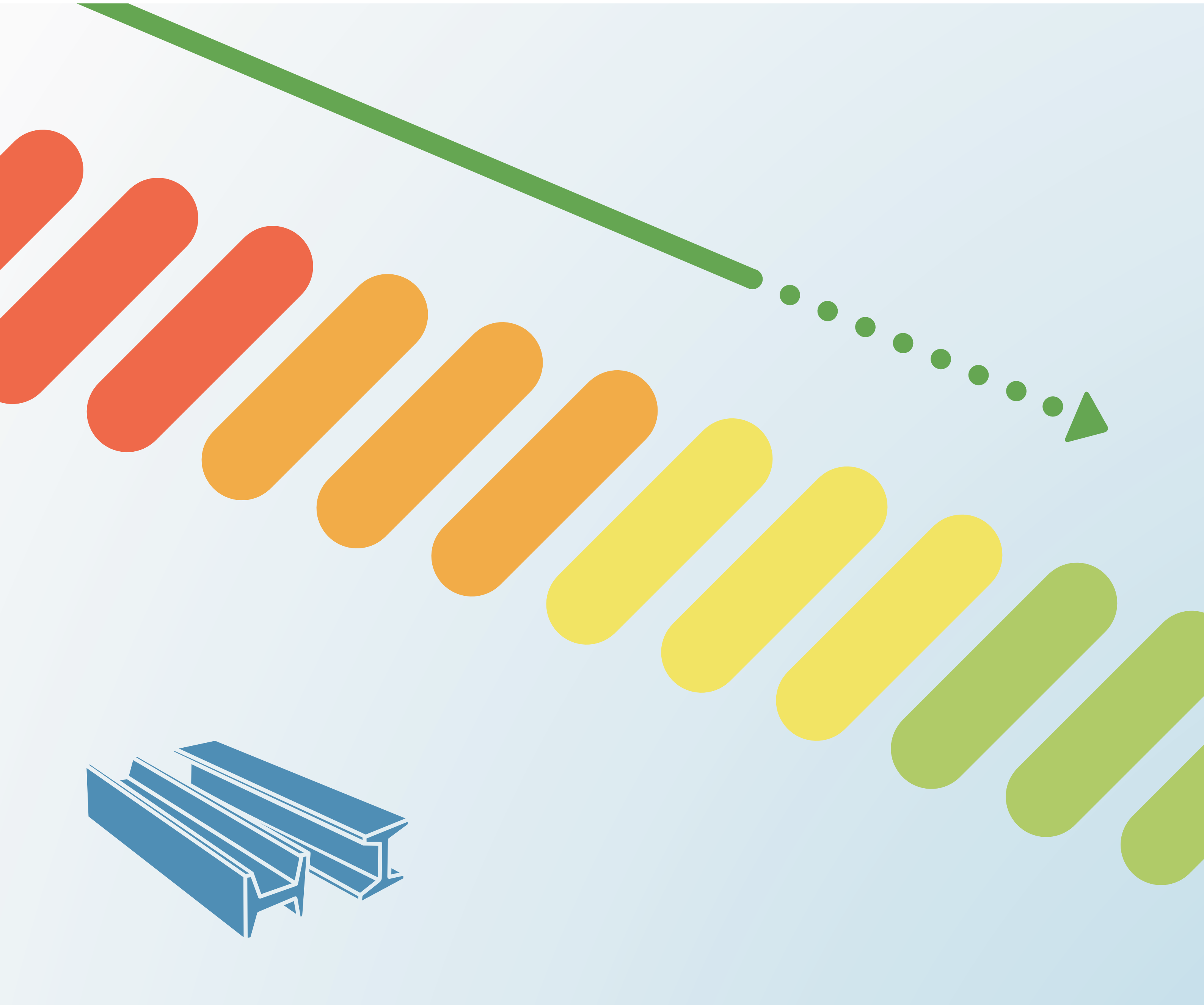


Climate Action Tracker

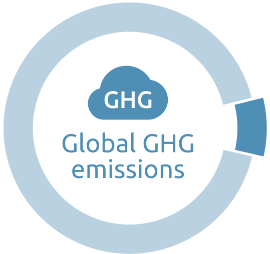
Decarbonising steel

National circumstances and priority actions

August 2024

NewClimate Institute
Climate Analytics

Summary



Steel production
7–8% of global emissions

Decarbonisation of this "harder-to-abate" sector by mid-century is very possible and a fundamental step to reaching net zero

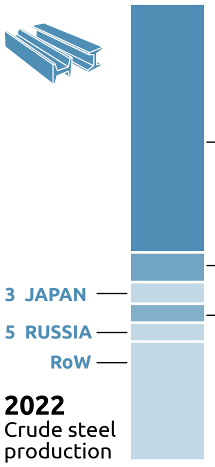
Iron and steel production currently contribute around 7-8% of global greenhouse gas (GHG) emissions, so decarbonising this sector is fundamental to reaching net zero and meeting the Paris Agreement's 1.5°C warming limit.

While decarbonising the steel sector is now technically feasible, different countries face different challenges in making this happen at the pace needed. This so-called "hard-to-abate" sector has seen rapid developments in recent years.

The main challenge for the sector is shifting infrastructure from today's predominant blast furnaces that run on GHG-intensive coal-derived coke to electric arc furnaces (EAFs) running on clean power that process scrap steel, or direct reduced iron (DRI) produced with zero carbon feedstocks, such as green hydrogen.

Different contexts and steel production portfolios

Examples of 3 leading steel producing nations with unique challenges to decarbonise and build a green steel industry



1 CHINA
54.1%
1020 Mt
Expansion has largely plateaued after rapid and massive expansion of mainly coal based BF-BOF infrastructure in early 2000s

2 INDIA
6.6%
125 Mt
Industry is in a state of steady growth and has the opportunity to redirect expansion plans towards green steel making processes

4 UNITED STATES
4.3%
81 Mt
A mature market with ample scrap steel availability, US steel is largely EAF based that has an easier path to decarbonisation

This report highlights that the specific challenges different countries face differ substantially according to the status of the steel industry and its likely future development. Determining the fastest possible speed of action therefore needs to take these challenges into account.

