Green iron trade

Unlocking opportunities for Japan

December 2025

Agora Industry

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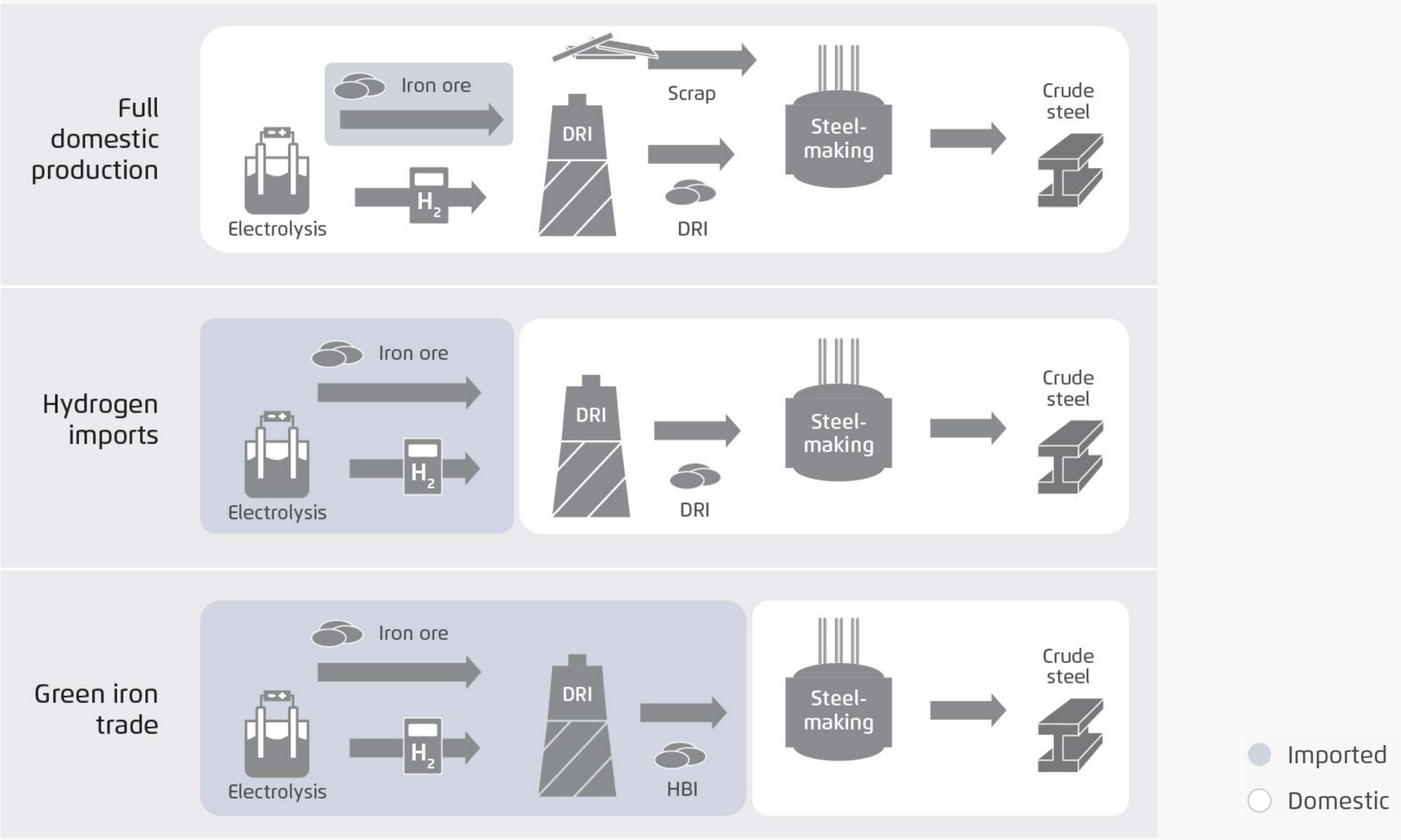
Key Findings

1. **The steel industry accounts for around 12 percent of Japan's total carbon dioxide emissions and remains vital to the country's economic competitiveness, energy security and technological leadership.** Investing in the transition to green steel is both a climate necessity and a strategic opportunity to safeguard jobs, strengthen industrial value chains and position Japan as a leader in clean industrial innovation.
2. **For Japan, importing green iron from regions rich in iron ore and renewable energy offers the most cost-competitive and feasible pathway to decarbonise primary steel production.** By importing green iron, Japan could cut steelmaking costs by 12 to 15 percent by 2040. The partial decoupling of energy-intensive ironmaking from downstream steel production could enable a cost-competitive transformation of Japan's steel sector while contributing to the global transition through international green iron supply chains.
3. **Developing green iron import value chains anchored in transparent standards, traceable certification and credible life-cycle carbon accounting will be key to establishing Japan's role as a clean steel manufacturing hub.** Although several demand-side measures have been introduced to stimulate green steel markets, the current mass balance-based definition should evolve into a standard that emphasises transparency, traceability and additionality, supported by standardised life cycle assessments and carbon metrics to enhance credibility and global alignment.
4. **Strategic partnerships with key green iron-exporting countries such as Australia, Brazil and South Africa are essential to unlock investment and enable large-scale trade.** These partnerships should combine long-term offtake agreements, harmonised product criteria and de-risking instruments to attract finance, ensure price stability and accelerate the emergence of a global market for green iron.

