
[311] Primetals, FINEX: Innovative and Environmentally Friendly Ironmaking
[312] POSCO, Discover the Technology that is Making Steel Production More Sustainable, 06 May 2017

In February 2024, POSCO announced the opening of its Hydrogen Reduction Ironmaking Development Centre at its Pohang steelworks.[313] The centre will develop POSCO's **HyREX** process, which adopts the multi-stage fluidised bed reactor technology of FINEX, but uses green hydrogen as the reducing agent, replacing non-coking coal - see Figure 2.4.

Figure 2.4: POSCO HyREX Iron Reduction Process



Source: World Steel [314]

POSCO is building a 0.3 Mtpa demonstration plant of its HyREX technology in Pohang, Korea, set to begin production in 2027, followed by a commercial-scale plant to verify the technology by 2030. The DRI product of HyREX will be then further refined in an EAF or further reduced in an ESF depending on the ore input. POSCO's design allows it to incorporate its DRI technology with third-party smelter manufacturers.

As highlighted in Figure 2.4 above, POSCO is demonstrating its HyREX process' performance in an ESF, supplied by SNNC, a ferronickel manufacturer jointly established by POSCO and SMSP, the largest nickel exporter in New Caledonia.

Boston Metals

Boston Metals is developing a molten oxide electrolysis (MOE) process that will use renewable energy to reduce all grades of iron ore to high Fe content liquid metal. Electrochemical reduction bypasses coke production, iron ore sintering and pelletisation, blast furnace reduction and BOF refinement, with the product able to be refined in an EAF.[315]

In the MOE process, an inert anode is immersed in an electrolyte containing iron ore, then electrified. The cell is heated to ultra-high temperatures of 1,600ºC. As the cell heats, the electrolyte comprising silica and alumina melts and dissolves the iron oxide. Iron ore is reduced from the charge applied across the electrodes, with molten iron forming around the

[313] POSCO, POSCO Takes a Significant Step Towards Realising the Dream of Hydrogen Reduction Ironmaking, 02 February 2024
[314] World Steel, Update on the Development of POSCO's HyREX, 05 September 2023
[315] Boston Metals, Decarbonising Steelmaking for a Net-Zero Future

cathode. The hot metal can then be tapped, leaving the impurities (e.g. acidic gangue) in the solution.

A schematic of the cell is available in Appendix F.

CEF notes this technology has been around for over a decade, and is supported by multiple funding rounds from the likes of BHP,[316] ArcelorMittal,[317] the World Bank, Microsoft's Climate Innovation Fund, and Saudi Aramco, but there have been no plants built. Boston Metals have constructed an MOE facility in Minas Gerais, Brazil, focussed on the extraction of 'high-value metals' from mining waste i.e. not iron. After massive capital funding rounds for 12 years, it is problematic that no steel supply chain participant has backed even a steel-specific pilot plant. A key issue is the significant energy requirements of electrochemical reduction, in addition to the low technology readiness of electrolysis reactors and its ability to operate flexibility with raw material fluctuations. In addition, Boston Metal's proprietary inert anode is not as inert as needed for the process.

[316] Boston Metals, Boston Metals Raises $50m to Decarbonise Steelmaking, 11 January 2021
[317] Boston Metals, Boston Metals Closes $262m Series C Funding Round, 06 September 2023

