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# JAPAN AND STEEL PRODUCTION TECHNOLOGY PATHWAY ANALYSIS

Japan's resources may have limited potential for $H_2$-DRI-EAF steelmaking, but Nippon Steel's strategy of internationalisation has one eye on a new steel map

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## STEEL AND INDUSTRIAL RELOCATION

### GREEN HYDROGEN-BASED DRI-EAF

*Green $H_2$-DRI-EAF is a clear technology pathway for the decarbonisation of steel*

The steel industry is looking hard for technology pathways designed to decarbonise iron- and steel-making. The solution with the most attention and financial support is the replacement of fossil gas with green hydrogen ($H_2$) to make direct reduced iron (DRI) which is then fed into electric arc furnaces (EAFs) running on 100% renewable electricity. This method has the most potential to remove emissions in large-scale primary steel production (derived from iron ore); secondary production (based on scrap, which can be directly fed into EAFs) will only suffice half of global production in 2050.[1]

Coal is the current bloodstream of steel production and the main source of emissions; blast furnaces combined with basic oxygen furnaces (BF-BOF) are relied on for primary steelmaking which emit around 2 tonnes of $CO_2$ for every tonne of steel.

The dynamics of profitable steelmaking will be permanently transformed. Unlike current fossil-based steel production, green $H_2$-DRI-EAF steel production is competitively advantaged by the availability of renewable electricity, consumed in copious amounts during water electrolysis for green hydrogen production, and EAF steelmaking. Renewable energy intermittency can be managed by using multiple sources (e.g. both wind and solar), distributed grid systems, and process flexibility which electrolysers and EAFs (in batch mode) support. In the absence of abundant, reliable and cheap renewable electricity, green hydrogen may be imported, but in any event, a sizeable portion of overall energy demand will still require electrification.

For Japan, however, importing green hydrogen (or any other colour like grey hydrogen made from fossil fuels) is a non-starter. Gaseous hydrogen's volumetric energy density is prohibitively low; compression, liquefaction (to at least -253°C) or chemical upgrading to, for example, ammonia ($NH_3$ which is liquefied at -33°C) is required for efficient storage and transportation, all costly and energy-consuming processes. By extension, and with the steel industry already being an industry dominated by multinational producers, the most competitive decarbonised steel will come from geographies with the cheapest and most abundant renewable energy production and iron ore.

This will drive Japanese steel companies to look outside Japan, towards other countries in which to build greenfield $H_2$-DRI-EAF plants that have access to the key steelmaking feedstocks described above. This article explores where these might be.

## THE KEY FACTORS THAT WILL DRIVE INDUSTRIAL RELOCATION

*Steel producers will look at industrial relocation to access cheap renewable electricity and iron ore for green $H_2$-DRI-EAF*

The following regionally-unique factors will drive industrial relocation in the sector:

- Abundant, reliable and affordable renewable energy, and therefore, green hydrogen.
- Abundant, high-quality and affordable iron ore. Higher quality ore is required for DRI using shaft furnaces (minimum 67% Fe) in comparison to blast furnaces (minimum 65% Fe). Especially considering the global average ore quality is 62% Fe, the increased beneficiation requirement will change the dynamics of profitable usable ore production.
- Abundant, high-quality and affordable scrap steel, which will become available as in-use steel stocks reach the end of their useful lifetime within the automotive, construction and machinery sectors - a product of economic development and industrial growth.

Consequently, the following supply chain considerations emerge:

- Islanded energy system vs grid connection: Being close to renewable energy is fundamental. The more this is secured from captive or islanded energy systems the better as 100% renewable electricity supply is assured, removing reliance on grids that still have fossil fuel power plants and triple digit emissions factors. A combination of renewable energy sources, e.g. solar and wind, alongside a portion of dispatchable power, will be optimal to mitigate daily and seasonal variability. The least-cost solution will be ultimately driven by capacity-scale renewable energy installations with zero process emissions.
- Captive mines vs imported ore: Industrial relocation does not necessarily mean importing iron ore is off the table. Japan and other industrial countries with limited iron ore resources have been importing iron ore for years (where the economics of storage and transportation are completely different to hydrogen) but this has been for a core fleet of brownfield BF-BOF. For $H_2$-DRI-EAF, where new and greenfield plants must be built, being close to captive mines that have the required high grade iron ore deposits is a clear advantage.