We explore the specific challenges for three countries – China, India and the US – to highlight what is needed to make progress in decarbonising their steel sector. Three big differences between them are:

- The existing infrastructure for various technologies
- Future trends in steel production and capacity
- Factors that limit the potential for lower GHG-intensive steel production, such as scrap steel availability and access to high-grade iron ore

China

China's is the world's largest producer of crude steel, with a high contribution from the coal-based Blast Furnace to Basic Oxygen Furnace (BF-BOF) production route and, with that, a high emissions intensity. Existing infrastructure in China is relatively young, so switching to cleaner production will require it to decommission some existing steel plants.

Steel production in China is unlikely to increase in the coming decades, and scrap steel is becoming more available, allowing China to shift toward electric arc furnaces that recycle this scrap – a much cleaner technology.

India

India's steel industry is the world's fastest-growing, and one of the most emissions-intensive. The sector is expected to continue to grow in the coming decades to meet increasing demand for roads, buildings and other infrastructure. The presently planned steel production infrastructure to meet that demand is carbon-intensive and, if built, risks locking in emissions.

As India doesn't have a lot of scrap steel available, it will still need to produce raw steel to meet demand. Clean technologies for producing raw steel, such as green hydrogen-based DRI, are in a prototype phase, with some plants under construction. India is in a fortunate position with respect to domestic availability of high-grade iron ore but still faces challenges with scaling up green hydrogen. India will need international support to shift its development to cleaner technology routes.

The United States

Steel production in the US has a relatively low emissions intensity because its steel industry is older and there is a high amount of both Electric Arc Furnace (EAF) capacity, and scrap steel available for recycling. To further reduce emissions from this sector, the US could close its remaining blast furnaces and prioritise decarbonising its power sector. The Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Law are boosting US steel demand while promoting emerging clean technologies, such as green hydrogen.

Global developments will also impact the decarbonisation of steel production, such as the development of low-cost green hydrogen, the availability of high-grade iron ore, and the decarbonisation of the power sector. Decarbonising steel therefore still relies on investment in research and development, and rapid scale-up of the necessary technologies.

The conclusions we draw above demonstrate some specific challenges that these three individual countries will face on the path to a zero-emission steel industry. Other countries are in similar situations with respect to their existing infrastructure, expected future demand and availability of resources. Such countries can draw similar insights from this analysis for developing their Paris compatible steel industry.

1.5°C Key takeaways

- The electrification of steelmaking and decarbonising the power sector are fundamental to ensuring zero carbon emissions from of the steel sector by 2050.
- Maximising scrap recycling through EAF should be a paramount strategy for the decarbonisation of the steel sector.
- Decarbonising DRI-EAF by using green hydrogen instead of fossil fuels will be an important route for producing zero-carbon primary steel. Scaling up production will depend on technology advancements and the availability of raw materials.
- Phasing down BF-BOF capacity globally is a necessary step toward a 1.5°C compatible steel sector, given the insufficiency of CCUS for emission reductions.
- New steel infrastructure should be zero emissions wherever possible, and new fossil fuel-dependent blast furnace infrastructure should not be planned or constructed.
- Phasing down BF-BOF capacity globally is a necessary step toward a 1.5°C compatible steel sector, given the insufficiency of CCUS for emission reductions.

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Introduction

Background and objectives

Over 1.8 billion tonnes of steel are produced globally each year for a wide range of applications, including construction, transportation infrastructure, vehicles, machinery, renewable power generation facilities, etc. The steel industry is a major carbon emitter, contributing 7-8% of global GHG emissions (excl. LULUCF) (IEA, 2020; WSA, 2023b).

Steelmaking has traditionally been viewed as a "hard-to-abate" industry due to limited alternative technologies for primary production and the enduring lifespan of steel mills and equipment. But recent advancements in technology, policy commitments, and private investments have made the transition possible (Davis et al., 2021).

Moving towards achieving a net zero sector aligned with the global 1.5°C goal, the carbon intensity of global steel production should experience a substantial reduction. Currently standing at 1,890 kg CO_2/t crude steel (kg CO_2/tcs), this figure should drop to 1,340-1,350 kg CO_2/tcs by 2030 and further decrease to 0-130 kg CO_2/tcs by 2050 (Climate Action Tracker, 2020a; Boehm et al., 2023).

The main challenge to decarbonising the steel industry is its heavy reliance on coal, which varies significantly across regions and countries with different social and economic contexts. Strategies for replacing coal-based steel production capacity with cleaner alternatives will vary for each country and hinge on several factors:

- Projected demand for steel.
- Existing infrastructure for different technologies and their age distribution.
- Constraints associated with alternative steelmaking routes, such as the availability of high-grade iron ore and scrap steel.
- Access to and affordability of emerging clean technologies, such as green hydrogen.

By understanding these factors, this report lays the groundwork for the development of tailored national benchmarks. We look at three country examples of China, India, and the US, to show how current circumstances and projected demand for steel determine what a path to a net zero steel production could look like. Each of the three countries faces unique challenges in decarbonising their steel sector over the coming decades. We discuss the prospects for different steel production and decarbonisation pathways specific to each country, as well as identifying their priorities:

- China, as the world's largest steel producer, should find routes to decommission its Blast Furnace to Basic Oxygen Furnace (BF-BOF) capacity, replacing it with green steel production where needed, and expand scrap recycling through new electric arc furnaces (EAFs).
- India needs to focus on integrating clean technologies, such as green hydrogen, into its rapidly growing steel industry while ceasing further investment in and construction of BF-BOF plants.
- The US has a well-established steel industry that relies heavily on scrap steel recycling: it should prioritise decarbonising power generation as well as further electrifying the steel sector.