Appendix

A . MIDREX DRI Flowsheet

FIGURE 1.
The MIDREX® Reformer

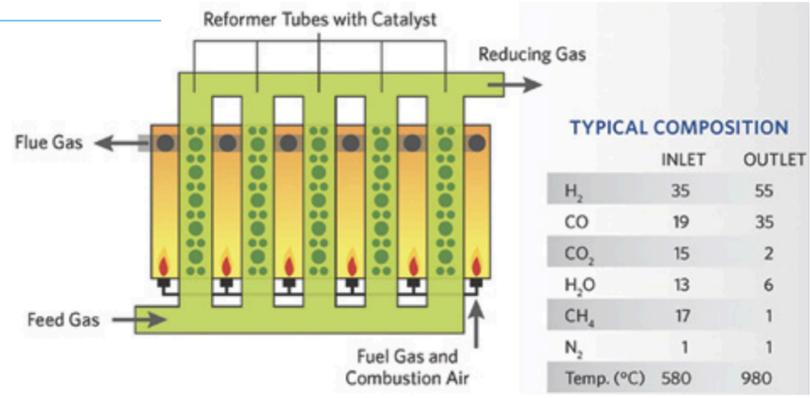
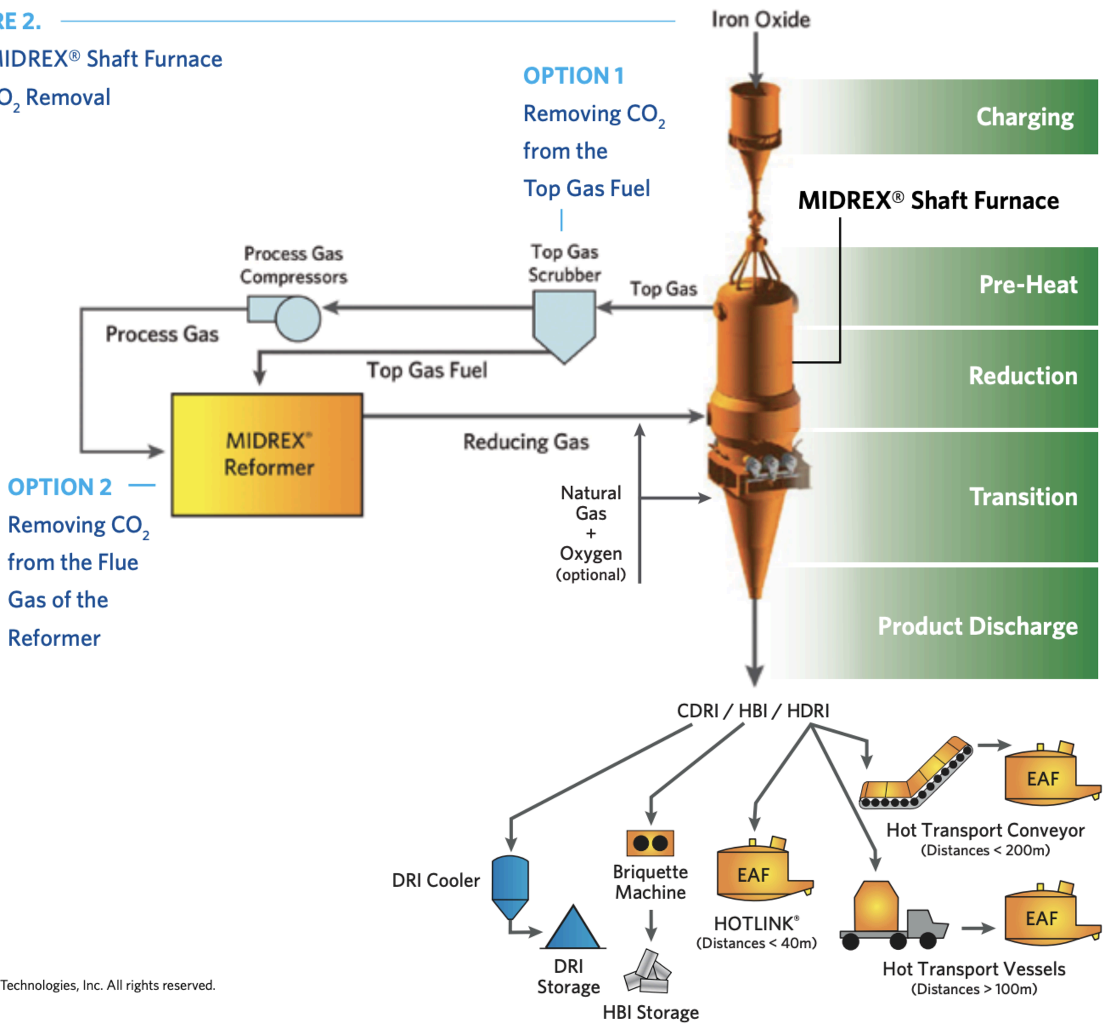