Green steel supply chains: a diversified approach

The value chain shifts for exporters and importers from iron ore to green iron

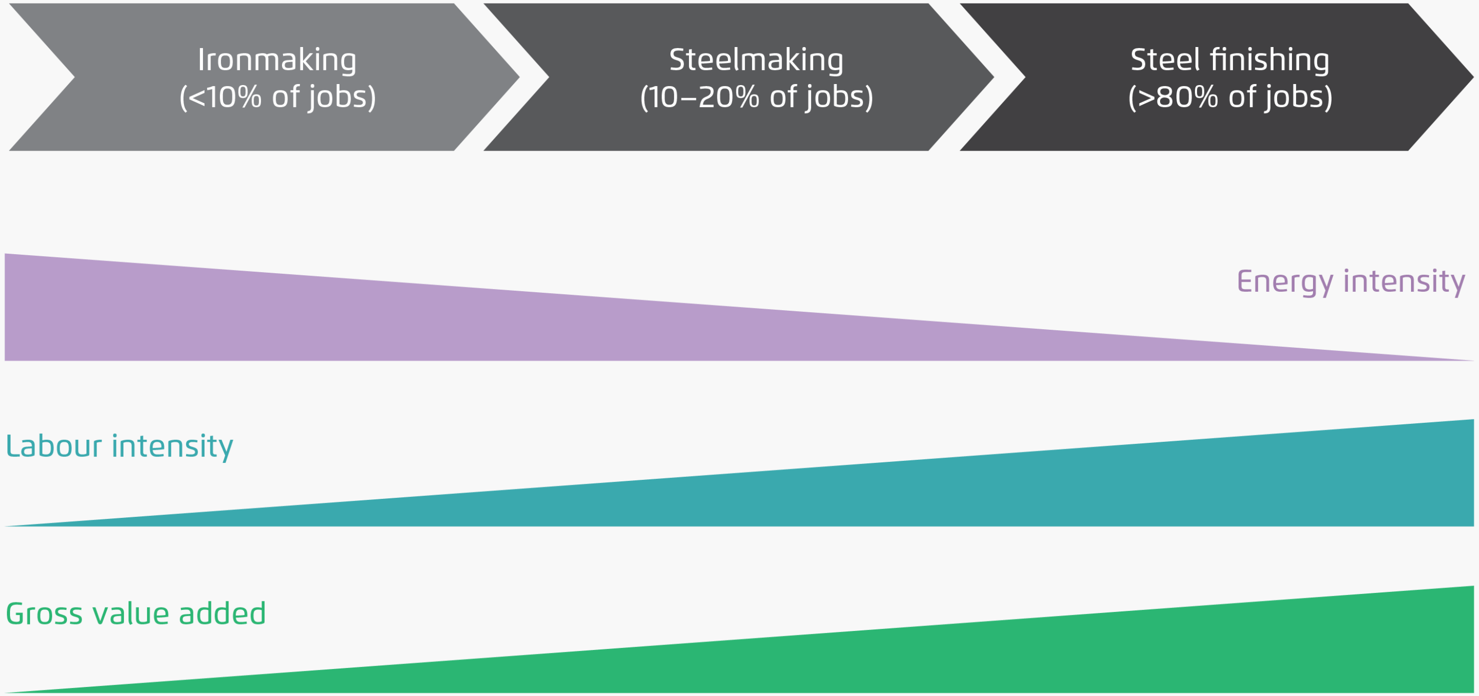


- → Producing green steel via DRI shifts the energy inputs from coal to clean electricity and H_2.
- → Green iron can be shipped as HBI, complementing domestically sourced metallic inputs (iron and steel scrap) and thereby providing steelmakers some flexibility in their raw material inputs compared to the integrated BF-BOF route.
- → This reduces the demand for domestic or imported H_2 and associated renewable energy and infrastructure.

Adapted from Verpoort et al. (2023).
Steelmaking refers to either the EAF process when DRI uses DRI-grade (high-grade) iron ore, or to the Smelt-BOF process if lower-grade iron ore is used for DRI production.
For more information on low-carbon iron production, refer to Agora Industry (2024).

Around 90 percent of jobs in the steel sector are in the more labour-intensive steelmaking and steel finishing sectors

Downstream steelmaking is also less energy-intensive and delivers higher gross value added



 | [1] Steel sector and downstream steel finishing share of employment calculated based on WV Stahl (2025), Statistisches Jahrbuch der Stahlindustrie 2024/2025.

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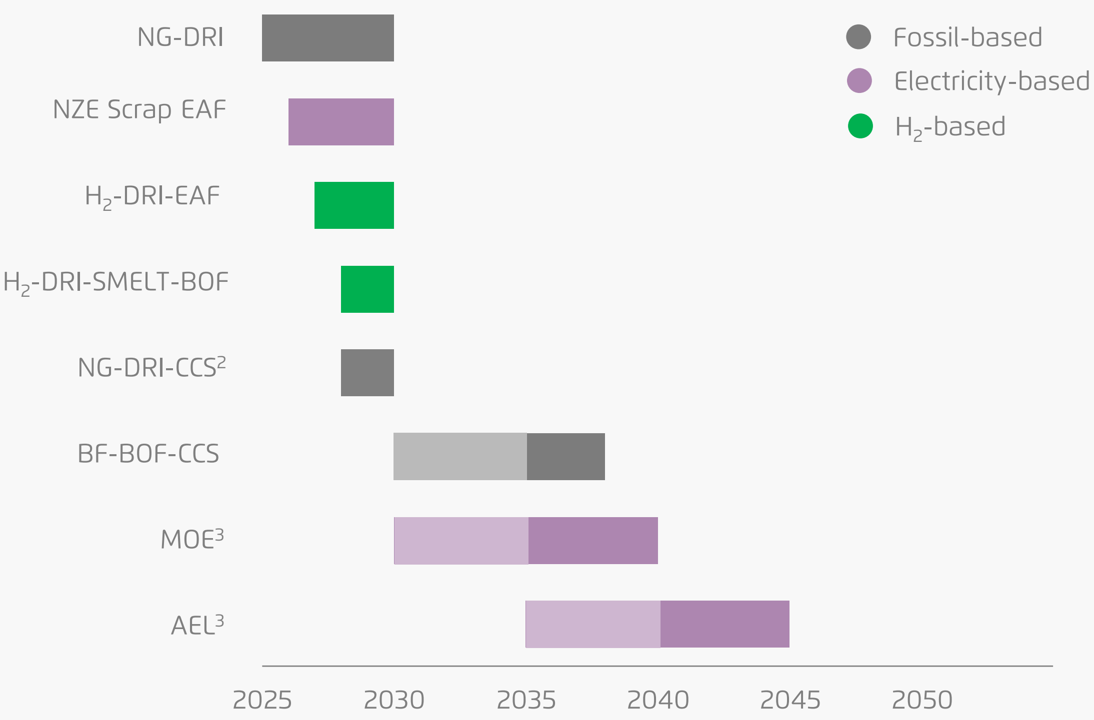
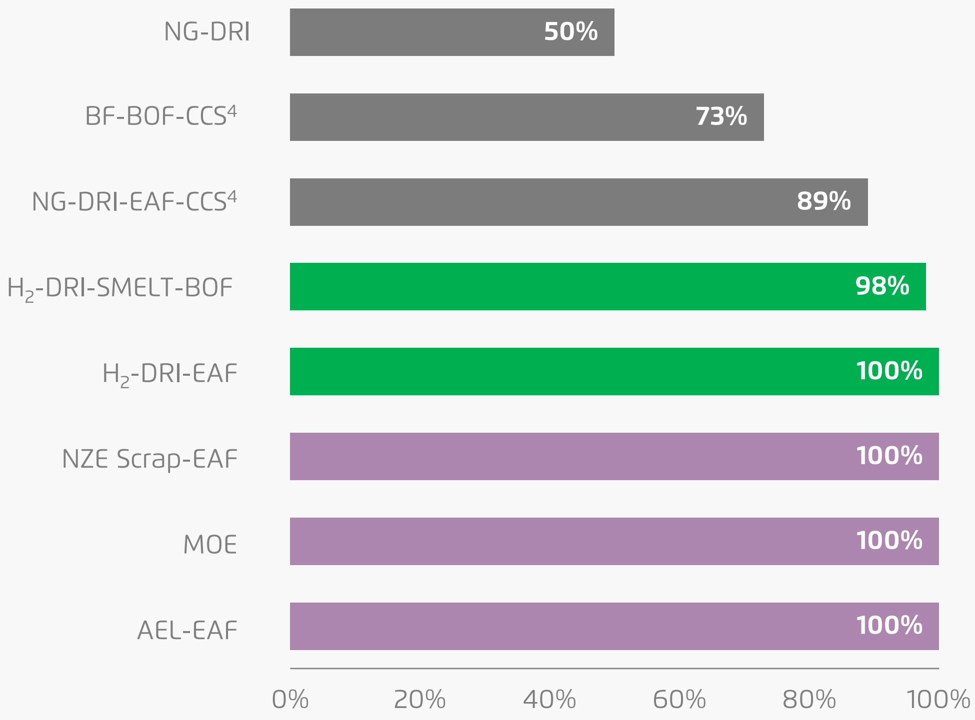
Next-generation steelmaking

By 2030, mature technologies like scrap-based EAF and H_2-based DRI routes will drive the decarbonisation of the steel sector

Expected market readiness[1] of different breakthrough technologies for steelmaking

