Transition Asia

WILL CHINA WIN THE GREEN STEEL RACE? H_2-DRI-EAF MARKET AND POLICY DEVELOPMENT TO 2030

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CONTENTS

KEY TAKEAWAYS

1. China could win the race to be the top green primary steel producer by 2030 based on its competitive advantages in renewable electricity and green hydrogen production (H_2). The policy discussions and modelling for the 15th Five Year Plan need to codify this ambition and formalise subsidies.

2. The pipeline of recently announced H_2-ready DRI production across almost all the steel majors, suggests China should be on track to deliver world leading production volumes of 15–20 mtpa of low carbon primary steel by 2030. But there will be different regional winners and losers inside China.

3. Demand from Chinese EV manufacturers and strong demand signals for green steel will drive the Chinese market rather than international carbon pricing adjustments in the near term, effects that will be felt up the supply chain to high grade iron ore suppliers.

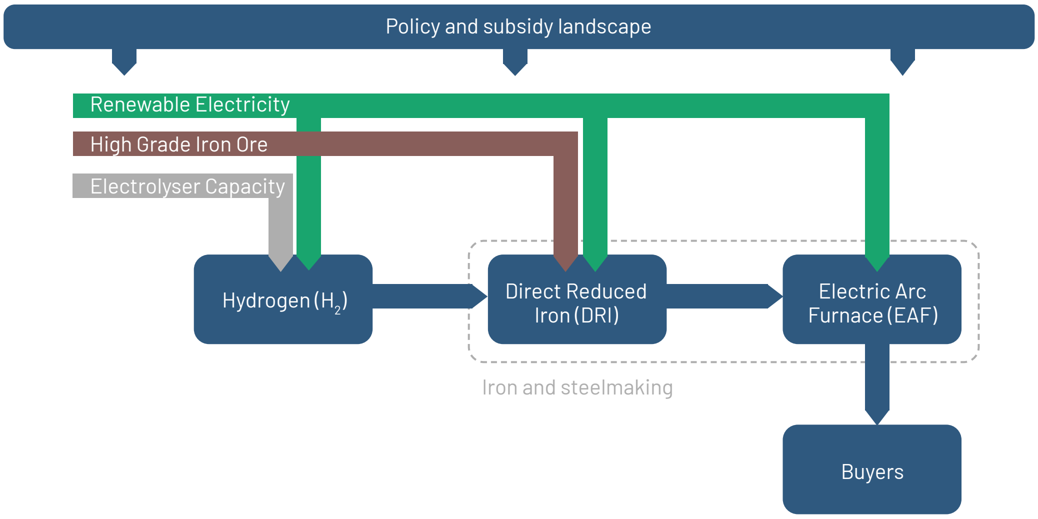
4. Current EAF targets of 15% capacity share by 2025 need to be raised again for 2030 to 20%. We do not see either the suspension of the steel capacity replacement mechanism or market consolidation as barriers to switch to EAF production either for secondary or primary green steel.

INTRODUCTION

The most mature pathway for low carbon primary steel production beyond 2030 is currently H_2-DRI-EAF. This paper gives an overview of the process and breaks it down into its constituent parts. It also explains why China is positioned to maintain its preeminence in primary steel production given its resource, technology and financial strength.

In order, we will explore the overall process and then look at green hydrogen (H_2), the direct reduction of iron (DRI) and electric arc furnaces (EAFs). Finally we provide a series of recommendations for policy makers in China to accelerate as a leader in this space, as subsidies for the decarbonisation of steel become a hot topic.

Figure 1: The Constituent Parts of H_2-DRI-EAF or Green Primary Steel



Source: Transition Asia

H_2-DRI-EAF: AN OVERVIEW

The H_2-DRI-EAF process, whilst not entirely new, is emerging as the frontrunner in the race to beat traditional and coal intensive blast furnace-basic oxygen furnace (BF-BOF) process.

The DRI process uses (pelletised) iron ore as a feedstock and just like a blast furnace that heats iron ore with coal, it removes oxygen from the ore to convert it into metallic iron. DRI technology does not melt the iron ore like a blast furnace, it "reduces" it. And it can use a number of gases to do this. Right now almost all DRI comes from gases that originate from fossil fuels. That is, Gas-DRI.

The opportunity being explored at scale is to use hydrogen as a reductant, stripping oxygen atoms from the iron ore to produce (direct reduced) iron and water (as a byproduct). That is, H_2-DRI.

Producing steel with 100% hydrogen leads to significant emission reductions compared to the blast furnace route. Although over 99% of global hydrogen is produced from fossil fuels or their by-products, it can be produced via electrolysis and if powered by renewable electricity sources, the hydrogen can be emission free.[1]

After H_2-DRI the iron can be "charged" in an electric arc furnace to produce steel. Many current analyses of the market also point out that direct reduced iron can be compacted for shipping and storage into Hot-briquetted iron (HBI) and this offers opportunities for uncoupling the EAF part of the value chain from H_2-DRI. Or "offshoring" HBI. The fundamental benefit is that an EAF running on renewable electricity, "charged" with DRI made from green hydrogen completes the removal of most of the reliance on fossil fuels in all parts of the H_2-DRI-EAF value chain.