FIGURE 2.
The MIDREX® Shaft Furnace and CO_2 Removal

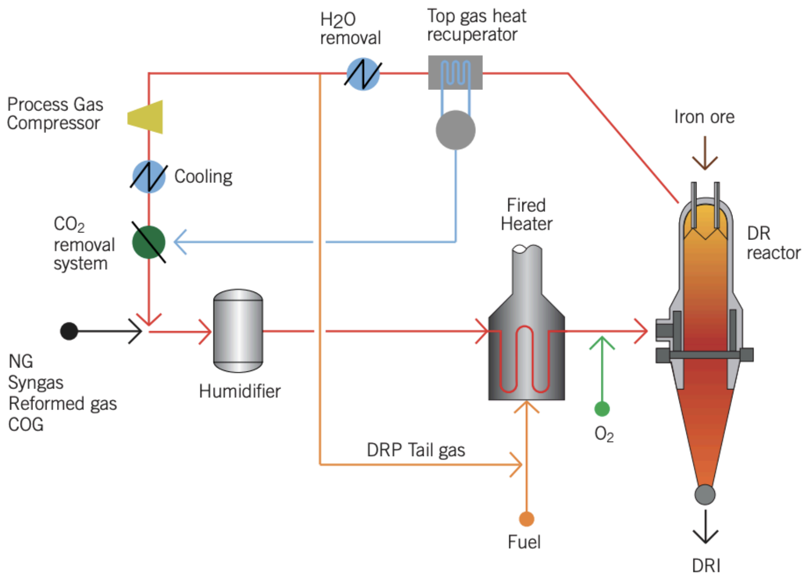


Source: MIDREX [318]

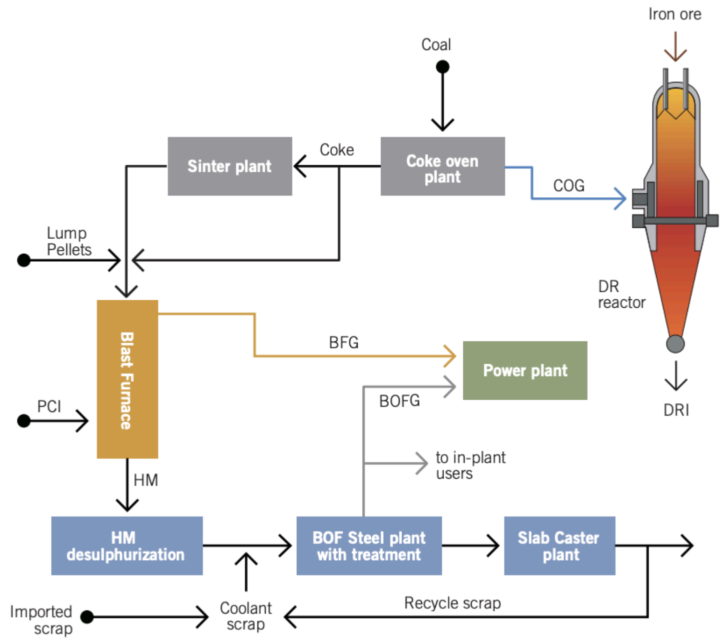
[318] MIDREX, Ironmaking Technology for a Sustainable Steel Industry, 05 June 2023

B. Danieli's Energiron Process

Standard ENERGIRON process flowsheet.