Some of these considerations can be applied not only to the countries discussed in this report but also to others facing similar circumstances. By understanding the unique challenges and opportunities of each nation, policymakers, industry leaders, and stakeholders can develop tailored strategies for decarbonising the steel sector. While not exhaustive, these insights provide valuable guidance for navigating the complexities of steel sector decarbonisation.

	China	India	US
Existing infrastructure	Significant capacity of young emissions-intensive blast furnaces	Significant coal-based capacity. Small but increasing emissions-intensive blast furnace fleet	Mostly transitioned from emissions-intensive blast furnaces to lower emission electric arc furnaces
Trend in steel production	Stable	Increasing	Stable
Scrap steel availability	Medium	Low	High
Main individual challenge	Decommissioning of the young blast furnace fleet before end of economic lifetime	Scaling up green hydrogen steel production to meet growth in demand; requires international support	Decarbonising the power grid to provide green electricity to electric arc furnaces
Common challenges	▸ All new installations should be EAFs or green hydrogen steel ▸ No new blast furnaces and phase-out existing ones ▸ Collect/recycle as much scrap steel as possible ▸ Decarbonise the electricity grid		

Current steel production routes & their decarbonisation options

Steel can be primarily produced from iron ore, as well as recycled from scrap steel. Primary steel production involves two main routes - the BF-BOF route and the DRI-EAF route, where the iron ore is reduced into iron and then refined, formed, and treated into crude steel. Steel can also be recycled from scrap steel through an EAF, also known as secondary steelmaking (Figure 1).

Blast Furnace to Basic Oxygen Furnace (BF-BOF)

The BF-BOF route is currently the dominant method for producing steel, constituting 71% of total production, yet it is acknowledged as one of the highest carbon-emitting and energy-intensive approaches (WSA, 2023b).

A significant amount of coking coal is used in the blast furnace (BF) process to reduce iron ore and produce pig iron. The pig iron is then refined in a basic oxygen furnace (BOF). To decarbonise BF-BOF steelmaking, options like improving energy efficiency and switching to different fuels have limitations, as the existing technologies still rely on coal. The use of emerging CCUS technologies to reduce emissions from BF-BOF steelmaking is being discussed and piloted but capture rates substantially below 100% mean that CCUS is also limited and cannot fully decarbonise steel production (see below).

Electric Arc Furnaces (EAF)

The second most common production route today uses EAF to recycle scrap steel, contributing 22% of global steel production (WSA, 2023b). The scrap-based EAF route requires about one-third of the energy in the BF-BOF route, which can be exclusively fed by electricity and could therefore be fully decarbonised if the power is produced from clean sources (Climate Action Tracker, 2020b).

The expansion of scrap recycling is limited by the local availability and quality of scrap steel which vary significantly across countries. Technological constraints prevent the complete removal of some impurities like copper and tin from scrap, necessitating the continued production of high-quality primary steel for certain products (Transition Asia, 2023).

Direct Reduced Iron to Electric Arc Furnace (DRI-EAF) with green hydrogen

In addition to recycling scrap, EAF can also contribute to primary steelmaking by upgrading or refining DRI, offering another low-emission alternative to BF-BOF. Today, this production route only makes up about 7% of global steel production (WSA, 2023b).

In the DRI-EAF process, iron ore is directly reduced into sponge iron that is then fed into an EAF for steel manufacturing. The reducing agents currently used, carbon monoxide and hydrogen, come from reformed natural gas, syngas, or coal.

By replacing the reduction agent with green hydrogen, the DRI route has the potential to achieve significant decarbonisation. This route currently faces challenges due to varying access to high-grade iron ore in different countries, impacting DRI production feasibility. Additionally, the ability to produce low-cost green hydrogen varies across nations, influencing the economic viability of hydrogen-based DRI production (IEEFA, 2022b).