Moving away from BF-BOF production processes, (depending on how the hydrogen is produced) DRI-EAF based steel production offers the potential to significantly reduce emissions from 1.8tCO_2 per tonne of crude steel to 0.65tCO_2 per tonne for natural gas based DRI and 0.05tCO_2 per tonne for H_2-DRI.[2] This process should be viewed as the basis of standards, policies and investment for the decarbonisation of the sector.

In the remaining sections we break this down opportunity in the Chinese context: getting to the world's cheapest green hydrogen; "Hydrogen-ready" DRI technology and high grade iron ore supply; market developments and policy targets for EAFs in China; strong demand side signals; and, policy and subsidy recommendations for the growth of H_2-DRI-EAF.

H_2: GETTING TO THE WORLD'S CHEAPEST GREEN HYDROGEN

ELECTROLYSER CAPACITY

Currently the majority of hydrogen in China's limited DRI steel projects originates from either coke ovens or natural gas with limited green hydrogen being produced from renewable electricity sources. What is required and predicted in China is a massive growth in green hydrogen production: the electrolysis of water using renewable electricity from wind or solar which separates the water into hydrogen and oxygen.

China's Mid-and-Long-Term Hydrogen Industrial Development Plan (2021–2035) represents the country's most comprehensive hydrogen strategy to date. Whilst not exclusively dedicated to green hydrogen, the plan sets targets for renewable hydrogen production of 100,000 to 200,000 tonnes annually by 2025 as part of its supply-side initiatives.[3] By the

1 https://iea.blob.core.windows.net/assets/ecdfc3bb-d212-4a4c-9ff7-6ce5b1e19cef/GlobalHydrogenReview2023.pdf
2 https://transitionasia.org/wp-content/uploads/2024/07/Green_Steel_Economics_240725.pdf
3 Green hydrogen is defined as ≤ 4,9 Kg CO_2 per kg H_2

end of 2024, China is expected to have installed 2.5 GW of electrolyser capacity, surpassing the country's annual green hydrogen production target a year ahead of schedule. This new capacity will enable the production of 220,000 tonnes of green hydrogen per year, exceeding China's target 2025 a year ahead of schedule.[4]

Of the two main types of electrolysis, alkaline electrolysis and Proton Exchange Membrane (PEM) electrolysis, alkaline is the cheaper with the global market dominated by China. PEM electrolysis is more energy efficient and more suitable for variable electricity production like Solar PV. PEM electrolysis uses a membrane for ion movement, with electrodes immersed in an electrolyte solution.

Although renewable hydrogen development is slow, and near non-existent for steel production, state-owned oil and gas giant Sinopec has successfully commissioned 260MW PEM project, constructing a further 390 MW plant and rumoured to be considering a 1GW plant. Additionally, a domestic consortium is investing US$4.5 billion in one of the world's largest green hydrogen projects using PEM electrolysers.[5] [6] Importantly, the consortium intends to utilise domestically manufactured PEM electrolysers, highlighting the country's growing interest in advancing this technology, albeit, behind global counterparts.[7]

Box 1—China Tech Delivery Runs Ahead of Targets

> China has a track record of catching up with high tech developments and dominating market share as befits its size and scale. Capacity installed for electrolysis appears to be no different. The IEAs hydrogen review articulates this well. *"In 2020, China accounted for less than 10% of global electrolyser capacity installed for dedicated hydrogen production...In 2022, installed capacity in China grew to more than 200 MW, representing 30% of global capacity...By the end of 2023, China's installed electrolyser capacity is expected to reach 1.2 GW—50% of global capacity... [and it] accounts for more than 40% of the electrolysis projects that have reached final investment decision globally."* [8]

Source: Transition Asia, IEA

Driving down the costs of electrolysers will be key to realising lower hydrogen prices in China where there is no green hydrogen production currently at scale. Well-coordinated industrial strategies have propelled China forward as the market leader in wind and solar electricity where Europe and Japan have historically been the strongholds for these

4 https://www.rystadenergy.com/news/china-hydrogen-targets
5 Fengzhen municipal government, state-owned China Power Construction (PowerChina) Kunming Institute, and Tsinghua University connected Rongke Hydrogen Energy
6 https://www.hydrogeninsight.com/production/worlds-largest-pem-green-hydrogen-project-announced-in-china-backed-by-4-5bn-of-investment/2-1-1479258
7 TA Analysis, https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map
8 https://www.iea.org/reports/global-hydrogen-review-2023/executive-summary

industries. Building and maintaining a favourable policy environment while leveraging the positive early signals from domestic investors can help scale Chinese electrolyser manufacturing capabilities and ultimately drive down costs.

RENEWABLE ELECTRICITY SUPPLY

Powering electrolysers for green hydrogen production and EAFs for steel production will require vast amounts of renewable electricity. While heavy industries seeking to decarbonise operations through the use of renewable electricity have previously moved to hydropower rich provinces, record droughts and volatile hydrological levels in China have led to government curtailment of these industries reliant on this source of electricity. The transfer of heavy industries seeking to electrify with RE in hydropower rich areas cannot continue sustainably.

Instead, heavy industries should seek to decarbonise utilising renewable electricity that is more reliable. Steel mills located in the steel belt provinces of Hebei, Jiangsu and Shanxi, although not located in the most optimal provinces for renewable electricity resources, still benefit from high levels of solar irradiation and good quality wind power; comparable to northern Spain and much of Sweden respectively (where European H_2-DRI projects are based), raising prospects for renewable electricity deployment for use in the heavy industries that dominate these provinces.