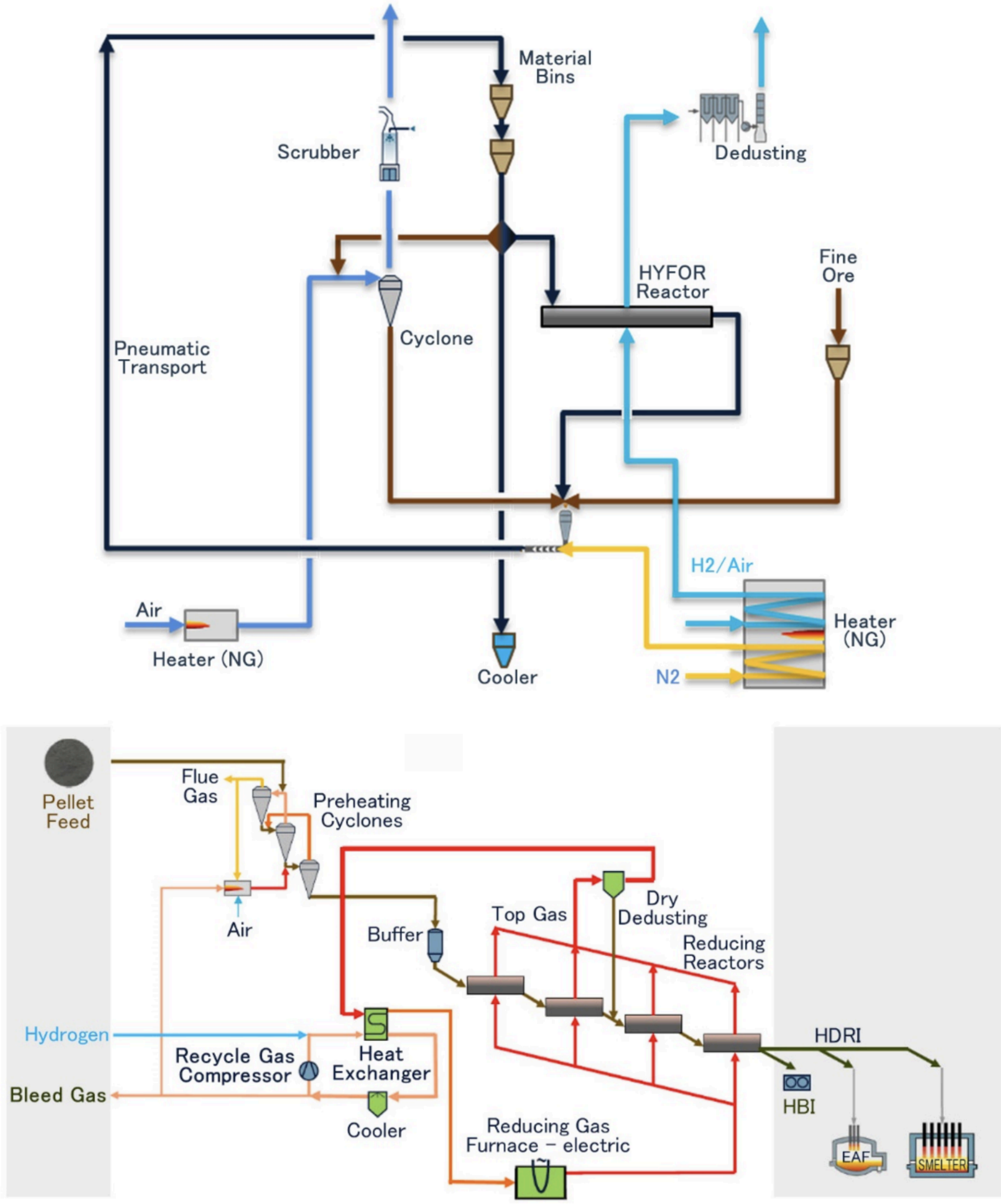
ENERGIRON DR plant flowsheet for integrated iron making plant.



Source: Danieli [319]