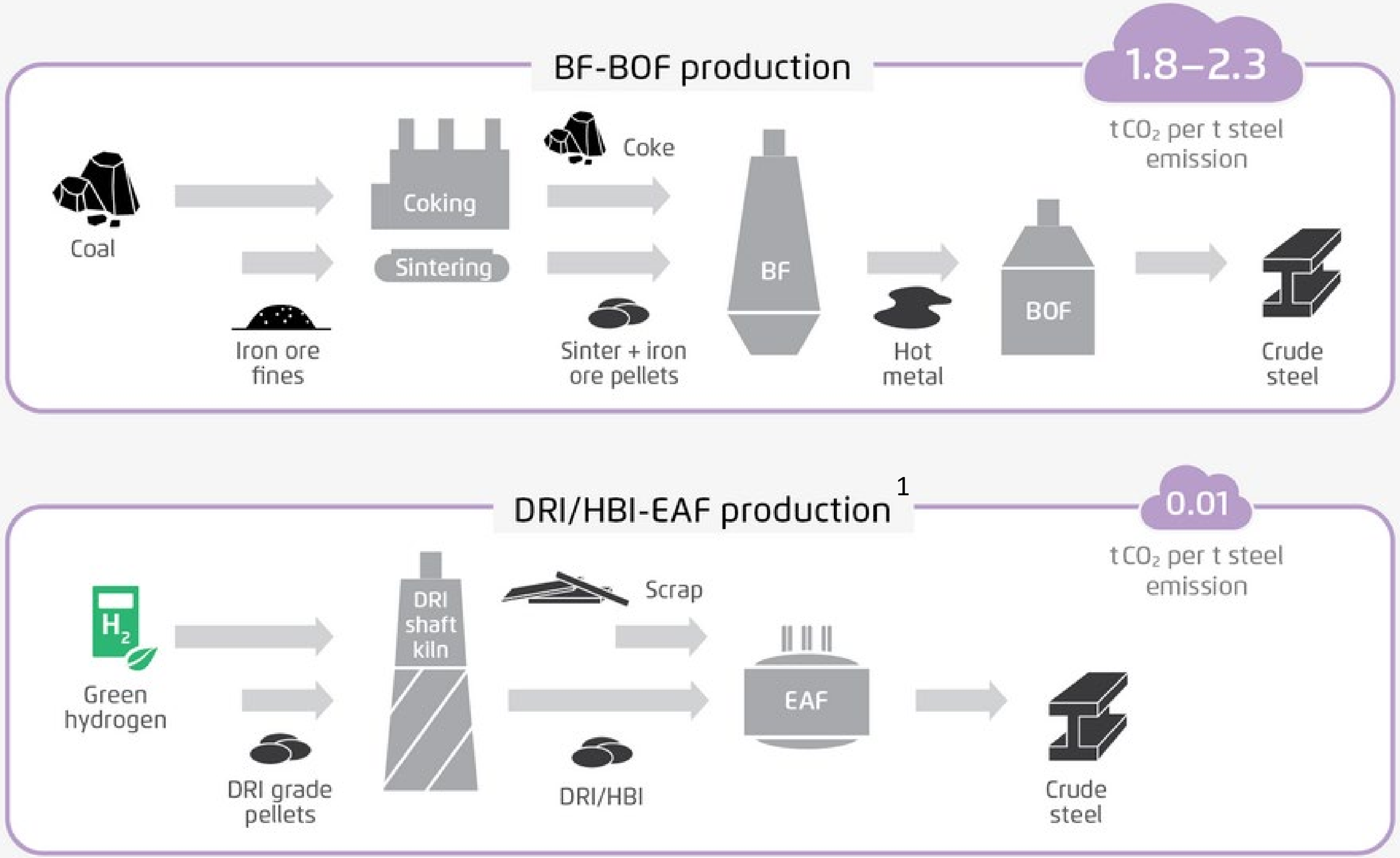


CO_2 abatement potential of different technologies compared to the integrated blast furnace route (BF-BOF)[4]



Agora Industry and Wuppertal Institute (2022, 2023). [1] Implies that TRL 9 is reached, marking the shift from small commercial trials to full market deployment. [2] Current commercial NG-DRI-CCS projects are not considered breakthrough technologies as they do not achieve large CO_2 emissions reduction rates. [3] Due to their low TRL at the time of modelling, MOE was not foreseen to reach market readiness before 2035 and AEL before 2040. [4] CCS calculations are based on ambitious assumptions. Achieving high CO_2 capture rates at a BF-BOF plant is technically and economically challenging due to the many CO_2 point sources at the site. Note that upstream methane emissions (beyond analysis scope) can substantially increase the full carbon footprint of steel, both for BF-BOF and NG-DRI with CCS.

DRI/HBI-EAF route can produce steel with just 0.01 tonnes CO_2 per tonne of steel – a fraction of emissions compared to conventional BF-BOF



 [1] The DRI-SMELT-BOF route (not pictured here) is another viable route for green iron trade, which is described further in Agora Industry and Wuppertal Institute (2023).

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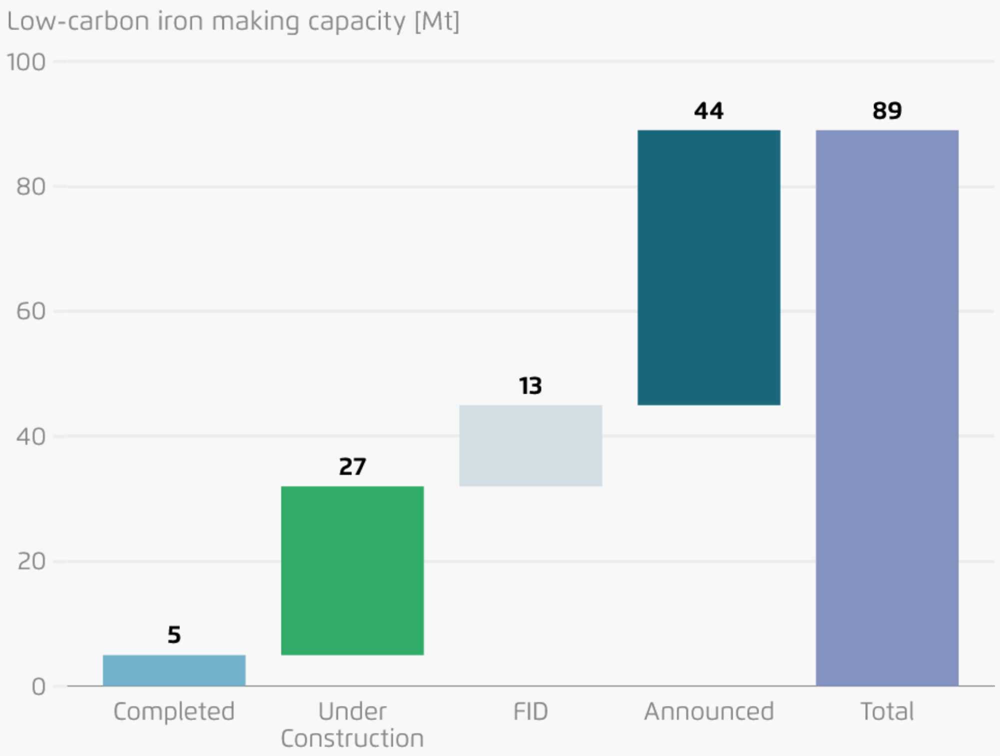
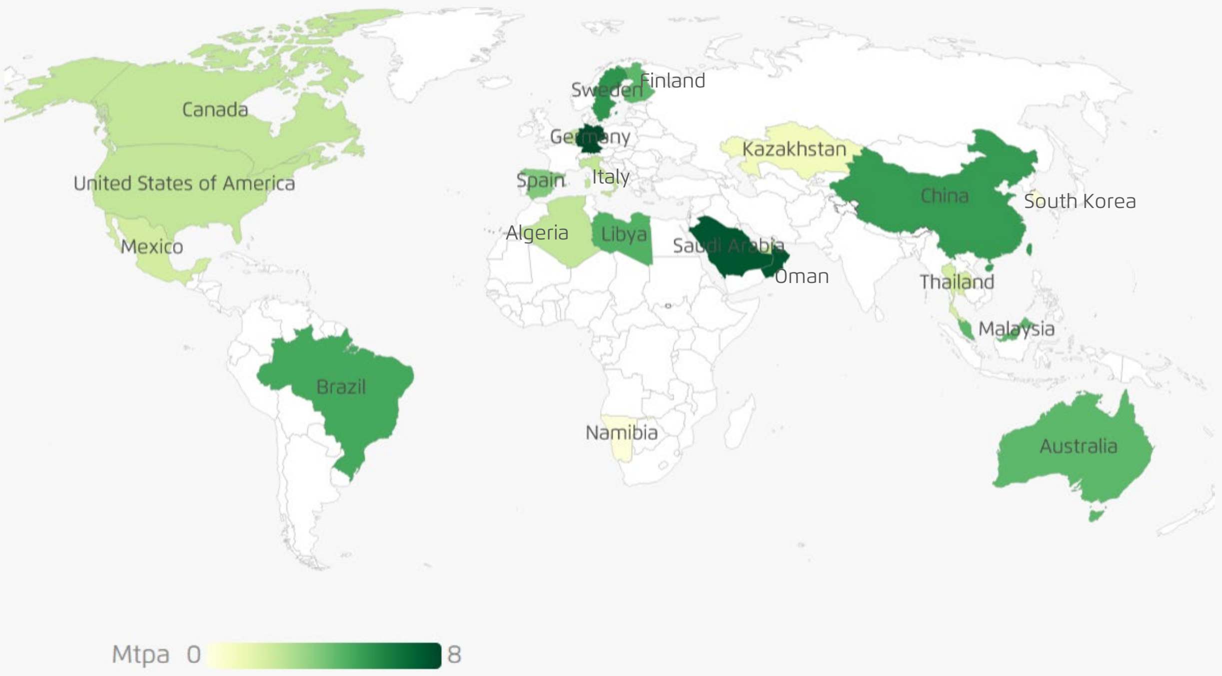
The transition to green steel is gaining momentum, with the EU and MENA region emerging as front-runners in the shift to H_2-DRI by 2030