In the northern area of China, particularly Inner Mongolia, which has high levels of curtailed renewable electricity, there are some of China's best conditions for solar and wind. Inner Mongolia is leveraging these rich resources within their strategic hydrogen plan with 2.2GW wind and solar infrastructure mainly designated for feeding green hydrogen electrolysers. China Baowu has also declared that it will build 1.5GW of electrolysers in the province at some point in the future.

Utilising China's renewable electricity resources for the production of green steel will rely on the sector's ability to navigate the country's complicated regulatory environment. China is still among the most challenging countries to procure renewable electricity. While corporate power purchase agreements (CPPAs) in Europe and North America have provided price certainty and decarbonised electricity supplies, CPPAs, or "bilateral contracts" as they are termed in Chinese are still in a nascent phase amid market and regulatory uncertainty.

The regulatory framework for CPPAs is still evolving, with uncertainties about how central and local governments will structure and enforce related regulations. Challenges in grid access and the well-founded risk of curtailment in certain regions still affect the feasibility of CPPAs. The design mechanisms of the broader electricity market, as well as potential financial and credit risks associated with long-term commitments, add complexity.

Again, it is scale and growth that provides cause for optimism. China's 14th Five-Year Plan in 2021 restated China's ambition for 1,200 GW of wind and solar energy combined by 2030.

But with "EV wars" and an inherent conservatism in China's targets,this target was met in July 2023. The estimated new additions for the remainder of 2024 is expected to bring China's installed solar and wind energy capacity to 1,310GW by the end of this year.[9]

CHINA TARGETING $2.4/KG FOR H_2 BY 2030

All of this adds up to China being the leader in electrolyser capacity and renewable electricity production. And doing so with competitive CAPEX in the former and a low levelised cost of electricity in the latter. Both should drive the most competitive hydrogen price globally.

Many analysts like Bloomberg point to $2/kg[10] as a benchmark for green hydrogen to be competitive with fossil hydrogen. Indeed, ArcelorMittal is flagging $2/kg as the number for economic production of low carbon steel in its pilot project in Northern Spain in addition to "progressive European carbon taxes".

As we show in our techno-economic analysis (see Further Reading) at zero carbon pricing, green H_2-DRI-EAF steelmaking in China is costlier than both BF-BOF and NG-DRI-EAF methods, requiring a H_2 price of about $2/kg to match the costs of NG-DRI-EAF and around $1.4/kg to reach cost-parity with BF-BOF (where both are unsubsidised).

The same discussion leads to "spatial decarbonisation" (the movement of DRI production to areas of low hydrogen production costs and then shipping this iron in the form of Hot Briquetted Iron to an EAF as the least cost pathway—and alternative—to storing and shipping hydrogen to the DRI facility).[11] Or put more simply, offshoring the production of HBI to, say, Australia or Brazil.

Spatial decarbonisation particularly benefits producers in countries like Japan that are not suited for low cost hydrogen production and believe it has merits for companies like Nippon Steel. However, whilst there may be some decoupling of hydrogen production from DRI in terms of location inside China (as provinces compete for a new green hydrogen market) this is not a threat to the H_2-DRI-EAF value chain as a whole inside China.

More importantly, the China Hydrogen Alliance (CHA) expects the production cost of green hydrogen, including capex, to fall below RMB 25/kg or around $4/kg in China by 2025 and $2.40/kg by 2030. As we have seen above from recent growth in electrolyser and RE capacity growth, we believe this figure has some potential to be conservative and that there is some upside here by the end of the decade.

9 https://www.scmp.com/business/china-business/article/3268707/china-meet-its-2030-renewable-energy-target-end-year-state-owned-researcher
10 https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf
11 https://www.hydrogeninsight.com/industrial/green-hydrogen-is-too-expensive-to-use-in-our-eu-steel-mills-even-though-weve-secured-billions-in-subsidies/2-1-1601199

DRI: "HYDROGEN READY" DRI TECHNOLOGY AND HIGH GRADE IRON ORE SUPPLY

THE "HYDROGEN READY" PROJECTS

Europe moved first on H_2-DRI-EAF. China's iron and steel industry is playing catch up and in the last twelve months has witnessed a real shift in ambition and construction with several notable H_2-DRI projects announced, in construction and in operation. Whilst there is little visible top down policy here, and what is, is covered under the umbrella term "hydrogen metallurgy", a number of corporations are on the move.

Table 1: H_2-DRI Projects of Significance in China

Project Location	Company	Project Name	Capacity (tonne per annum)
Zhangjian, Guangdong	Baosteel	Baosteel Zhanjiang Iron & Steel DRI expansion Project	1 M
Zhangjiakou, Hebei	HBIS Group	HBIS Group Paradigm Project	1.2 M
Wuhai, Inner Mongolia	Jianlong Steel	Jianlong-Inner Mongolia Saisipu Company H2-DRI Project	0.3 M
Rizhao, Shandong	Rizhao Steel	Rizhao Steel Hydrogen-based Gas DRI Project	0.5 M
Xingtai, Hebei	Xingtai Steel	Low Carbon Hydrogen-rich Iron Making Technology Transformation Project	1.65 M
Jinzhong, Shanxi	Zhongjin Metallurgical Tech	Hydrogen-based DRI Project	0.3 M
Baotou, Inner Mongolia	Mintal Group	Gas-based Shaft Furnace DRI Project	1.1 M