[319] Danieli, Energiron/HYL: DRI Technology by Tenova and Danieli, January 2020

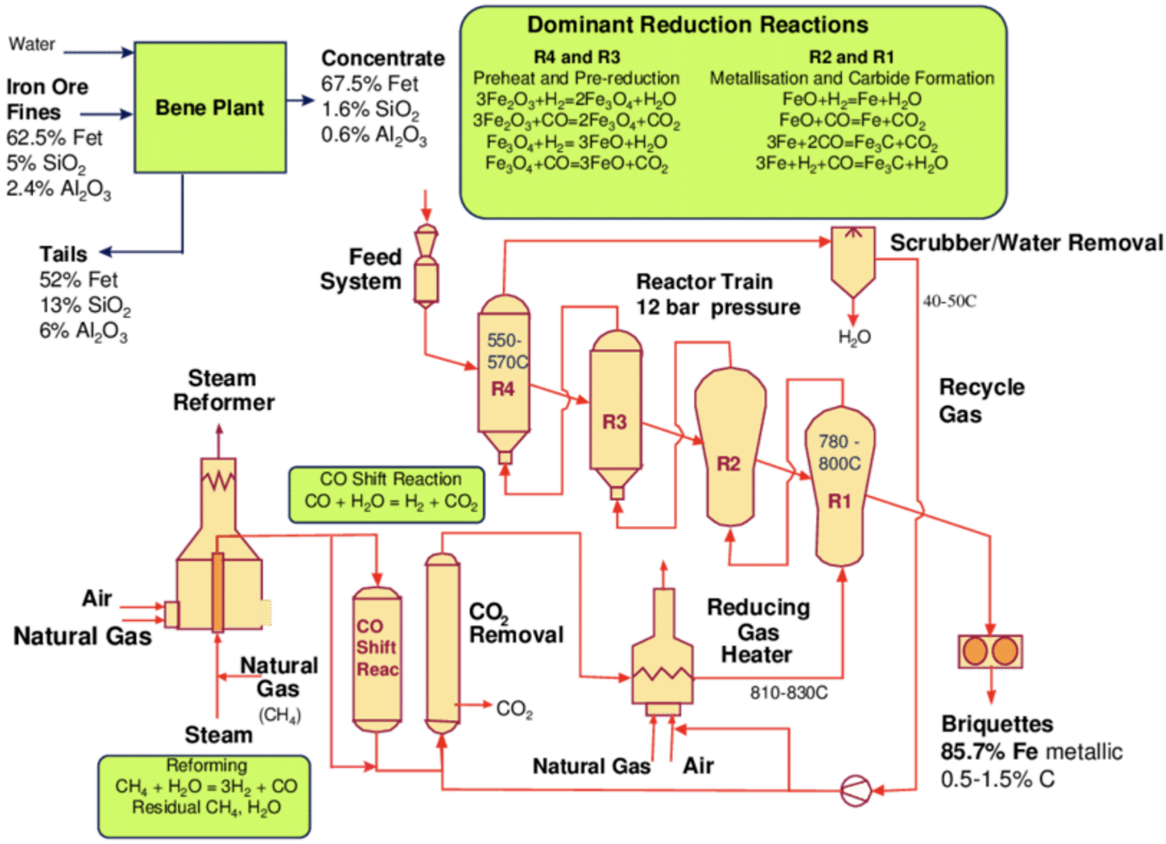
C. Primetal Technologies' HYFOR Process



Source: Mitsubishi Heavy Industries [320]

[320] Mitsubishi Heavy Industries, HYFOR - Hydrogen-based Fine ore Reduction, June 2022

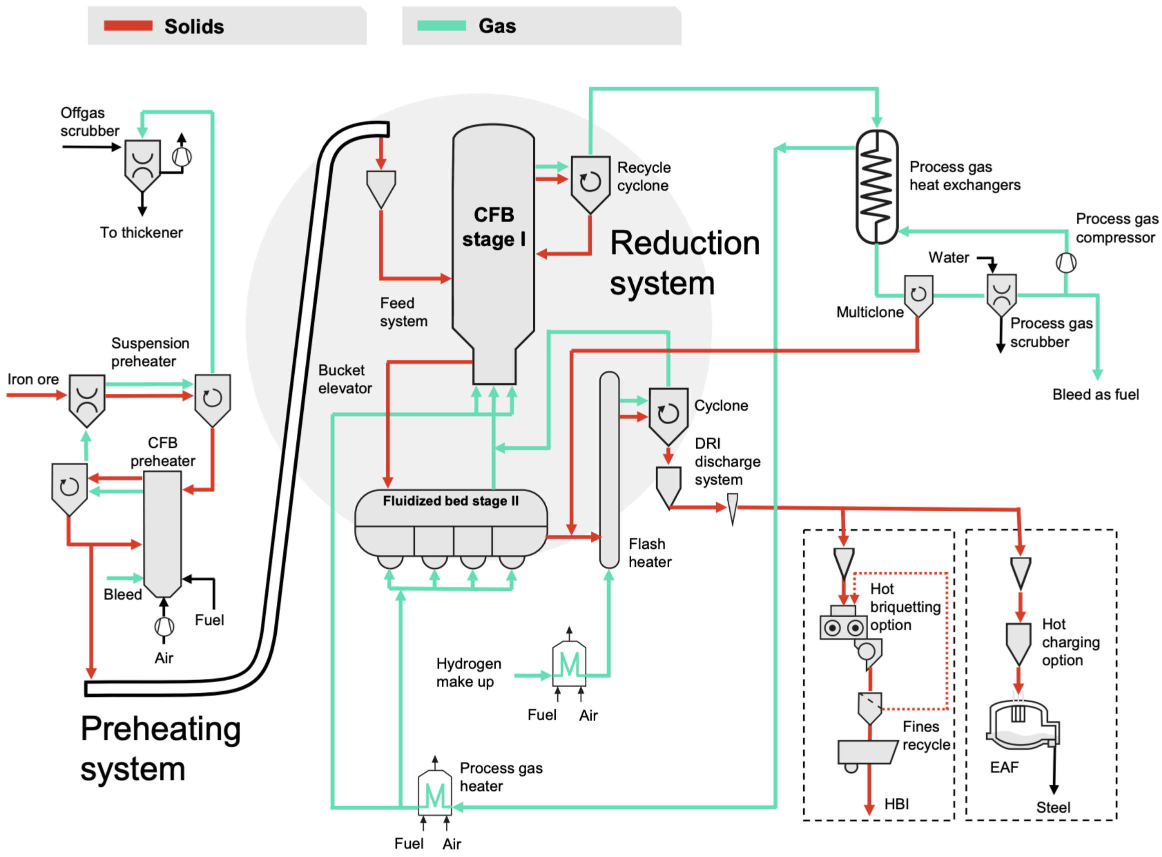
D. Primetal Technologies' FINMET Process