2030 low-carbon steel announcement pipeline by project status



2030 low-carbon steel announcement pipeline by country



 Agora Industry (2025) Low-Carbon also includes announced projects that are initially based on fossil gas. The large majority of the projects have plans to switch to renewables based H_2 in the future but many have unspecified timelines on when that switch to H_2 will occur.

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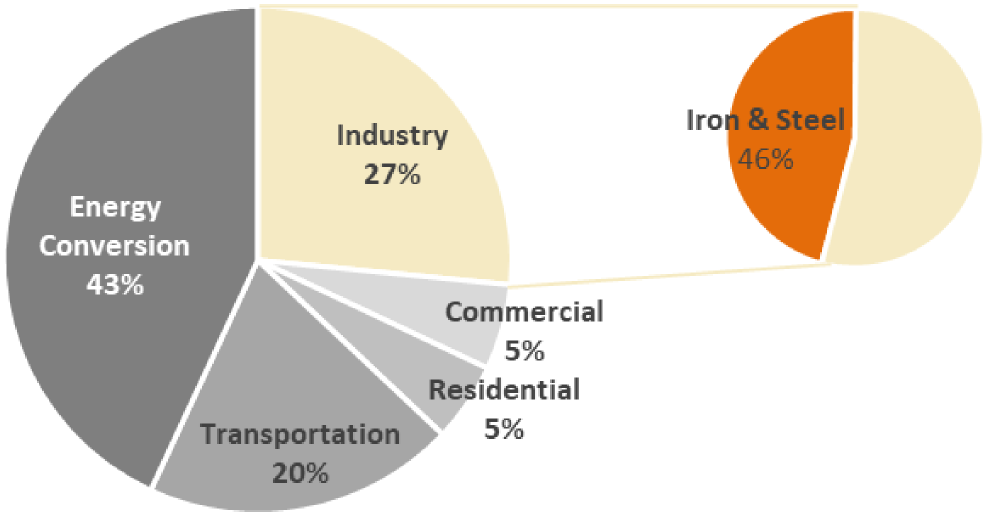
Opportunities of green iron trade: the case of Japan

A clean industrial strategy for green steel transition can strengthen the competitiveness of Japan's steel industry

- Japan accounted for 84 million tonnes of crude steel production in 2024 (third place globally)[1]
- Steel sector accounts for 46% of Japan's industrial emissions (FY 2023)
- Concentrated market with three major producers accounting for 74% of crude steel production in FY 2023[2]
- Shares of crude steel production: BF-BOF: 74% and EAF: 26% (2023)[3]
- 41% of steel production is being exported (crude steel based, FY 2023)[4]
- 9 of 19 coal-based blast furnaces (47%) will reach reinvestment decisions by 2030, 68% by 2035[5]



Source: National Institute of Environmental Studies, Direct emissions by sector

[1] https://worldsteel.org/data/world-steel-in-figures/world-steel-in-figures-2025/; [2] Crude strrl production: METI Statistics, 3majors' production: Matal Daily, teel Yer Book2024; [3] METI Statistics; [4] METI Statistics; [5] Based on materials released by each company and media reports

Japan's steel decarbonisation roadmap will be driven by 1) shift to EAFs, 2) partial reduction with hydrogen in BFs with CCUS, and 3) hydrogen reduction of iron

Major steel manufacturers plan shifts from BFs to EAFs by 2030

→ Nippon Steel 2.9 Mt; JFE 2 Mt

→ Government subsidising up to one third of CAPEX , with quality and emission reduction requirements

→ Imported HBI for EAFs becomes key

Hydrogen reduction in BFs with CCUS

→ R&D ongoing since 2008 with government support

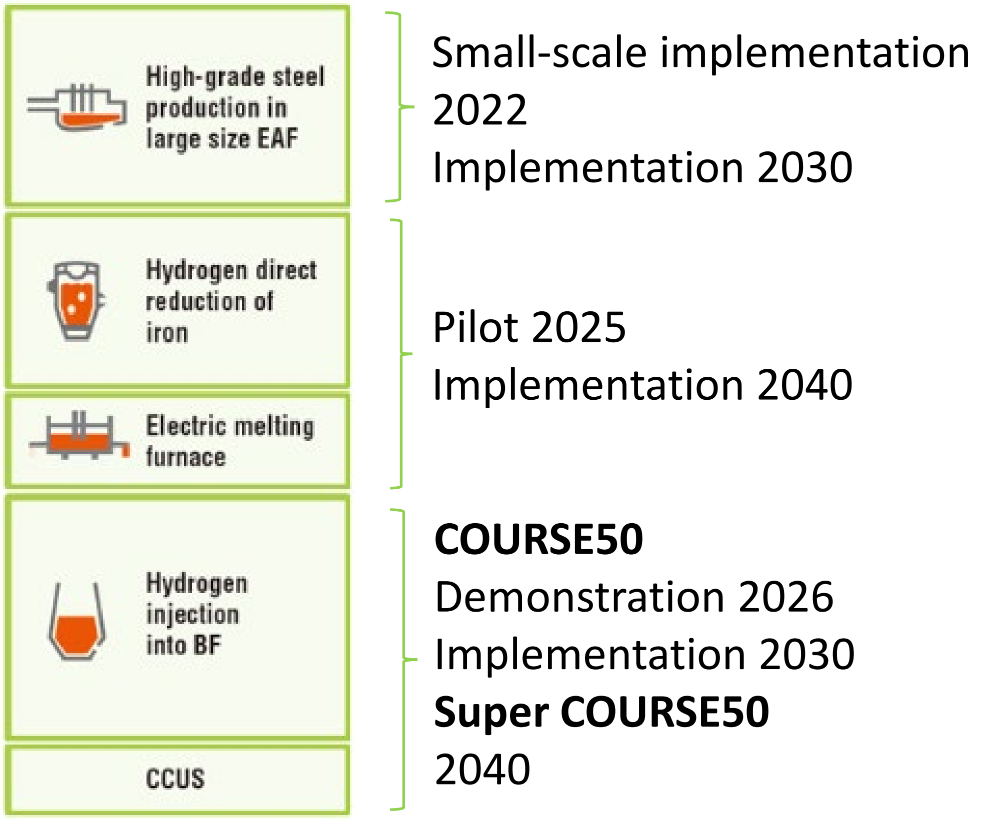
→ Project COURSE50 aims for 30% CO_2 emission reduction (10% by hydrogen; 20% by CCUS), project SuperCOURSE50 for -50%