Source: Transition Asia

The above table references from multiple sources to outline key details of significant initiatives such as Baosteel Zhanjiang's substantial steel plant in Zhanjiang, Guangdong, HBIS Group's H_2-DRI project in Zhangjiakou, Hebei, and Jianlong-Inner Mongolia Saisipu Company's venture in Wuhai, Inner Mongolia.[12] Additionally, Rizhao Steel in Rizhao, Shandong, Xingtai Steel in Xingtai, Hebei, and Zhongjin Taihang Mining Co in Jinzhong, Shanxi, contribute to China's evolving steel production landscape. The table provides an overview of these H_2-DRI projects and their annual capacities.

12 H_2-DRI projects of significance are classified by Transition Asia as having the capacity of producing material quantities of DRI, using established DRI technologies or utilising hydrogen produced from electrolysis. R&D projects have not been considered as "significant".

The majority of the country's H_2-DRI projects are located in the northern provinces of the country surrounding Beijing. These provinces are China's steel producing heartlands with the provinces of Hebei, Jiangsu, Shandong, Henan, and Anhui accounting for more than 60% of China's crude steel output. Notably, Inner Mongolia Autonomous Region is also host to two H_2-DRI plants. In recent years, the traditionally coal-intensive region has become a hotspot for renewable electricity projects due to its high potential for wind and solar power.

Table 2: Table of Projects and Their Hydrogen Sources

H_2-DRI Project	Hydrogen Sources
Baosteel Zhanjiang Iron & Steel Co., Ltd. DRI expansion Project	Natural gas, coke oven gas[13]
HBIS Group Paradigm Project	Coke oven gas[14]
Jianlong-Inner Mongolia Saisipu Company H_2-DRI Project	Coke oven gas[15]
Rizhao Steel Hydrogen-based Gas DRI Project	Vinyl acetate production[16]
Xingtai Steel Low Carbon Hydrogen-rich Ironmaking Technology Transformation Project	Smelting furnace off- gas[17]
Zhongjin Taihang Mining Hydrogen-Based Direct Reduction Project	Coke oven gas[18]
Mintal Group Gas-based Shaft Furnace DRI Project	Coal[19]
Angang Group Green Hydrogen Zero Carbon Project	Green hydrogen[20]

Source: Transition Asia

The majority of these projects are "hydrogen ready" but running on fossil hydrogen produced from natural gas or coke oven gas. Competitive green hydrogen prices, supply, transport and storage to facilitate the conditions for a switch from fossil hydrogen to green hydrogen is key. That is, the production capacity is now running ahead of the green hydrogen supply chain and market development should be geared towards this bottleneck.[21][22]

Notably, Angang Steel RE-H_2-DRI Project is the world's first project to utilise green hydrogen in a "zero carbon fluidised bed" and started construction in 2022. "This project uses iron ore of 65% purity as the raw material, adopting hydrogen as the reducing gas,

13 https://www.danieli.com/en/news-media/news/second-energiron-dri-plant-china_37_743.htm
14 https://www.danieli.com/en/news-media/news/hbis-producing-dri-using-more-60-hydrogen_37_818.htm
15 https://www.asiachem.org/en/fcv_20230115
16 https://news.gmw.cn/2020-05/27/content_33862795.htm
17 https://www.sohu.com/a/574216091_313737
18 http://www.mme-co.de/en/Home/projects/DRI-CSTM.html
19 https://www.asiachem.org/en/fcv_20230115
20 http://www.sasac.gov.cn/n2588025/n16303206/c28962599/content.html
21 Coking coal heating produces hydrogen as a byproduct, captured through coke oven gas (COG) desulfurization. In the coke oven process, coal heats without air, generating coke and COG with hydrogen, methane, and carbon monoxide. Hydrogen capture involves COG generation, desulfurization, gas purification, separation, and utilisation in the DRI shaft.
22 Hydrogen production via steam methane reforming (SMR) reacts methane with steam using a nickel-based catalyst, yielding hydrogen, carbon monoxide, and carbon dioxide. After processing to enhance hydrogen content and remove impurities, the gas undergoes water-gas shift reaction and purification for industrial use. The SMR process is carbon-intensive, producing 8–10 kg of CO_2 per kg of hydrogen. Coal gasification-derived hydrogen is more carbon-intensive, releasing 18–20 kg of CO_2 per kg of hydrogen (source: https://www.hydrogennewsletter.com/gh2-facts/)

hydrogen will be supplied by electrolysis of water, not fossil fuels. The research project will produce 10,000 tonnes of DRI per annum".[23]

Moreover, if all of these projects were delivered around 5–6m tonnes of green steel would be produced. A figure that exceeds demand in Europe in 2023 for the product.[24] Inevitably we expect this green steel produced in China to be used by domestic industry especially the auto sector and we explore this below, but here China wins on scale again. These commitments have propelled China past Japan and South Korea into the market leader in East Asia. And we expect them to grow further before and by 2030.