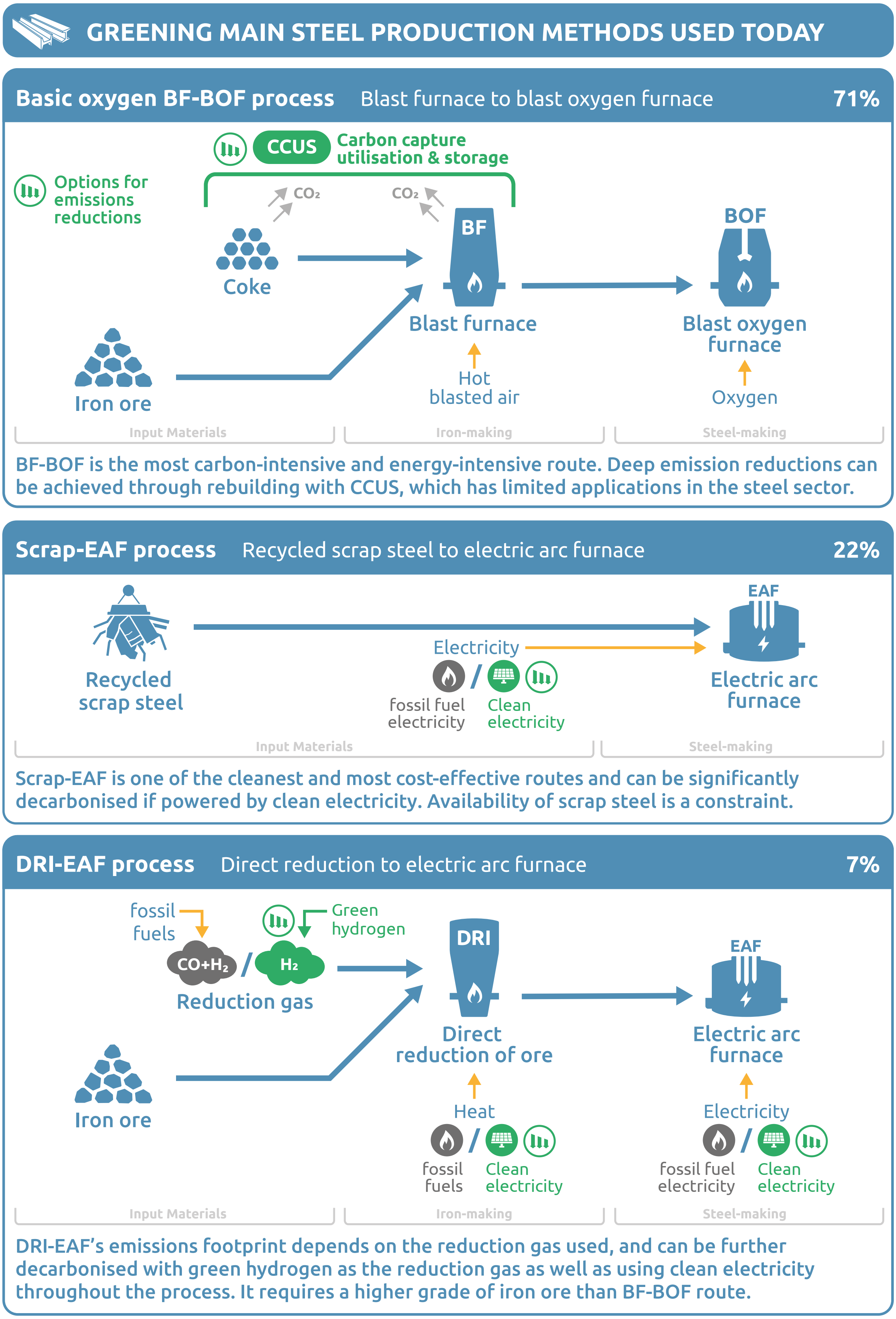

Figure 1 The three major steelmaking routes with decarbonisation options

What makes the steel decarbonisation challenge different across countries?

The most appropriate steel decarbonisation route for a country and the transition pathways are primarily determined by three factors: future steel demand and current infrastructure, the availability of scrap steel, and access to high-grade iron ore and low-cost green hydrogen. Here, we outline how these different factors can help determine decarbonisation priorities for countries. Below, we further elaborate on what that means for China, India, and the US.

Demand and infrastructure

The growth trajectory of steel demand directly influences the build-out or decommissioning of steelmaking infrastructure and the economics of the sector in each country.

With steel demand fluctuating across nations—some experiencing shrinkage, stabilisation, or expansion—decisions regarding the need for new infrastructure to meet growing demand or the potential replacement of existing infrastructure become crucial. A country's future steel production prospects also hinge on the strategic decisions of steel companies, including whether they choose to continue domestic steel production, or expand abroad.

Global steel production is anticipated to increase from 1.8 billion tonnes in 2022 to approximately two billion tonnes in 2030 and 2.5 billion tonnes in 2050 in most business-as usual scenarios, while situations in different countries vary significantly (IEA, 2020; WEF, 2022; IEA, 2023b; Bronk-Company, 2023).

A country's demand for steel products stems from various sectors, including construction, machinery, energy, transportation, and other infrastructure. Different stages of development result in varying landscapes and outlooks for steel demand.

For instance, compared to the current global average steel consumption of 224 kg per capita, India's per capita consumption stands at 82 kg, indicating substantial room for growth driven by a burgeoning domestic need for infrastructure development.

In contrast, countries like China, with a per capita steel consumption of 649 kg, and the US, at 279 kg per capita, have relatively saturated infrastructure markets, leading to expectations of stabilised or declining domestic steel demand levels (WSA, 2023a).

Countries currently have various steel production infrastructure in place which will determine the optimal route toward decarbonisation.

While scrap-based EAF steelmaking backed with a clean power system is considered the cleanest and most cost-effective production method available, not all countries' steel industries are ready to transition to this cleaner production model, especially those with heavy blast furnace assets that are subject to carbon lock-in.

In order to design a suitable transition pathway and establish the proper benchmarks towards a net zero steel industry, it is essential to understand different starting points for countries, such as the share of steel produced via different routes as well as the age of the operating assets.

Blast furnaces typically operate for around 40 years, undergoing lifetime-extending relining every 15–20 years at a cost of 25-50% of that required for a new blast furnace (Steel Watch, 2023; Swalec and Grigsby-Schulte, 2023). By 2030, approximately 1,090 million tonnes per annum (Mtpa) of existing coal-based blast furnaces, constituting 73% of the fleet, will have reached the end of their 40-year operational life (Swalec and Grigsby-Schulte, 2023). The strategic decision between relining existing blast furnaces and building EAFs equipped with cleaner technologies shapes the trajectory towards net zero in the steel industry.

Availability of scrap for secondary steelmaking

Scrap-based EAF is considered as one of the cleanest and most cost-effective steelmaking pathways while being independent of nascent technologies like green hydrogen and CCUS.

The adoption of EAF technology represents a sustainable departure from blast furnaces, utilising electricity rather than coke as the energy input, thereby enhancing steelmaking efficiency and significantly lowering carbon emissions.

In comparison to DRI-EAF, choosing scrap as the primary raw material for EAF operations not only mitigates the environmental toll associated with raw material extraction, but also addresses the energy-intensive processes integral to transforming iron ore into steel. By prioritising the circular economy principles facilitated by EAFs, the steel industry can effectively contribute to the realisation of the Paris Agreement's ambitious climate objectives.

The pivotal role of scrap recycling extends beyond environmental considerations; it significantly contributes to energy conservation. The re-melting of scrap demands significantly less energy compared to the production of iron or steel products from iron ore. Consequently, integrating iron and steel scrap through re-melting not only alleviates the strain on landfill disposal facilities but also curbs the accumulation of discarded steel products in the environment, aligning with sustainable and resource-efficient practices.

Scrap availability is the biggest limiting factor in expanding clean, efficient, and cost-effective secondary steelmaking (De Villafranca Casas et al., 2022).