→ Implementation of an existing BF from 2026

Hydrogen reduction of iron

→ R&D stage by 2030

Natural gas DRI in BF and EAF is being considered as transition technology

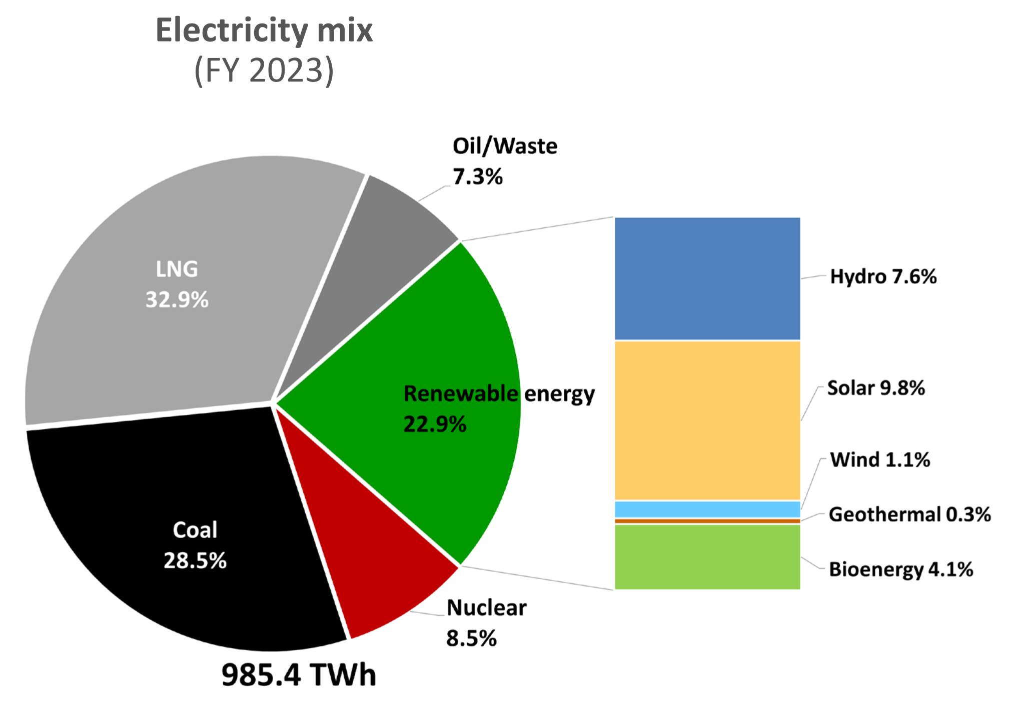


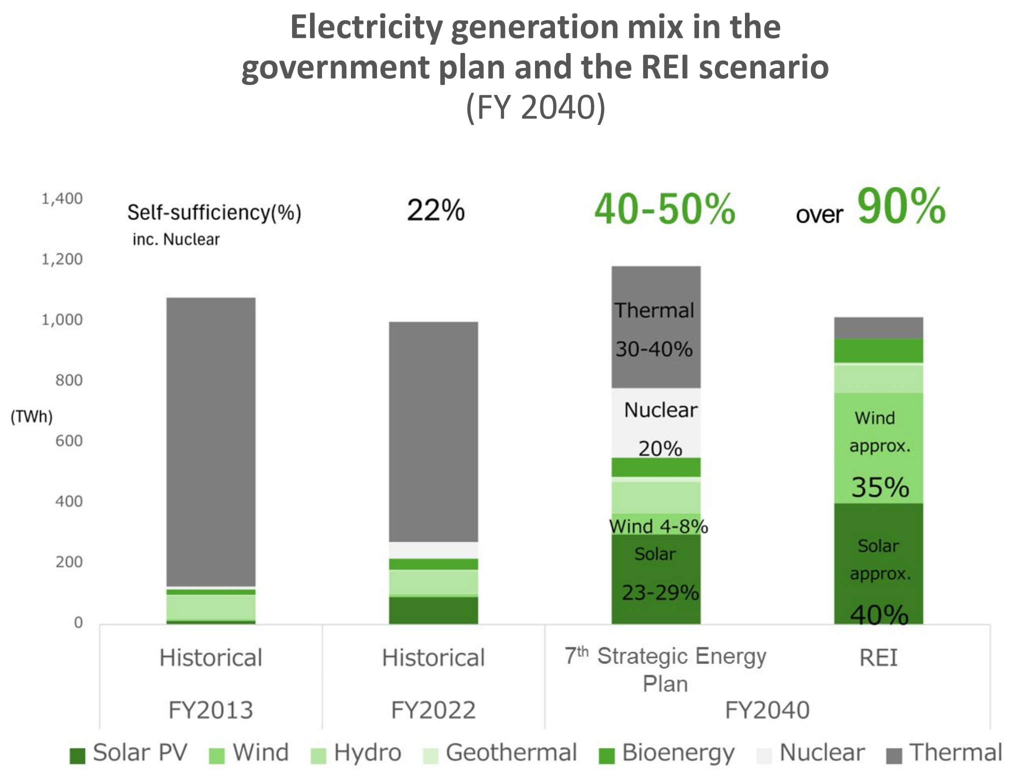
Source: Nippon Steel

Green Innovation in Steelmaking (2025): https://www.greins.jp/course50/en/research/, https://www.nipponsteel.com/en/csr/env/warming/zerocarbon.html
Kobelco (2025): https://www.kobelco.co.jp/english/releases/1211747_15581.html, https://www.jfe-steel.co.jp/en/release/2023/230718.html
Nippon Steel (2025): https://www.nipponsteel.com/common/secure/news/20250530_200.pdf

Expanding renewables in Japan's power sector can accelerate the decarbonisation of its steel industry

Renewable share of electricity generation (FY 2023); government and REI scenario for FY 2040





Source left: METI, Agency for Natural Resources and Energy.
Source right: Complied and edited by REI, referring to Agency for Natural Resources and Energy "The 7th Strategic Energy Plan" (Feb., 2025)
https://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/7th_outline.pdf

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Japan is also promoting the import of HBI, aimed at securing high-quality iron ore

→ **Investments for securing DRI-grade ores:** Major Japanese steelmakers and trading houses are securing high-quality iron ore through investments in Brazil, Canada and Australia for low-carbon steel production.

→ **DRI production plants**: Feasibility studies and memoranda of understanding (MOUs) for constructing large-scale DRI plants in Oman and UAE, involving Japanese BF steelmakers and trading houses.

→ **Strategic trade partnerships:** Investments into iron mines and DRI production infrastructure is key for securing DRI imports to Japan. However, more push is required to ensure the transition from fossil gas-based DRI to green hydrogen-based DRI through key partnerships.

Several demand-side measures have been initiated to create demand-pull for green steel

→ **Revised green procurement law (Jan 2025):** Japan's updated procurement law introduces the mass balance method for steel, requiring carbon footprint calculation and disclosure. Public procurement of green steel is encouraged as long as compliance requirements are met, supporting the adoption of low-carbon materials in government-funded projects.