THE DRI TECHNOLOGY

Whatever the origin of the hydrogen, the DRI technology that uses it as a reducing agent is proven and in production around the world. Currently, two main direct reduction technology providers dominate the global market: Tenova and Midrex. Both technologies provide the opportunity to include varying compilations of reducing gas within the shaft to reduce ferrous ores into metallic iron. In general, natural gas-based hydrogen makes up around 50% of reduction gases within the shaft, while carbon monoxide makes up the remainder. Midrex has hydrogen proportions of up to 80% proven commercially; however, the Enigeron technology from Tenova is the technology of choice for the landmark HYBRIT project in Sweden, utilising 100% green hydrogen as a reductant.

Tenova's technology is currently appearing more popular than Midrex's technology for the purpose of H_2-DRI due it being a more compact system, resulting in increased pressure needed for efficient H_2-DRI processes compared to natural gas based DRI. Furthermore, the America-based Midrex currently faces headwinds in China due to ongoing geopolitical affairs. Both technologies however can produce various forms of iron, such as hot briquetted iron (HBI), cold DRI (CDRI), and hot DRI (HDRI), which can be used in different steelmaking processes. Iranian DRI technology, with the country's long history in DRI production, is also used in some Chinese H_2-DRI projects. Shaft-based DRI is not the only method for gas-based DRI; batch and fluid bed processes also exist albeit operating on a much lower level of market adoption. The two flagship H_2-DRI-EAF projects of Baosteel and HBIS both use Tenova technology.

SECURING HIGH GRADE IRON ORE

For the production of H_2-DRI-EAF steel, a higher-premium quality iron ore with a minimum iron content of around 67% is required. The iron ore is typically pre-processed into pellets or lump ore for use in the direct reduction process. South America, Canada, Sweden, Bahrain and Iran are prominent suppliers of this high-grade iron ore. This means a change in procurement for China which is currently organised with national policies.

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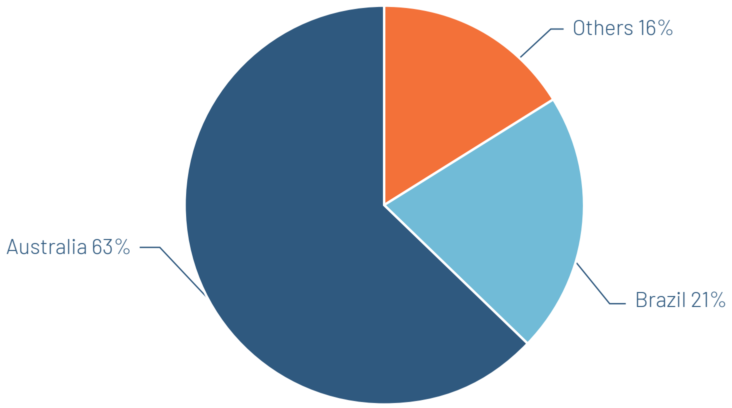
23 https://finance.eastmoney.com/a/202311052894807388.html
24 https://gmk.center/en/news/demand-for-green-steel-in-europe-will-reach-3-68-million-tons-in-2023-study/

China's iron ore landscape is currently characterised by its predominant use of blast-furnace iron ore (~62% Fe (iron) content). China imports approximately 80% of its iron ore due to the relatively low-grade iron ore (~34.5% Fe content) available domestically. In 2023, imported iron ore mainly came from Australia (63%), Brazil (21%) and other countries including India and South Africa (16%).[25]

Figure 2: China—Imported Iron Ore by Origin, 2022



Source: Wind data, and Everbright Securities Research as of end 2023

In response to potential risks and political factors, Chinese companies are strategically establishing mines in various regions. Notably, there is a significant shift toward West Africa, particularly Guinea, as China seeks resource security and reduced dependence on Australia. The acquisition of mining rights for the high grade iron ore mine in Simandou, Guinea, reflects China's strategy to secure key future resources.[26]

Chinese steel companies have also invested in iron ore mines in Peru, Algeria and Liberia, providing an increasingly diverse supply chain. The government's aim to increase iron ore storage to 370 million tonnes by 2025 illustrates its strategy for resource security.[27] Geopolitical considerations also influence China's iron ore imports, as seen in the reduced imports from India and Australia due to increasingly strained political relationships.[28]

The procurement of high grade iron ore does not appear to be an immediate bottleneck for H_2-DRI-EAF. Indeed public policy is already aimed at stable supply in price and quantity. Here the "Cornerstone Plan" to improve the Chinese steel industry's capability of resource security is key.[29]

25 Wind data, and Everbright Securities Research as of end 2022
26 https://www.riotinto.com/en/operations/projects/simandou
27 https://www.scmp.com/economy/china-economy/article/3168796/china-aims-fundamentally-solve-iron-ore-shortages-cornerstone
28 https://gmk.center/en/news/chinas-steelmakers-seek-to-increase-the-use-of-domestic-resources-of-the-iron-ore/
29 "China's "Cornerstone Plan" Aims to "Fundamentally" Solve Iron Ore Shortages." South China Morning Post, 1 Mar. 2022, www.scmp.com/economy/china-economy/article/3168796/china-aims-fundamentally-solve-iron-ore-shortages-cornerstone. Accessed 3 Mar. 2023.

EAF: THE MARKET DEVELOPMENTS AND POLICY TARGETS IN CHINA

Most EAFs in China utilise scrap as a feedstock producing secondary steel (Scrap-EAF). However, as primary steel production is still emerging, EAFs must be built to accommodate low carbon iron in the form of DRI or HBI and run on renewable electricity to maximise carbon mitigation.