The steel sector in developed countries such as the US has one of the lowest CO_2 emissions intensities, thanks to its ample availability and consumption of scrap steel. In emerging economies such as China and India, where domestic scrap steel production is increasing, Scrap-EAF is expected to play a greater role in the steel sector in the future.

The global steel scrap supply is projected to increase steadily from 750 Mt in 2017 to 1 billion tonnes by 2030 and further to 1.3 billion tonnes by 2050, with uneven distribution across regions (Çiftçi, 2018). In relatively highly industrialised and urbanised developed countries, the growth of scrap availability is expected to be slow: it is estimated to rise from 320 Mt in 2017 to 350 Mt by 2030 and 380 Mt by 2050 (Çiftçi, 2018). The remaining growth will be driven primarily by developing countries, notably China, reflecting the dramatic surge in its consumption of steel products over the past 30 years.

Access to high-grade iron ore and low-cost green hydrogen

The DRI-EAF with green hydrogen can be one of the cleanest routes for making primary steel.

But currently, it only contributes to 7% of total steel production. The potential for countries to mainstream DRI-EAF steel production while decarbonising it with green hydrogen varies across regions, mainly influenced by two key factors: access to high-grade iron ore and the ability to produce low-cost green hydrogen.

Access to high-grade iron ore places a limiting constraint on expanding DRI production.

DRI-EAF steelmaking requires a higher grade of iron ore, with a minimum iron content of 67%, given the heightened sensitivity of the EAF to impurities compared to a basic oxygen furnace (IEEFA, 2022c). Today, DR-grade iron ore constitutes approximately only 4% of global iron ore exports (Fastmarkets, 2021). Therefore, countries with access to their own high-grade iron deposits may have an advantage in switching to this route, while trade can still enable the switch where the deposits are not locally available.

Meanwhile, the overall quality of iron ore has been on a downward trajectory over the past two decades, presenting potential hurdles for the expansion of DRI-EAF steelmaking (IEEFA, 2022c). Research suggests a significant shortage of commercially available DR-grade iron ore by the early 2030s (Barrington, 2022).

Looking ahead to 2050, increased investments in ore beneficiation – processes to enhance iron ore quality - hold promise for satisfying an escalating demand for DR-grade iron ore needed for green steel production (Barrington, 2022). Beneficiation has additional environmental benefits in that it can increase the amount of iron ore that is usable, reducing mining waste.

The availability and affordability of green hydrogen largely determine whether a country can establish a zero-carbon primary steel production.

Currently, only 1% of global hydrogen production derives from electrolysis using renewable power sources, with the production cost of green hydrogen averaging two to three times that of grey or blue hydrogen (IRENA, 2023; Schelling, 2023). As of 2021, global green hydrogen production capacity remains minimal, at just 0.027 Mt.

However, transitioning to a 1.5°C pathway necessitates a rapid expansion of green hydrogen use. Globally and across all sectors, it's estimated that 58 Mt of green hydrogen will be needed in 2030 and 329 Mt in 2050 (Boehm et al., 2023). = Ramping up green hydrogen production to these levels will require major investments this decade. Many governments are providing support to this nascent industry - as of 2023, 41 governments had adopted hydrogen strategies, although not all of these are exclusively green hydrogen focused (IEA, 2023a).

Access to CCUS technology

Despite the scaling up of CCUS globally, its application in the steel industry remains limited.

Among the 41 CCUS facilities currently in operation and the 351 in the pipeline, most are categorised as being only in the "early development" stage (Global CCS Institute, 2023). The only commercial-scale CCUS facility in the steel sector, located in the United Arab Emirates, captures CO_2 emissions from a DRI plant. Even at full capacity, the plant's capture rate is estimated to be only 19%-26% (IEEFA, 2024). Furthermore, the captured CO_2 is used for Enhanced Oil Recovery (EOR), which itself is an emissions-intensive process that prolongs the use of fossil fuels. (The University of Edinburgh, 2023).

Aside from the operating Al Reyadah CCUS plant, there are three CCUS facilities for steel production in the pipeline, two of which focus on DRI-based steelmaking instead of the dominant and most carbon-intensive BF-BOF route (Global CCS Institute, 2023).

CCUS technology does not efficiently and cost-effectively reduce emissions from BF-BOF steelmaking, whether retrofitting an operating plant or rebuilding a new one.

Retrofitting existing BF-BOF facilities with CCUS facilities faces significant challenges, with moderate capture rates of maximum 50% (De Villafranca Casas et al., 2022). The low CO_2 concentration in blast furnace exhaust gases complicates and increases the expense of CO_2 capturing. And the presence of multiple CO_2 emission point sources in the process (such as from coke ovens, sinter plants, blast furnaces, and basic oxygen furnaces) adds to the costs by necessitating the installation of multiple capture facilities and infrastructure (Swalec and Grigsby-Schulte, 2023).

Capture rates could by increased to up to 90% through a complete plant rebuild and the integration of CCUS and CO_2 concentrating facilities (Bataille et al., 2021). However, residual upstream emissions, like coal mine methane leakage, remain unaddressed (Witecka et al., 2023).

CCUS cannot be the excuse for continuing the construction of new coal-based capacity.

Carbon capture on blast furnaces is not compatible with near-zero emission targets. CCUS facilities in the steel sector may be viable under specific conditions, such as in nations with little access to DRI-grade iron ore or scrap steel. But considering the residual emissions and technological uncertainties around CCUS, its implementation should not necessarily justify the development of new coal-based steelmaking capacity. Instead, countries should first consider electrified steelmaking using either green hydrogen based DRI or scrap steel.

Country profiles

We examine the implications of these different factors for three countries that are currently in very different situations regarding steel production: China, India and the US. For each we describe the current status of the industry in that country, look at what a rapid path to decarbonisation would look like, and the actions that would be needed to shift on to that path.