## A COUNTRY COMPARISON OF GREEN STEEL POTENTIAL

The following analysis looks at a selection of countries that score well on the key axes described above and are meaningful locations for industrial relocation by Japanese steel companies.

*Analysis of geo-spatial data is driving the new steel map*

The analysis for 2050 below models the breakdown of a levelised cost per tonne of steel, based on geo-spatial data. At the heart of the analysis is a facility optimisation model for 44 regions within the top-17 iron ore producing countries (that has examined the NPV for least-cost iron and steel production over a 20-year project lifetime for 1 Mtpa output) and a machine learning tool that feeds back into the model by changing and improving curve gradients and parameter estimation. Developed at the Department of Engineering Science, University of Oxford, this has allowed the creation of a new steel map of over 300 iron ore deposits. We focus on a selection of these that are of interest to Japanese steel producers and consumers.

*Table 1 - Green Steel Potential*

| Selected countries | Status |
|---|---|
| Sweden | Major leader by investment in $H_2$-DRI as part of the HYBRIT project.[2] Has achieved proof of concept and is attracting European car industry demand. |
| Spain | Location of another major European $H_2$-DRI-EAF project by Arcelor Mittal with outsourced islanded power to the government of Spain and assumed imported iron ore. Operated by the JV partner of Nippon Steel in India and separates $H_2$-DRI from EAF (i.e. non-integrated mill). |
| India | Expected to be the most significant double digit growth market for steel. Has experience in syngas DRI and has EAF facilities in production at scale. [3] |
| China | Expected to be the major least-cost provider of green hydrogen by 2030. Current producer of the majority of world's steel and the major competitor to Japan.[4] |
| Brazil | Major iron ore producer at 20.5% of global market share and has land and potential for capacity scale renewable energy installations.[5] |
| Australia | Major iron ore producer at 53.6% of global market share and has land and potential for capacity scale renewable energy installations.[6] |
| Iran | Competitive advantage on core factors but not currently a major steel producer at less than 1.5% global market share.[7] |
| South Africa | Competitive advantage on core factors but not currently a major steel producer at less than 0.3% global market share.[8] |

We have excluded Japan based on the scale and need for iron ore, not renewable electricity potential. Japan does have some iron ore deposits but these are only meaningful for niche production. Nippon Steel is the fourth largest steel producer in the world at just under 50 Mt in 2021 for the group and will have to look overseas to carry on production in Japan at these levels. We use India as a key proxy and partner for production of $H_2$-DRI overseas (because of the joint venture between Nippon Steel and Arcelor Mittal) as well as possibilities in Australia (given its role as the key supplier of iron ore to the Japanese steel industry).

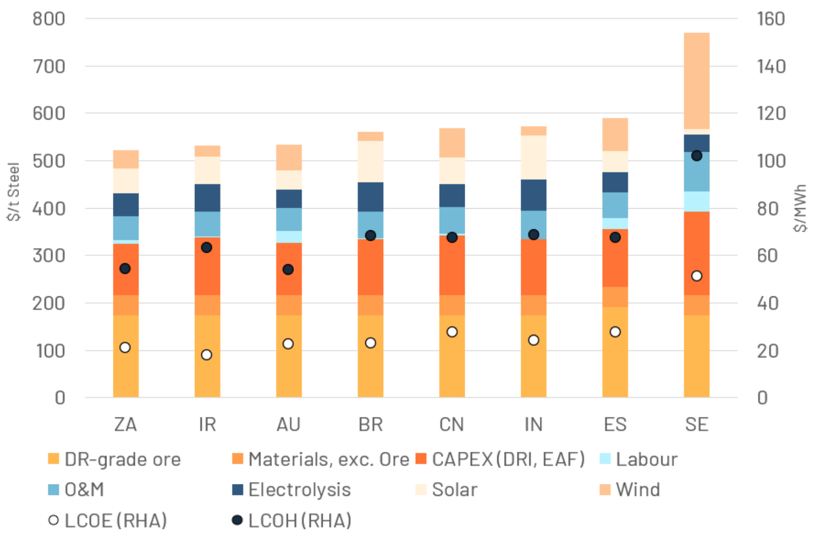
# A NEW MAP?