Source: AusIMM International Conference[321]

[321] AusIMM, Port Hedland FINMET Project - Fluid Bed Production of High Quality Virgin Iron for the 21st Century, September 1997

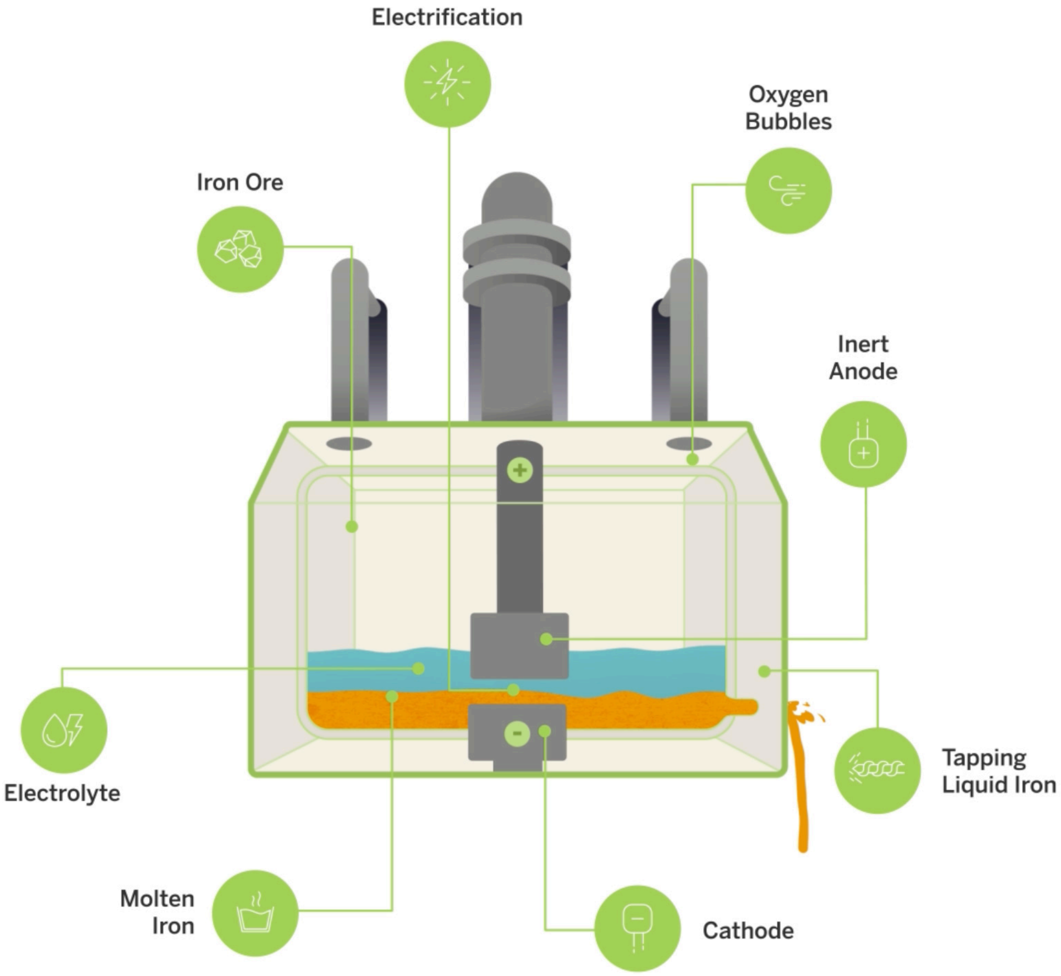
E. Metso Outotec's Circored Process



Source: Metso [322]