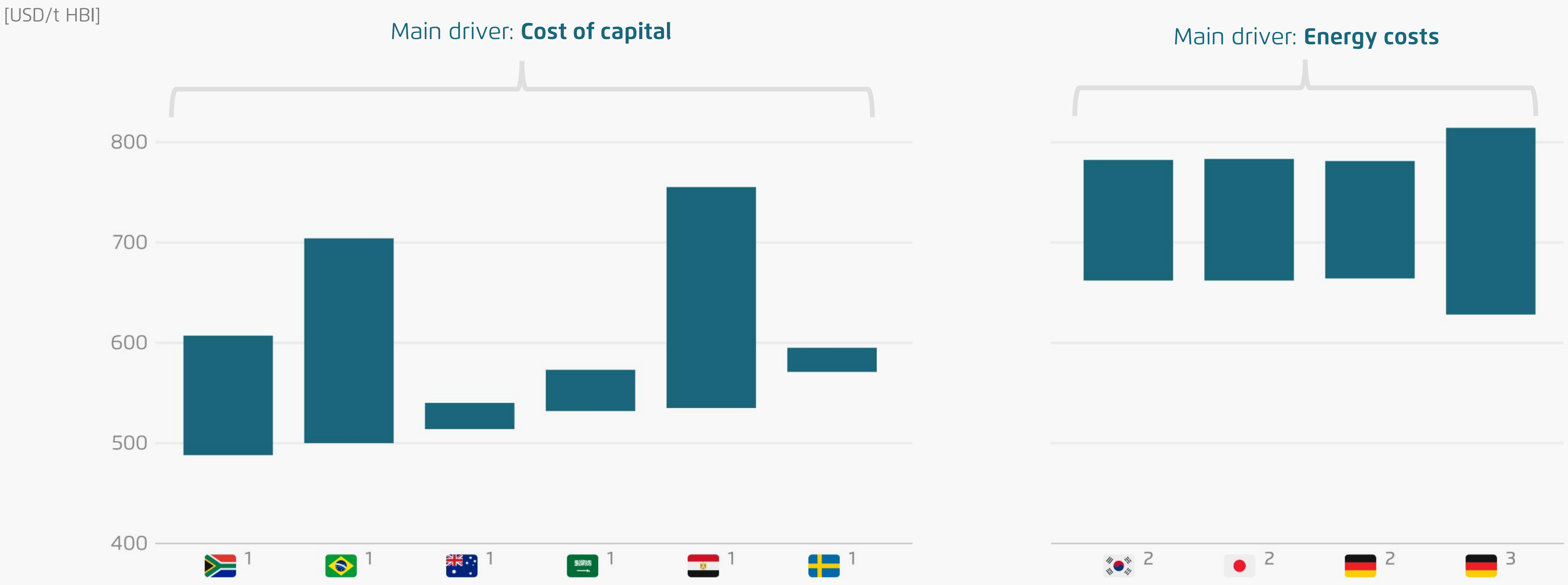
→ **Clean Energy Vehicle (CEV) subsidy:** To promote the use of green steel in the automotive sector, Japan provides an additional subsidy of up to JPY 50,000 per electric vehicle for automakers incorporating green steel, adding to the existing subsidy for electric vehicles (of up to JPY 850,000 per electric vehicle).

→ **GX leading implementation declaration (GX League):** Companies participating in the GX League and committing to low-carbon technologies gain strategic advantages in applying for GX subsidies, reinforcing Japan's push towards industrial decarbonisation.

→ **Mass balance steel**: Government definition of green steel currently uses a "mass balance approach" based on Japan's *Iron and Steel Federation* guideline.

Green HBI production costs are mainly driven by cost of capital in potential exporting countries and by hydrogen costs from high energy costs in potential importing countries

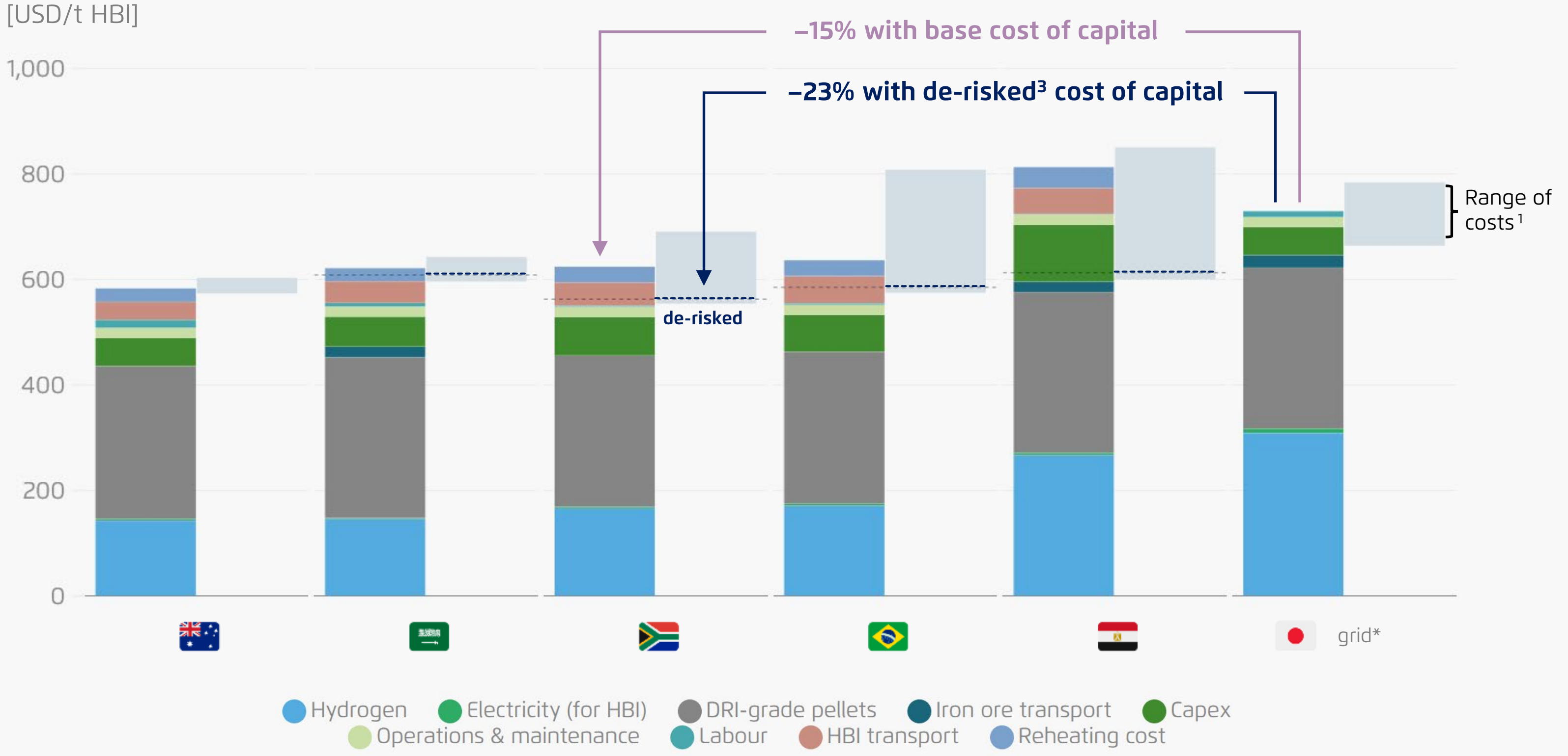
Range of HBI production costs in 2040



Agora Industry (2025). [1] driven by variable renewable energy; [2] grid-based electricity procurement; [3] hydrogen imports via pipeline from Tunisia (upper bound) and Denmark (lower bound). HBI production costs based on Oeko-Institut, Agora Energiewende and Agora Industry (2024): PtX Business Opportunity Analyser, version 2.0. For detailed information on the scenarios assessed, see slides in the Appendix.