## PROJECTED COSTS IN 2050, A COUNTRY COMPARISON

Chart 1 presents the results of the model. It breaks down wind and solar as key renewable energy inputs, $H_2$ electrolyser costs, CAPEX, OPEX, labour, materials and DR grade iron ore. It shows the cost per tonne of steel on the left hand axis and pulls out the levelised cost of energy, storage and hydrogen on the right hand axis.

***Chart 1 - projected green steel cost comparison, facilities installed in 2050 (0% scrap)***

*A facility optimisation model and machine learning tool looks at costs per tonne across selected countries*




*The new steel map is a combination of winners, regional plays and traditional steel producing countries*

The model is conservative in some of its core assumptions (e.g. on learning rates for renewable electricity to 2050) but the conclusions are, for the most part, about relative competitiveness:

- Global winners? There are two winners with low costs across the breakdown per tonne of steel. Both Iran and South Africa are clear options for the least-cost production of the decarbonised technology pathway of $H_2$-DRI-EAF. These are small but not embryonic industries in both countries and they should be a key focus for industrial relocation towards 2050;
- Regional plays? Despite the scale and speed of $H_2$-DRI prototypes in Europe, it will not emerge as the long term least-cost leader in $H_2$-DRI-EAF production. Costs in the long term remain too challenging for the key variables of renewable energy and labour in particular. But these can be successful regional plays (e.g. decarbonised steel made in Scandinavia and demanded by the auto industry in the same geography).

Elsewhere, it is no surprise that Australia and Brazil will shape a new steel map with their iron ore deposits. Nor is it only about their renewable energy potential and low levelised costs of solar, wind and hydrogen. It is also driven by both round the clock and year round availability of these renewable energies which translates into lower CAPEX.

China and India are in the middle of the pack. China is well placed to remain a global leader and we see India as a leading market for international ventures. In the context of these rankings we explore Nippon Steel's strategy below and look at India as a possible option for near-term industrial relocation.

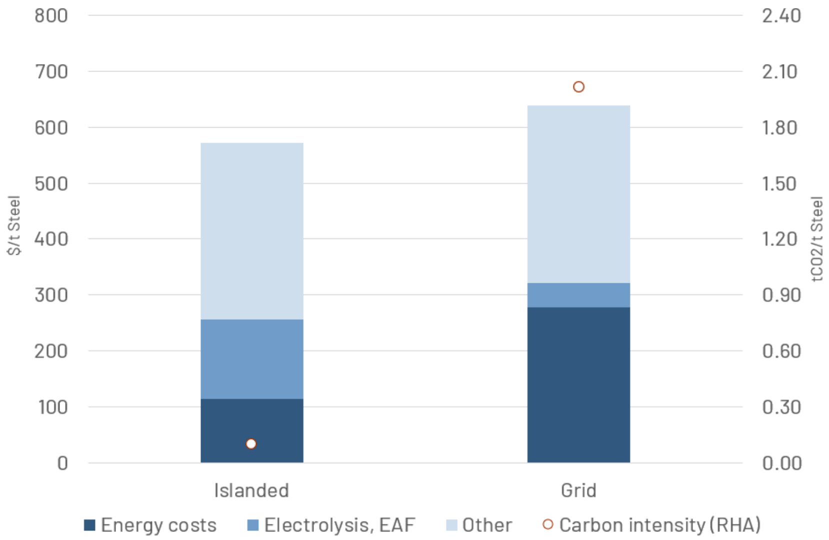
## TO ISLAND OR NOT TO ISLAND? GREEN ENERGY AS THE KEY DRIVER

One of key supply chain configurations worth revisiting is the nature of the renewable energy system for production. The results are unambiguous. For both decarbonisation potential and least-cost, grid solutions will simply be too expensive and too high in carbon intensity.