322 Metso, Fine Ore Direct Reduction: Circored

F. Boston Metals Molten Oxide Electrolysis Schematic



Source: Boston Metals [323]

[323] Boston Metals, [Decarbonising Steelmaking for a Net-Zero Future]

G: CEF Estimates of Key Green Iron Production Factors

CAPEX (per Mt)	Factor	Value	Unit
	DRI Plant	450	$m
	PEM Electrolyser	1,000	$m
	Energy	2,500	$m
	Total	**4,000**	**$m**

Electrolyser Capacity (per Mt)	Factor	Value	Unit
	Low Hydrogen Use	496	MW
	High Hydrogen Use	698	MW

Energy Demand (per Mt)	Factor	Value	Unit
	Low Hydrogen Production	3.0	TWh
	High Hydrogen Production	4.3	TWh
	Iron Heating	450	GWh
	DRI Operating	95	GWh
	Briquetting	10	GWh
	ESF Smelting	480	GWh
	Total (Low H2)	**4.1**	**TWh**
	Total (High H2)	**5.3**	**TWh**

Water Consumption (per Mt)	Factor	Value	Unit
	Water Intensity	25	L/kg H2
	Water Use (Low H2)	1.35	GL
	Water Use (High H2)	1.90	GL

H. ARENA Funding Awards for Hydrogen and Low-Emission Iron & Steel Research

Entity	Project	ARENA ($m)	Project ($m)
The University of Wollongong	Australian Pilbara Iron Ores in an Electric Smelting Furnace Process	2.0	4.2
Australian National University	De-risking large-scale Australian fine-ore hydrogen ironmaking	4.8	13.7
The University of Newcastle	Electric Smelting of Australian Hematite–Geothite DRI	2.9	5.9
MIH2 Pty Ltd (subsidiary of FFI)	Low Temperature Direct Electrochemical Reduction for Zero Emissions Iron	5.0	42.6
HILT CRC Limited	Upgrading Iron Ore for DRI Production Using Seawater Reverse Osmosis Brines Project	1.4	5.7
Macquarie University	Upcycling of steelmaking slag for material reuse	1.5	7.2
CSIRO	Low temperature iron ore agglomeration process for Australian iron ores	2.6	5.3
University of New South Wales	Blast Furnace Innovations: Integrating New Injections & Burdens for Sustainable, Low-Carbon Ironmaking Transitions	4.4	18.1
Iron & Steel Funding Round		**24.6**	**102.7**
Future Energy Exports CRC Limited	Development and demonstration of safe, efficient hydrogen liquefaction through optimised mixed refrigerants and plant design	2.1	6.3
Cavendish Renewable Technology Pty Ltd	Efficient, scalable and modular ammonia to hydrogen/electricity conversion system development and demonstration	1.6	4.3
Hysata Pty Ltd	High-temperature, Ultra-high Efficiency Green Hydrogen Production	3.0	5.9
Curtin University	Hydrogen export using a powder	5.0	16.5
Monash University	Lowering the cost of proton exchange water electrolysis systems	2.3	7.2
Australian National University	Accelerating the Commercialisation of the Direct Solar-to-Hydrogen Technology	2.2	7.5
University of Melbourne	Mega-Scale Liquid H2 Storage with Super-Insulated Full-Containment and Zero-Boil-Off	3.1	6.6
The University of Sydney	Advanced Manufacturing Alkaline Electrolyser Cell-Stacks for Affordable and Scalable Green Hydrogen Production	2.2	5.9
University of New South Wales	Production, Multiphase Electrolysers for Renewable Ammonia Production	1.9	7.2
Australian National University	H2 storage enabled by nano-scaffolded gas hydrate capsules with ground-source energy utilisation	1.4	5.5
Jupiter Ionics Pty Ltd	Capital Cost reduction in electrochemical ammonia synthesis	2.5	6.5
RMIT	Solar-Energy-Driven Modular Floatable Device for Scalable Green Hydrogen Production from Wastewater	2.0	5.9
MIH2 Pty Ltd (subsidiary of FFI)	Scale up and demonstration of next generation CSIRO axial flow electrolyser for green hydrogen production	4.9	14.3
Hydrogen R&D Funding Round		**34.2**	**99.6**
Total Funding Round to Iron, Steel and Renewable Hydrogen R&D		**58.8**	**202.3**