Unlocking production in regions with high renewables potential could create significant cost-reduction opportunities

HBI production and import[2] costs in 2040 based on medium cost scenario

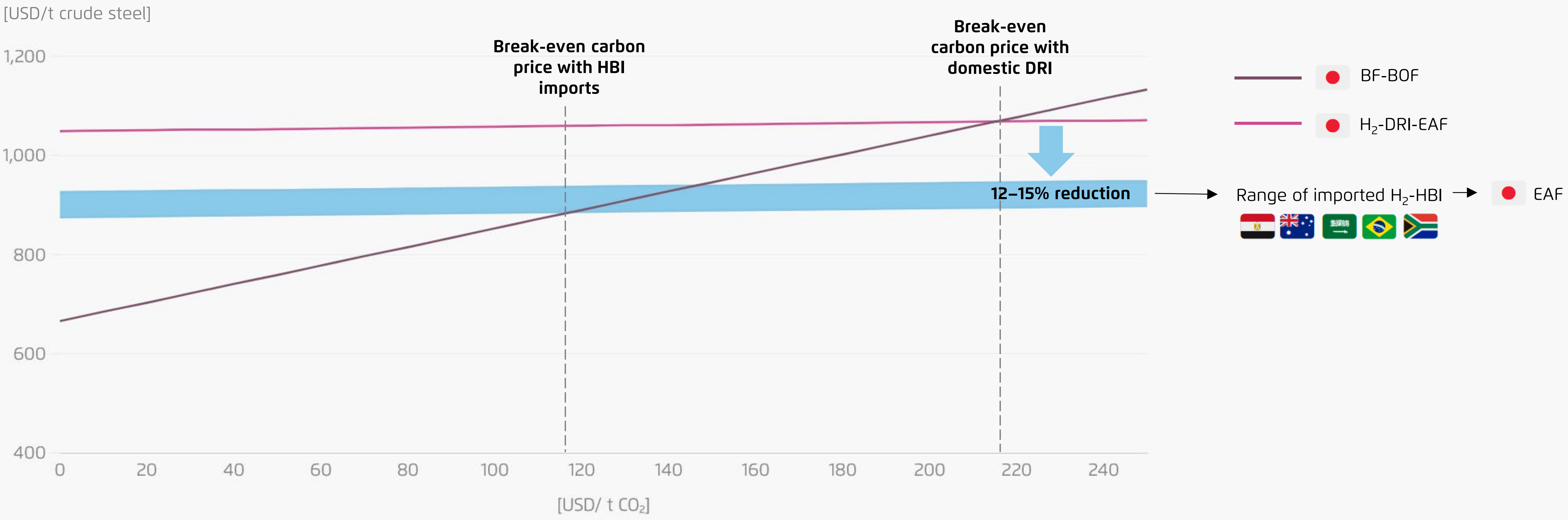


- → Projects in many exporting countries will need supporting derisking[4] measures to be developed.
- → As a global green iron market develops, access to cost-competitive HBI imports would enable more cost-effective steel production.
- → Using imported green HBI with up to 23% lower production costs can lead to a cost reduction of 15% of overall steelmaking in Japan, avoiding subsidy expenses of around USD 4.9 billion[5] by 2040.

Agora Industry (2025). *HBI production costs based on grid-based electricity procurement. [1] The light grey columns indicate the range of HBI production costs across low, medium, and high cost scenarios. [2] import costs include transportation and re-heating cold HBI; [3] de-risked cost of capital assumed to be 4.3%. [4] De-risking includes measures such as concessional finance and offtake contracts that result in lowering the cost of capital for investments in HBI production. For detailed information on the scenarios assessed, see slides in the Appendix. [5] Assuming that 33% of the projected steel production of 89 Mt by 2040 will come from HBI.

Green HBI imports from regions rich in iron ore and renewables could nearly halve the break-even carbon price needed for green steel to compete with BF-BOF in Japan

Crude steel production costs in 2040 using imported (de-risked)* and domestic HBI/DRI.
Importing HBI could cut 12 to 15% of steel production costs.



Agora Industry (2025). * De-risked cost of capital: 4.3%; production costs of green steel include: shipping costs of iron pellets and HBI, losses during transportation, cost of re-heating cold HBI as well as costs associated with higher tap to tap time by using cold HBI. For detailed information on the scenarios assessed, see slides in the Appendix.

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Japan policy recommendations

Key players must come together to create the enabling environment required to enable H_2-DRI project implementation

- National government & regulators
- Multilaterals (World Bank, UN bodies etc.)
- Think tanks / researchers
- Certification bodies (standards, MRV)

- HBI producer (steelmaker)
- Renewables / hydrogen developers (solar, wind, PPAs)
- Technology provider (electrolyser, DRI, etc.)
- Trading Houses (clean commodity supply chain)
- HBI off-taker / steelmaker (off-take agreement)
- Engineering firm (EPC, plant design)

- Local communities
- Labour / trade organisations
- Environmental & community NGOs

- Concessional finance (DFIs, MDBs)
- Equity investors (project consortium)
- Commercial debt provider (commercial banks)
- Export credit agencies

1) Domestic industrial policy: creating market confidence and support domestic H_2DRI commercialisation

1. **Create lead markets to drive business cases for green iron**
   - Use green public procurement and private sector incentives (e.g., embodied carbon limits, minimum green content) to drive early demand
   - Make GX-ETS and carbon pricing more robust to incentivise investment in low-carbon technologies
   - Develop a credible certification system moving beyond mass-balance, with transparent life cycle assessments and carbon metrics to support procurement and market alignment
   - Engage automotive, construction and manufacturing sectors in shaping standards to strengthen trust and market uptake

2. **Support domestic projects**
   - Continue and strengthen R&D on H_2DRI, with the aim of enabling domestic commercialisation
   - Support for domestic H_2DRI projects should be coupled with large-scale renewable energy initiatives to optimise domestic green hydrogen production
   - Given the risks associated with full reliance on overseas sources for H_2DRI, Japan should develop and reinforce its own domestic projects.

2) International collaboration: leveraging trade to drive investments into green supply chains

1. **Develop strategic international partnerships**
   - Create and leverage strategic partnerships between governments (such as the EU-South Africa Clean Trade and Investment Partnerships and the MoUs between Korea and Australia) with a focus on clean industrial supply chains and integrating green iron into trade agreements
   - For green iron value chains, prioritise engagement with key suppliers with high-renewable and green hydrogen potential
   - For gas-first DRI projects, facilitate strategic partnerships and agreements to transition to green hydrogen based DRI

2. **Establish offtake mechanisms**
   - Engage with demand side platforms (such as SteelZero, Industrial Deep Decarbonisation Initiative UNIDO and First Movers Coalition) for both public and private procurement to aggregate demand and create certainty for first movers

3. **Enable financing for green iron projects and value chains**
   - Reduce financing barriers for international joint ventures or project developers facing high costs of capital via blended finance (such as concessional capital, results-based climate funding, public-private partnerships)
   - Deploy de-risking instruments to reduce investment and project risks (such as guarantees on counterparty credit, foreign currency and political risk via export credit agencies, multilateral and bilateral development banks)

4. **Set global standards and support technology transfer**
   - Engage bilaterally and within multilateral platforms (such as the Climate Club) to harmonise green steel and hydrogen standards
   - Position Japan as a key partner by leveraging its technology leadership to support joint ventures, skills building and knowledge-sharing in next-generation EAFs, green iron and hydrogen