This underlines the importance of independent, least-cost AND lowest carbon islanded energy systems. This can reduce steel costs by $66 per tonne in the case of India. Here, the clear mandate for policy makers is to create a flexible energy system for heavy industry that allows the creation of capacity scale solar and wind to drive the green hydrogen and green energy requirements of greenfield $H_2$-DRI-EAF.

***Chart 2 - A comparison of (continuous-load) grid and (variable-load) islanded energy systems for $H_2$-DRI-EAF in India***

*Variable-load islanded energy systems will be least-cost and lowest emissions*



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# THE NIPPON STEEL STRATEGY IN CONTEXT

## STRENGTHS AND OPPORTUNITIES

*An opportunity for Nippon Steel outside Japan especially given joint ventures in India, which can compete with China on a new steel map*

Far from being an existential threat to their business, this is an opportunity for Nippon Steel. One which is beginning to be seen in their business and corporate strategy. After all, the proxy of India is competitive with China on $H_2$-DRI-EAF (Chart 1).

The declining demand for steel in Japan as an economy that is post-maturity and flatlining on many metrics (like population and total emissions) has led Nippon Steel to seek a "Tectonic Shift to Secure Non-consolidated Operating Profit".[9] It has successfully engaged in joint ventures with Arcelor Mittal and acquisitions of overseas businesses (notably EAF businesses in Thailand) to create a broader operational footprint. The analysis validates this strategy to look elsewhere for business opportunities and new technology.

In India, major investment is taking shape. "The US$22 billion to be invested in Gujarat involves a range of projects including 10 gigawatts (GW) of solar and wind development for the decarbonisation of steel production."[10] This announcement promised the use of green steel technology with no specifics but some analysts read this as an R&D entry into $H_2$-DRI. More concretely, utility scale renewable electricity projects are happening. "A 'round the clock' renewable energy project with 975 MW of nominal capacity in Andhra Pradesh will combine solar and wind power and be supported by a hydro pumped storage project."[11]

*Multinational steel corporations will look at the new steel map given that $H_2$-DRI-EAF is greenfield investment, but shipment of HBI to Japan is possible*

Even in Japan a commitment to "green steel" from Nippon Steel's current EAF plant in 2023 and investment in a new "large scale [hybrid] EAF" by 2030 capable of processing DRI could actually be consistent with overseas expansion. Transportation is key.

Whereas BF BOF processes have led to highly integrated steel mills, DRI could be compacted at high temperatures into Hot Briquetted Iron (HBI) and stored and transported at the same kind of marginal costs as iron ore. This raises the tantalising strategic prospect that Nippon Steel could separate HBI production from EAF steelmaking and expand the latter for a green steel market in Japan. For example, a geographic separation of $H_2$-DRI from EAF can be seen by their partner Arcelor Mittal in Spain.

In this context, we are currently modelling Nippon Steel's options for $H_2$-DRI-EAF (in India) and $H_2$-DRI-HBI-EAF (shipping HBI from India to Japan). The latter keeps islanded energy systems married to $H_2$-DRI in India, and energy intense hydrogen electrolysis in particular, but transports HBI to EAF facilities in Japan.

But as demonstrated in Chart 2 (in the case of India), this still means EAFs in Japan will need capacity scale renewable electricity resources in the form of captive power or PPAs until and unless grid electricity becomes decarbonised in Japan. It is therefore imperative that Nippon Steel lobby for a fit-for-purpose renewable electricity-driven power development that can meet their needs and size in Japan and make them winners on a new steel map.

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|---|---|
| BF | Blast Furnace |
| BOF | Basic Oxygen Furnace |
| DRI | Direct Reduced Iron |
| EAF | Electric Arc Furnace |
| $H_2$ | Hydrogen |
| $H_2$-DRI | Direct Reduced Iron from Hydrogen |
| HBI | Hot Briquetted Iron |
| PPA | Power Purchase Agreement |

**Data and disclaimer**

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Endnotes


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