Source: ARENA [324]

[324] ARENA, Funding Boost for Hydrogen and Low Emission Iron & Steel Research, 10 April 2024

I. HILT CRC Iron & Steel Projects

Program	Project	Start	End	Cost (A$)
RIP1.001	Understanding and eliminating adverse materials behaviour during and after direct reduction in shaft and fluidised bed processes	12-Jul-22	31-Aug-23	329,006
RP1.003	Scoping study assessing potential of clay, bauxite residue and iron making by-products for producing alternative construction materials for HILT CRC partners	15-Apr-22	31-Jul-23	526,963
RP1.004	Impact of hydrogen direct reduced iron melting in an electric furnace	01-Apr-22	30-Jun-23	401,642
RP1.005	Hydrogen Ironmaking: fluidised bed H_2DRI with Australian focus	01-Apr-22	30-Jun-23	405,912
RP1.006	Scoping study of the viability of high flux thermal pre-treatment of low-grade iron ores for improved liberation, beneficiation, and quality	01-May-22	30-Apr-23	420,371
RP2.001	Green hydrogen supply modelling for industry	01-Apr-22	30-Sep-22	120,456
RP2.002	Assessing carbon utilisation and recycling opportunities for the Australian heavy industry sector from a regional hub perspective	01-May-22	30-Jun-23	515,705
RP2.003	Green Heat for Industry	01-Apr-22	31-Mar-23	812,652
RP2.005	Hydrogen utilisation in industrial processes: understanding technical risks and impacts on demand	01-Jun-22	31-May-23	425,900
RP3.001	Review of regional hub development and the transition to a zero-carbon heavy industry	31-May-22	31-Mar-23	356,375
RP3.002	Lifecycle Analysis of current Australian heavy industrial processes	31-May-22	30-Apr-23	391,300
RP3.003	Review of trade and regulatory implications and emerging international government and trade policies in relation to emission-reduction objectives	31-May-22	30-May-23	348,142
RP3.004	Intermediate product exports for Australia-China green steel	01-Jun-23	31-Aug-24	487,489
RP2.006	Hydrogen supply within HILT regional hubs – H2 cost and synergistic opportunities	01-Jun-23	31-May-24	617,682
RP1.008	Green pyromet/hydromet beneficiation pathways	01-Jun-23	31-May-24	1,047,024
RP2.010	Utilisation of refuse-derived fuel in industrial processes: understanding the value proposition, risks and supply chains	01-Aug-23	31-May-23	353,025
RP1.009	Testing of Australian iron ores in a hydrogen direct flash smelting process	01-Jun-23	29-Feb-24	574,693
RP3.005	Market, cost and locational factors for green iron and steel in Australia	01-Jun-23	31-Aug-24	525,136
RP1.010	Hybrid hydrogen direct and plasma reduction of Iron Ore	01-Jun-23	31-Aug-24	530,483
RP2.007	Feasibility combustion study to identify challenges and opportunities for hydrogen into iron and cement sectors	01-Jun-23	31-May-26	1,848,868
RP2.008	Lost production and variability	01-Jun-23	31-May-24	289,219
RP1.012	Prevention of sticking in H2 fluidised bed DRI production	01-Oct-23	30-Sep-26	2,762,162
RP1.011	Upgrading iron ore for direct reduced iron production using products from seawater reverse osmosis brines	01-Aug-23	21-Jul-24	622,000
RP2.009	Advancing the viability of high temperature Thermal Energy Storage for industrial applications	01-Jul-23	30-Jun-23	924,324
RP3.006	Certification and verification to enable a successful low-carbon transition for heavy industry	01-Mar-24	28-Feb-27	1,216,691
RP2.012	Opportunities for Bioenergy in Australian heavy industry	01-Jan-24	31-Aug-24	340,584
RP2.013	Integrated CO2 capture and sequestration through mineral carbonation	01-Apr-24	31-Mar-27	3,156,172
RP2.014	Low-cost reliable green electricity supply for low-carbon heavy industry	01-Mar-24	28-Feb-25	174,430
RP2.016	Physical and chemical properties of ores associated with new processing technologies	01-Sep-24	31-Aug-26	1,173,990
				21,698,396

Source: HILT CRC [325]

[325] HILT CRC, Projects: Iron & Steel