China's current EAF steel production target is for 15% of steel production to be produced through EAFs by 2025 and 20% by 2030 (in both the Implementation Plan for Peak Carbon Emissions in the Industrial Sector[30] and as proposed by other government departments[31]). However, when compared globally, China's usage of EAF-produced steel remains underweight, with approximately 29% of global steel coming from EAFs each year. Beyond 2030, the China Iron and Steel Association has put forth a strategic proposal which envisions EAF steel constituting more than 30% of the total crude steel production by 2035.

No quantitative targets have been set for hydrogen metallurgy, a notable absence of concrete objectives in this domain. But the EAF fleet should be big enough to process H_2-DRI depending on the growth in demand.

BUYERS: STRONG SIGNALS ALREADY FROM CHINA AUTOS

Automobile companies in China have been leading the way in developing offtake agreements directly with steel mills, with numerous high profile MOUs having been signed so far.

One of China's largest steel producers, HBIS Group's Hansteel Company, began low carbon steel cooperation with Great Wall Motor for low carbon steel produced from H_2-DRI and high scrap ratio of around 30%.[32] HBIS Group's Tangsteel Company[33] also announced a memorandum with BMW for lower emission steel supply.[34] The volume of supply of steel itself is not disclosed, but the production facility of BMW in Shenyang where the company will receive the steel from HBIS produces as much as 650 thousand vehicles per year.[35] Compared with traditional BF-BOF steel, the lower emission steel produces between 10% and 30% less CO_2.[36] In addition to this, Baosteel plans to provide reduced emissions steel supply to BBAC (Beijing Benz Auto Co.).[37]

30 https://www.gov.cn/zhengce/zhengceku/2022-08/01/5703910/files/f7edf770241a404c9bc608c051f13b45.pdf
31 https://gmk.center/en/news/china-aims-to-increase-the-share-of-eaf-in-steel-production-to-20-by-2030/
32 https://news.bjx.com.cn/html/20230816/1326041.shtml
33 https://www.hbisco.com/en/news/group/t101/2064
34 https://www.bmw-brilliance.cn/cn/en/news/news/2022-8-4.html
35 https://www.bmw-brilliance.cn/cn/en/pr/shenyang.html
36 https://auto.cctv.com/2022/08/05/ARTIF4GCItEOauglknbGuE3B220805.shtml
37 https://www.bbac.com.cn/CN/4/41/3098.html

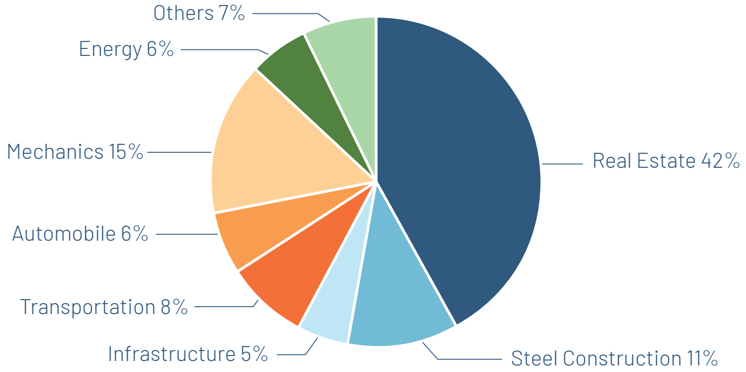
From 2026 onwards, with the help of the H_2-DRI-EAF, Baosteel will offer steel with a reduced carbon emission intensity ranging from 50% to 80% compared to BF-BOF steel. Subsequently, they aim to introduce green steel with an even more substantial carbon reduction of 95%.[38] Baosteel also signed a memorandum with Chery Automobile for low carbon steel at the end of 2023.[39] According to the memorandum, from 2024, Baosteel will gradually supply low carbon emission green steel with a carbon reduction of about 30% in Chery's existing production. From 2026, with the help of H_2 DRI technology, it will gradually supply low carbon emission green steel with a carbon reduction of more than 50%.

Most recently BMW-Brilliance and Beijing Shougang Co., Ltd. (including automotive plates produced based on electric arc furnaces (EAF) from 2026) and FAW-Volkswagen and Bao Steel have entered into agreements to offtake green steel.[40 41]

Although the Chinese automobile sector is a much smaller steel consumer than the building or machinery sector, the sector has driven H_2-DRI steel demand by developing long-term offtake agreements with steel producers for products with lower carbon intensities. The green positioning of many H_2-DRI-EAF plants are questionable given that the hydrogen is largely derived from coke oven or natural gas, this might be short-lived if the automobile sector continues to create demand side pressure for low carbon goods.

In fact the economics in the auto sector are not the primary issue. As highlighted in our previous research, the per unit cost for green steel in an EV, for example, is trivial compared to the total unit cost.[42] Our analysis suggests the marginal cost of green steel for a car is currently around $225/unit and $25/unit for H_2-DRI-EAF at $2kg hydrogen.[43 44 45]

Figure 3: China: Steel Downstream Sectors Consumption Share, 2022



Source: WIND

38 https://www.stcn.com/article/detail/738093.html
39 https://info.lgmi.com/html/202312/15/4445.htm
40 https://auto.online.sh.cn/content/2024-08/27/content_10236977.htm
41 http://bj.news.cn/20240731/86311b9758254f6d9540699e53e5a3f7/c.html
42 https://transitionasia.org/green-steel-economics-china-factsheet/
43 Levelised costs of steel are based on the cost of liquid steel and do not include downstream processing.
44 Hydrogen prices are landed prices at the steel mill.
45 Due to the capacity replacement policy, greenfield-greenfield cost is more comparable compared to a marginal-greenfield cost comparison as would suit most other countries.