Appendix

List of abbreviations

AEL: Alkaline iron electrolysis

BF: Blast furnace

BOF: Basic oxygen furnace

Capex: Capital expenditures

CCS: Carbon capture and storage

DRI: Direct reduced iron

EAF: Electric arc furnace

Fe: Iron

FID: Final investment decision

FY: fiscal year

GHG: Greenhouse gases

H_2: Hydrogen

HBI: Hot briquetted iron

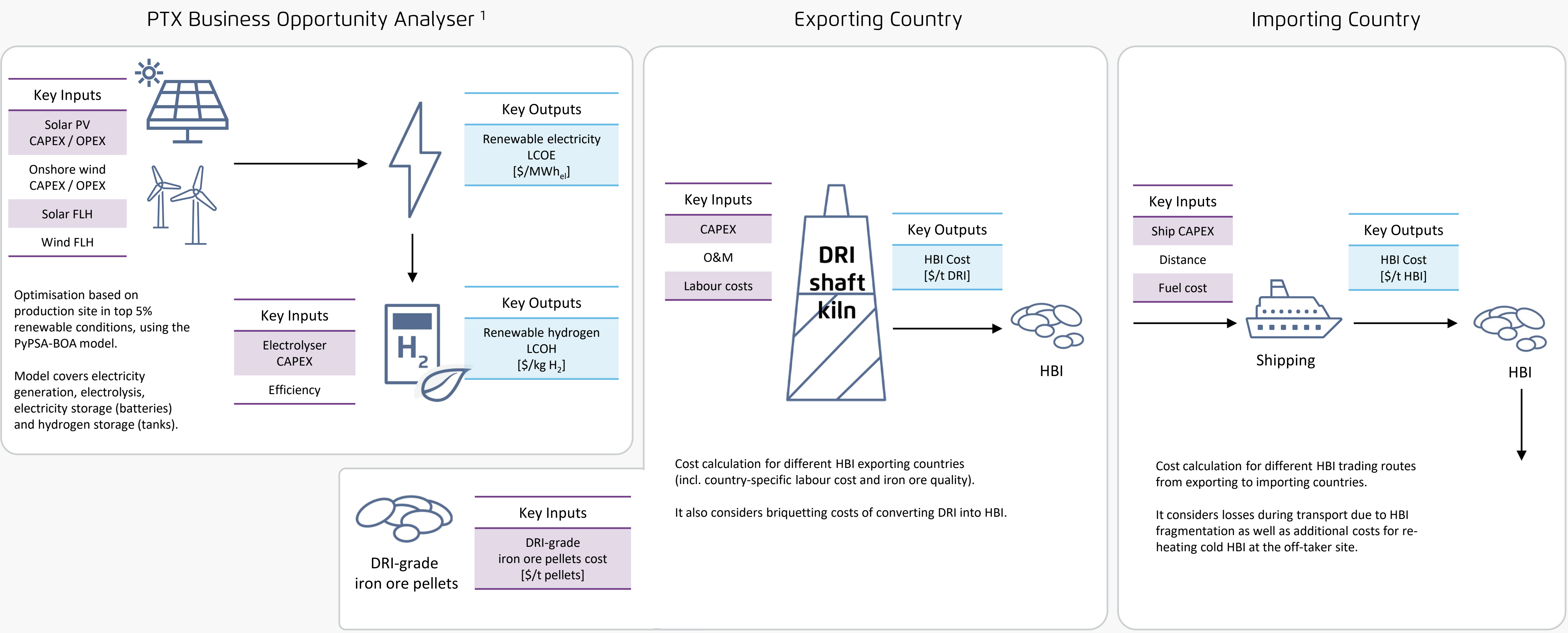
MOE: Molten oxide electrolysis

NZE-scrap-EAF: Near-zero emissions scrap electric arc furnace

Opex: Operating expenditures

R&D: Research and development

HBI production cost – calculation methodology



[1] Oeko-Institut, Agora Energiewende & Agora Industry (2024): PTX Business Opportunity Analyser, Version 2.0

Appendix – key assumptions

Overall values

Parameters		Value	Reference	Comment
Amortisation time (years)		20	Own assumption	-
Capacity utilisation (%)		90	Own assumption	72% for EAF charged with cold HBI[1]
DR grade iron pellets (USD_{2024} / tonne)		207	1, 2	Price for countries without DR grade iron ore. Countries with DR can produce pellets with lower costs.
DRI plant	CAPEX (USD_{2024} / tonne DRI per year)	633	2	Recent announcements values
	Fixed OPEX (% of CAPEX per year)	3	2, 4	-
	Electricity consumption (kWh / tonne DRI)	93	2, 3	Including DRI briquetting
	Hydrogen consumption (kg H_2 / tonne DRI)	69	2, 4	Including H_2 pre-heating
EAF plant	CAPEX (USD_{2024} / tonne CS per year)	468	2,	Recent announcements values
	Fixed OPEX (% of CAPEX per year)	3	2, 4	-
	Electricity consumption (kWh / tonne HBI)	651	2, 4, 5	Including re-heating of cold HBI (150 kWh / ton HBI)

[1] The capacity factor of the EAF was adjusted to account for lower productivity when charged with cold HBI compared with hot HBI due to a higher tap-to-tap time.

Appendix – key assumptions

Overall values

Parameters		Value	Reference	Comment
BF-BOF plant	CAPEX (USD_{2024} / tonne CS per year)	326	10	-
	Fixed OPEX (% of CAPEX per year)	3	10	-
	Coking coal (USD_{2024} / tonne)	257	2	-
Alkaline electrolyser	CAPEX (USD_{2024} / kW_{el})	657	8	-
	Fixed OPEX (USD_{2024} / kW_{el}-year)	13	8	-
	Efficiency	71.5%	8	-

Appendix – key assumptions

Country-specific values

Parameters	Case	Australia	Brazil	Egypt	South Africa	Saudi Arabia	Germany*	Germany**	Japan	South Korea	References
Discount rate*** (%)	High	4.3	14.6	14.3	10.8	5.1	4.3	4.3	5.3	4.9	6,7
	Medium (default)	4.3	7.7	14.3	8.3	5.1	4.3	4.3	5.3	4.9	6
	Low	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	6
CAPEX of wind onshore (USD_{2024} / kW)	High	1176	910	1269	868	1482	1456	-	-	-	8
	Medium (default)	1037	802	1119	765	1307	1624	-	-	-	8
	Low	977	756	792	721	1232	1531	-	-	-	8
CAPEX of solar PV (USD_{2024} / kW)	High	698	564	628	303	977	1042	-	-	-	8
	Medium (default)	528	426	475	389	357	434	-	-	-	8
	Low	411	332	370	515	278	505	-	-	-	8

* H_2 pipeline for Germany is based on H_2 production in Tunisia (high case), Spain (medium case) and Denmark (low case). ** grid-based electricity for Germany; *** country-specific equity risk premiums (ERP) and government bond yields are used as simplified approach in levelised cost calculations, since a more detailed weighted average cost of capital (WACC) is intrinsic to each individual project; All costs refer to 2040 technological scenario.

Appendix – key assumptions

Country-specific values

Parameters	Case	Australia	Brazil	Egypt	South Africa	Saudi Arabia	Germany*	Germany**	Japan	South Korea	References
Cost of renewable energy (USD_{2024} / MWh)	High	37	64	77.1	70	26	105	105	105	105	8,9
	Medium (default)	32	38	55.5	29	21	90	90	90	90	8,9
	Low	29	27	22.6	21	16	70	70	70	70	8,9
Cost of renewable hydrogen (USD_{2024} / kg)	High	2.3	4.0	4.3	4.5	2.4	4.6	5.2	5.2	5.2	8,9
	Medium (default)	2.1	2.5	3.9	2.5	2.1	2.9	4.5	4.5	4.5	8,9
	Low	1.9	1.9	2.0	2.0	1.8	2.8	3.5	3.5	3.5	8,9

* H_2 pipeline for Germany is based on H_2 production in Tunisia (high case), Spain (medium case) and Denmark (low case); ** grid-based electricity for Germany; All costs refer to 2040 technological scenario.

Imprint

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