China

National targets and government priorities

China boasts the world's largest steel-making capacity, contributing over half of the global crude steel production (WSA, 2023b). Meanwhile, China commands 59% of the global coal-based BF-BOF capacity, accounting for more than 60% of carbon emissions in the global steel industry (Jie et al., 2021; Swalec and Grigsby-Schulte, 2023).

In China, the steel sector serves as a substantial energy consumer and CO_2 emitter, contributing to 13% of the country's total energy consumption and 15% of CO_2 emissions (Zhang et al., 2023). The CO_2 emissions-intensity of China's steel industry is 1,970 kg CO_2/tcs in 2019, compared to the global average of 1,850 kg CO_2/tcs (Hasanbeigi, 2022; WSA, 2022). This is mainly due to China's high reliance on coal, which accounts for 75% of the energy inputs for steelmaking (Domenech et al., 2022).

China's latest Nationally Determined Contribution (NDC) aims to peak the country's carbon emissions by 2030 and strives for carbon neutrality by 2060. Meeting these broad objectives will require the steel industry to significantly reduce its energy consumption and CO_2 emissions. Notably, China has delayed its steel sector emissions peaking timeline to 2030 after initially consulting on a more ambitious target to peak in 2025, and reduce its emissions by 30% from the peak by 2030 (Climate Action Tracker, 2023a).

Demand and infrastructure

China's steel demand and production are anticipated to peak by 2025.

Following the pandemic in 2020, China experienced a decline in steel output of 3% in 2021 and 1.7% in 2022, stabilising at approximately 1.02 billion tonnes in both 2022 and 2023 (Lv and Hayley, 2024). This downturn primarily stemmed from decreased demand in the property sector, based on which the Rocky Mountain Institute (RMI) also projected that China's domestic steel demand will peak by 2025, gradually decreasing to 934 Mt in 2030 and 571 Mt in 2050 (Chen et al., 2021).

Steel production may not necessarily follow the same downward trend if companies choose to maintain operating rates for higher exports rather than retiring current capacity. To achieve the sector's carbon peaking target by 2030, the Chinese government has suggested that steel production will peak at around 1.16 billion tonnes in 2025, emphasising the importance of production control in reducing emissions (Zhang and Chow, 2021).

China's steel production capacity continues to rise slowly, posing challenges to emissions reduction in the steel sector.

Despite the target of controlling steel output and decreasing demand, companies continue to invest in new production capacity, totalling 207 Mtpa under development (Swalec and Grigsby-Schulte, 2023).

Continued investments in new capacity and sluggish domestic steel demand have together led to sustained losses for Chinese steel companies, with 2022 being the "worst year in two decades" for steel makers (Zhang, 2023). Addressing overcapacity and accelerating industrial transformation emerge as crucial drivers for production and emission reductions in the steel sector, underscoring the need for comprehensive strategies to effectively navigate these complexities.

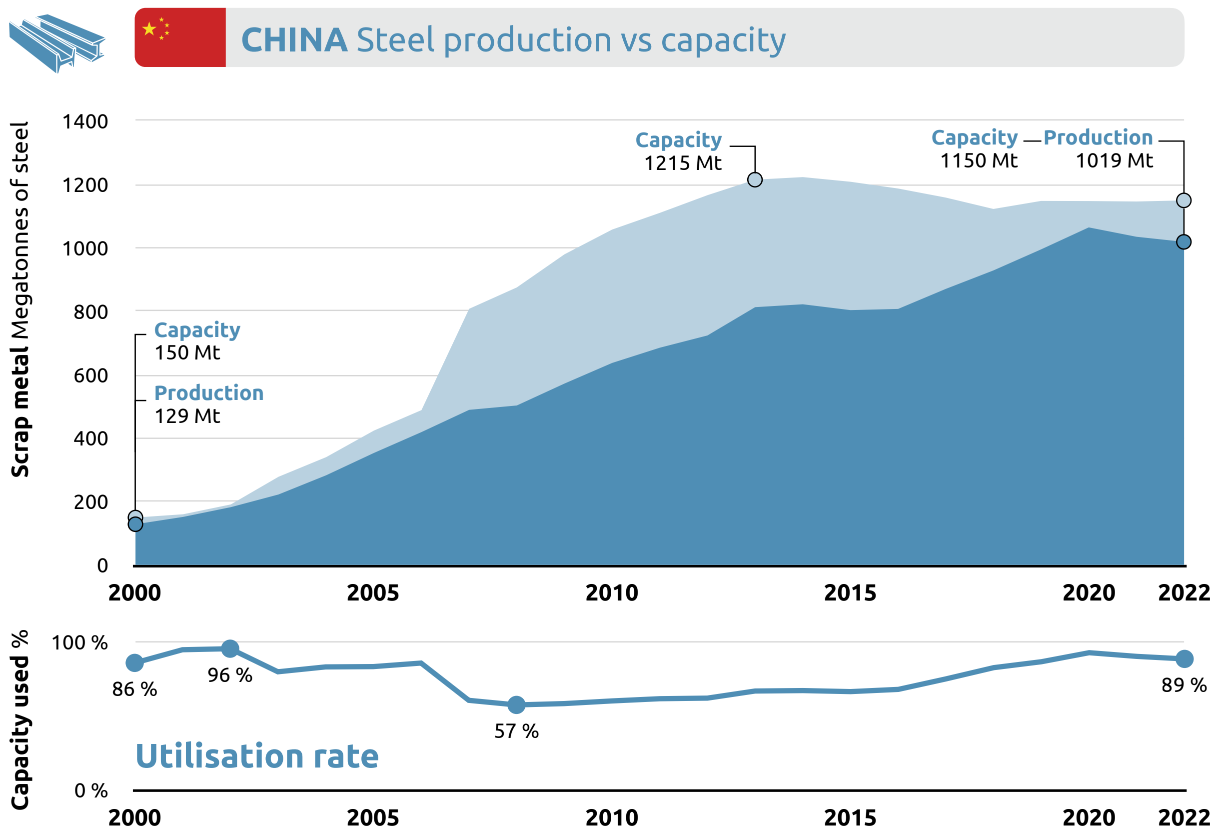

Figure 2 Crude steel production, capacity, and utilisation rate in China *(Source: OECD.Stat, World Steel Association)*