THE POLICY AND SUBSIDY LANDSCAPE FOR THE GROWTH OF H_2-DRI-EAF

POLICY IS EVOLVING RAPIDLY

The transition from one billion tonnes of predominantly BF-BOF-based steel production to more sustainable technologies is a substantial challenge. China advancing H_2-DRI-EAF technology will inevitably involve vast corporate and state expenditure including DRI and EAF technologies, hydrogen production and storage and transportation facilities. Furthermore, reaching 100% hydrogen as a reductant is extremely technically challenging, with most direct reduction plants reaching a maximum of 70% hydrogen rates in practice.

The macro perspective of the industry further dampens the outlook, China's post-pandemic economic recovery is experiencing a slower than expected trajectory, posing challenges to the steel sector. Chinese real estate, a major consumer of steel, is currently a significant headwind due to the financial struggles of key property firms. As some of these firms face bankruptcy and others grapple with default risks or profit losses, the demand for steel in the real estate industry has substantially decreased.[46] This sector alone accounted for 42% of the consumption of China's steel output in 2022.[47]

China's enormous steel capacity rose from 1.146 billion tonnes in 2021 to 1.173 billion tonnes in 2023. And because demand has not kept pace with steel capacity growth expansion, steel capacity utilisation declined, falling from 90.1% in 2021 to 86.9% in 2023, leading to negative impact on corporate profitability and some analysts calling it the most severe crisis ever in the industry.[48 49 50]

Further complicating matters are future and expected headwinds related to global carbon borders, with policies like the EU's Carbon Border Adjustment Mechanism (CBAM) coming into effect during 2023 but we do not believe this is the most significant driver at present.

More recently, as steel prices drop, China has suspended the steel capacity replacement mechanism and continues to pursue market rationalisation and concentration policies which means no new capacity of any kind can now be built and the industry is expecting a "shake out" imminently.

The overarching state objective for the iron steel sector is to build several world-class super-large steel enterprise groups and top-tier specialised companies, striving for the top

46 According to the National Bureau of Statistics (NBS) of China, the completion of real estate investment decreased 5.7% year on year in 2023, the slowdown of construction activities has reduced steel procurement
47 Wind data as of end 2022
48 https://gmk.center/en/infographic/chinas-steel-market-in-2021-2023-overcapacity-and-export-growth/
49 https://splash247.com/only-5-of-chinese-steel-producers-are-currently-profitable/
50 "Top steelmaker Baowu warns Chinese producers face severe crisis" https://www.ft.com/content/41c9fa0d-9b3e-48d4-b4b4-bb8f8863c0e0

5 steel enterprises to achieve an industry concentration ratio of 40%, and the top 10 steel enterprises to achieve a concentration ratio of 60%by 2025.[51] This has serious implications for the labour market in China and will not happen overnight. But in this context, market rationalisation is an opportunity to retire the oldest and least efficient blast furnaces and to make sure the winners of rationalisation have futureproofed EAF and DRI capabilities.

Fundamentally, these policy changes and ambitions are clear responses to market prices and overcapacity, not a decarbonisation mandate. Yet neither the suspension of the steel capacity replacement mechanism or market rationalisation should be considered a barrier to switch (rather than a swap) to EAF production as the key driver of both secondary and primary green steel outputs and near term decarbonisation.[52] Indeed, current EAF targets of 15% share by 2025 need to be raised again for 2030 to nearer 20–25% to make inroads into emissions reduction.

Similarly, to ensure China rapidly increases production of DRI, targets for production must be enshrined in national decarbonisation frameworks. This has to move beyond the definition of "hydrogen metallurgy" in particular to focus on H_2-DRI-EAF specifically.

SUBSIDIES AND FINANCE SIGNALS NEED TO ALIGN TO POLICY

Chinese industrial subsidies introduced at the start of the millennium transformed the global steel market turning China from a net importer to a net exporter. China now produces over half of the world's steel with subsidy-driven overcapacity in production which creates a price floor internationally.

Additionally, the iron and steel industry is grappling with rising debt risks, compounded by a lack of liquidity and reduced operational cash flows driven by high debt levels and rising or sustained high raw material costs.[53] The absence of relevant national subsidies for new and developing technology also challenges the finance and construction of cutting edge green steel projects. In this context, many of the steel companies that are looking at H_2-DRI-EAF and green steel more generally as an existential play but need subsidies and stronger financial signals to encourage investment.