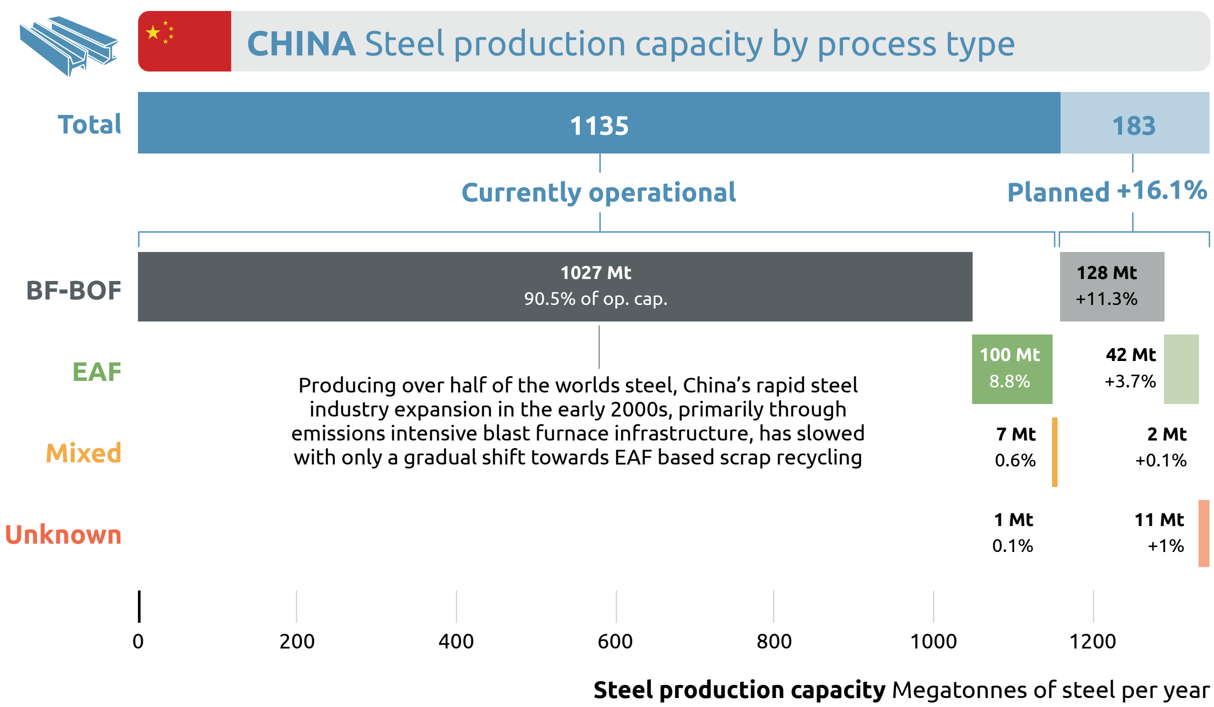

Figure 3 Current and planned Steel production capacity by different production process in China (Source: Steel Plant Tracker by Global Energy Monitor)

China's steel industry is emissions-intensive because it predominantly relies on the high-emitting BF-BOF production route.

90% of the greater than 1100 Mtpa production capacity follows the BF-BOF route while a modest 9% uses the EAF route with both DRI and scrap. Meanwhile, China has an additional 200 Mtpa capacity in the pipeline, marked by a notable increase in the share of EAF (21%).

However, compared to the large stock of existing BF-BOF capacity, the addition of alternative technological production capacity remains insignificant. If all planned plants were to be constructed, the share of steel production through BF-BOF methods would remain as high as 88% by 2025. Given the relatively modest capacity pipeline and the already peaked and stabilised demand for steel, achieving decarbonisation in China's steel sector necessitates addressing the substantial existing stock of blast furnaces (Figure 3).

The future of BF-BOF steelmaking and its decarbonisation

Phasing down China's existing blast furnaces is essential to reach carbon neutrality in the steel sector as CCUS would not be able to fully decarbonise them.

With over 1000 Mtpa of BF-based steelmaking capacity in operation, neither retrofitting or rebuilding with CCUS facilities could achieve effective or economical emission reduction.

Retrofitting the massive stock of BF-BOF in China with CCUS facilities can only achieve an emissions reduction rate of under 50%, while extending the lifespan of the coal-based plants, which could have been phased-out (De Villafranca Casas et al., 2022). Rebuilding new BF-BOF capacities with CCUS infrastructure and CO_2 concentration units would require massive investments but still be 1.5˚C incompatible because of the residual emissions.

Moreover, the application of CCUS would bring a cost premium to steel production. The cost premium would be even more difficult for Chinese steelmakers to bear, especially given the massive losses of steel plants due to overcapacity, and the government-driven lower prices to be more competitive in international trade (Gobitz, 2021; Zhang, 2023). Replacing BF-BOF steel production with cleaner and more cost-competitive production pathways (e.g. scrap-EAF) will therefore be inevitable.

Ceasing further investment and implementing an early retirement plan would yield significant reductions in China's BF-BOF capacity by 2050.

Blast furnaces typically operate for around 40 years and undergo lifetime-extending relining every 15–20 years (Swalec and Grigsby-Schulte, 2023). In China, 20% of BF-BOF plants are over 40 years old and have already undergone multiple relinings and reconstructions. Halting reinvestment in these plants for the subsequent cycle is crucial to gradually phasing down BF-BOF capacity and achieving a net zero steel industry by 2050 (Figure 4).

The remaining almost 80% of China's operating BF-BOF plants, totaling 770 Mtpa, haven't reached the age of 40. While it is imperative that any rebuild/relining of these plants incorporates CCUS technology to facilitate substantial emissions reductions, given the cost of CCUS and its as-yet-unproven technical viability, a more economically viable option may be to close them down.