Currently, there are several examples of subsidies for both CAPEX (e.g. EAFs in the US, UK and Spain) as well as subsidies for green hydrogen production). We are currently evaluating the 2030 targets that should be codified in China's 15th Five Year Plan and the levels of subsidy that need to be put on the table for China to keep its global preeminence in low carbon primary steel production. A green steel subsidy should be made up of two instruments: a CAPEX subsidy per tonne of capacity (for build) and a variable subsidy per

51 Guiding Opinions on Promoting High-Quality Development of the Steel Industry (Draft for comments), Ministry of Industry and Information Technology (MIIT), (2020)

52 Notice from the General Office of the Ministry of Industry and Information Technology on the suspension of steel production capacity replacement work, Ministry of Industry and Information Technology (MIIT), (2024)

53 Coking coal prices have increased significantly in recent years and the iron ore prices remain at high levels

tonne. The latter may be ratcheted or linked to the price of hydrogen—as green hydrogen gets cheaper the variable subsidy should get smaller until we hit $2/kg of green hydrogen. Where this green hydrogen is produced by the steel company itself, subsidies should also be available here.

RECOMMENDATIONS

We summarise below: current targets; level of readiness; and where applicable, a gap analysis where relevant for China, to establish mature green steel capabilities and maintain its preeminence in primary steel production.

DRI TARGETS

Where targets have been set for EAF-based steel, ironmaking production technologies have not featured targets pushing for a technological shift toward DRI. Chinese policy makers should set top down targets for DRI making technologies. Since the implementation of the capacity swap policy, new ironmaking facilities are largely BF to BF swaps with increased efficiencies. To ensure China rapidly increases production of DRI, targets for DRI production must be enshrined in industrial decarbonisation policies.

INCREASING EXPANSION OF EAFS

China's current EAF steel production target is for 20% of steel production to be produced through EAFs by 2030. While this target is still 7 years away, when compared globally, China's usage of EAF-produced steel remains underweight, with approximately 30% of global steel coming from EAFs each year. If excluding China, global EAF-based steel production nears 50%. Most EAFs in China utilise scrap as a feedstock producing low carbon secondary steel. However, as primary steel production is still required, EAFs must be built to accommodate low carbon iron in the form of DRI.

DOMESTIC ELECTROLYSER PRODUCTION

Driving the costs of electrolysers will be key to realising lower hydrogen prices in China where there is no green hydrogen production currently at scale for the steel industry. Well-coordinated industrial strategies have propelled China forward as the market leader in wind and solar electricity where Europe and Japan have historically been the strongholds for these industries, respectively. Building and maintaining a favourable policy environment while leveraging the positive early signals from domestic investors can help scale Chinese electrolyser manufacturing capabilities and ultimately drive down costs.

CORPORATE RENEWABLE ELECTRICITY SUPPLY

As one of the most affecting parameters of green steel production costs, cheap and available renewable electricity is crucial for the realisation of competitive green steel production. Required for hydrogen production, transportation and storage, heating and EAF power, the ability of steel manufacturers to source zero carbon electricity at such scale likely hinges on their ability to acquire non-captive, grid-based renewable electricity through corporate power purchase agreements CPPAs. With electricity prices needing to be close to technology specific levelised cost of electricity (LCOE) to reach competitive green steel prices, PPA market design is integral to low hydrogen costs and the viability of H_2-DRI in China. Where western baseload PPA markets have seen significant increases in costs due to high market prices and increasing cannibalisation risk, Chinese policy makers should seek to develop a favourable baseload PPA market mechanism designed for variable renewable electricity generation, providing offtakers the stability of continual power provision and hedged electricity prices.

CARBON PRICING

Carbon markets in Europe have seen marginal costs of fossil fuel intensive industries skyrocket. Expanding carbon pricing to the steel sector introduces the "stick" to the industry for failing to decarbonise. Encouragingly, signals that the iron and steel industry will be brought into China's ETS mechanism are becoming stronger. In less than 3 years, carbon pricing in China has more than doubled, exceeding 100 RMB/tCO_2 in May 2024. For this mechanism to benefit low carbon steel producers in the same direction as the power sector, policy makers should gradually introduce stringent benchmarks, bring in more market players such as renewables energy providers and the financial sector to increase market liquidity and explore introducing emissions allowance auctioning into the ETS.

GREEN HYDROGEN SUBSIDISATION

With the price of green hydrogen being the most cost effecting parameter of the H_2-DRI-EAF process, reducing the costs is crucial to the decarbonisation of the steel industry. Green hydrogen production is currently subsidised in the USA and Europe at $3/kg and $2.2/kg respectively.[54] European hydrogen subsidies are slightly more complex than those in the United States where the direct subsidy is provided to the producer based on the carbon intensity of the hydrogen produced. Policy makers in China should seek to establish a simple direct subsidy mechanism, providing producers with certainty around costs. As costs related to hydrogen production decrease, the subsidy can be reduced over time, similar to the feed-in-tariffs that have decreased RE prices.

54 https://www.menon.no/wp-content/uploads/2023-48-Hydrogen-subsidy-regimes.pdf

FURTHER READING

Green Steel Economics Comparing Economics of Green H2-DRI and Traditional Steelmaking Around the World

Decoding China's Steel Capacity Replacement Policies: A Decade-Long Journey, Pausing to Forge Ahead

DATA AND DISCLAIMER

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Founded in 2021, Transition Asia is a Hong Kong-based non-profit think tank that focuses on driving 1.5°C-aligned corporate climate action in East Asia through in-depth sectoral and policy analysis, investor insights, and strategic engagement. Transition Asia works with corporate, finance, and policy stakeholders across the globe to achieve transformative change for a net-zero, resilient future. Visit transitionasia.org to learn more.

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