Retirement, rather than relining, of China's existing BF-BOF capacity after 20 years would substantially reduce pre-2040 emissions from the sector.

Figure 5 delineates the anticipated BF-BOF capacity until 2050, accounting for varying rates of plant closures. In a scenario where China's current blast furnaces would continue to operate until each plant reached the lifetime of 40 years, there would still be 740-780 Mt of operating BF-BOF capacity by 2030 and 200-240 Mt by 2050. This presents a major challenge for decarbonisation, even if more CCUS facilities were installed. If existing plants were retired after 20 years of operation, China's BF-BOF capacity could be phased out already by 2045.

Halting the construction of new blast furnaces has a relatively modest impact on the overall capacity trend (Figure 5). This is because the announced capacity is much lower than the huge existing BF-BOF stock and projects already under construction in the country. However, given the existing over-capacity and need to shift to cleaner technologies, these new BF-BOF projects should not go ahead.

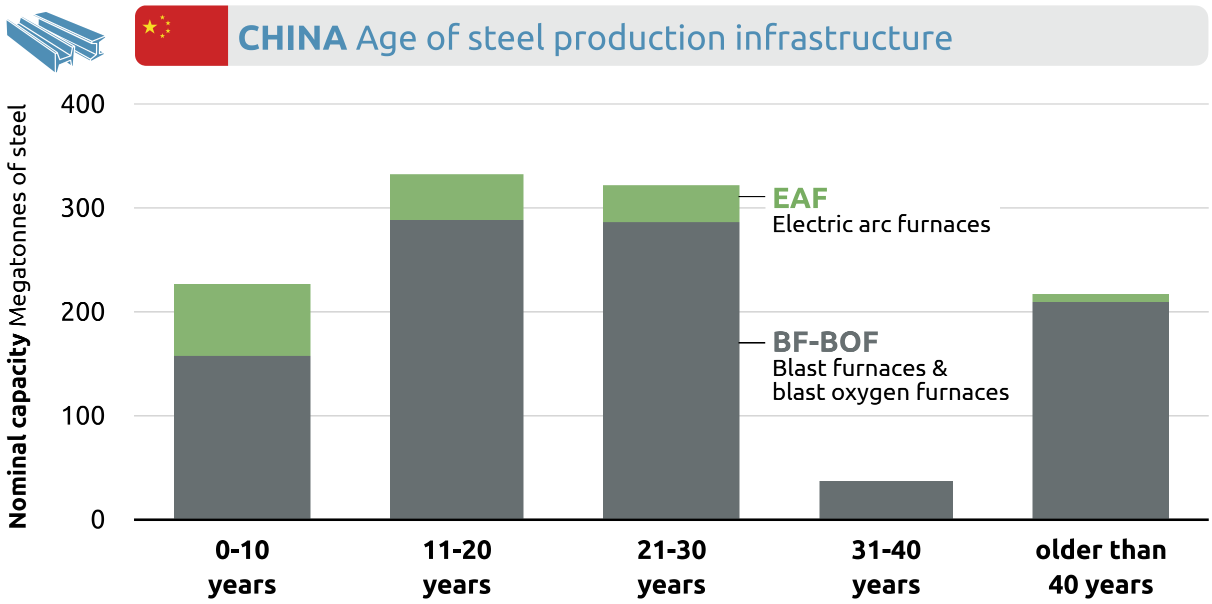

Figure 4 Capacity of Steel Plants of different Age in China (Source: Steel Plant Tracker by Global Energy Monitor)

Financial feasibility emerges as a primary impediment to ceasing all reinvestments on blast furnaces, given that many plants might struggle to recover upfront investments, imposing a substantial financial burden on investors. Nevertheless, this contrast underscores that, in an ideal scenario, expeditious and substantial measures can effectively diminish the extensive blast furnace inventory in China, provided there is ample funding available.

The future of scrap-EAF steelmaking

Expanding EAF capacity is one of the prerequisites for increasing clean secondary steelmaking in China.

Currently, EAF steel production only makes up less than 10% of the total steel made in China, with about 100 Mtpa of electric-based capacity in operation (Jiang, 2023). If the dominant BF-BOF route does not make way for EAF, it will be difficult to decarbonise steel production in China. Therefore, the Chinese government is encouraging steel companies to phase out outdated BF-BOF capacity and adopt EAFs, aiming to have 15% of steel production produced through EAFs by 2025 and 20% by 2030 (Zong, 2022).

However, progress has been slow - although local governments have been approving 52.5 million tonnes of EAF projects annually, their share of total crude steel production hasn't increased as expected, as investments continue to pour into coal-fired steel projects (Chen, 2023).

Speeding up the pace of EAF construction and BF-BOF phase-out, and thus expanding the share of electricity-based rather than coal-based steel making, can accelerate China's move towards a 1.5°C compatible steel industry.

Scrap availability is becoming less of a constraint for China with more steel products being recycled by 2050.

As the world's largest consumer of scrap steel, China recycles 250 Mt of scrap every year (Figure 6) —a figure that falls far short of supporting its annual production of 1 billion tonnes. China's longstanding leadership in steel production and stocks means there's huge potential for scrap production (Net Zero Industry, 2021; Mission Possible Partnership, 2022).

As the current stock of steel ages, the supply of scrap is expected to rise significantly by 2050.

Projections indicate that China's scrap steel availability will gradually rise, ranging from 300 to 390 Mt by 2030 and further to 400 to 630 Mt by 2050 (Figure 6) (Çiftçi, 2018; Chen et al., 2021; Mission Possible Partnership, 2022). To ensure sufficient collection, sorting, processing, and recycling of scrap, the government has established a target to recycle at least 320 Mt of scrap steel by 2025, aligning with its ambition to foster a circular economy during China's 14th Five-Year Plan (FYP) period (China NDRC, 2021).

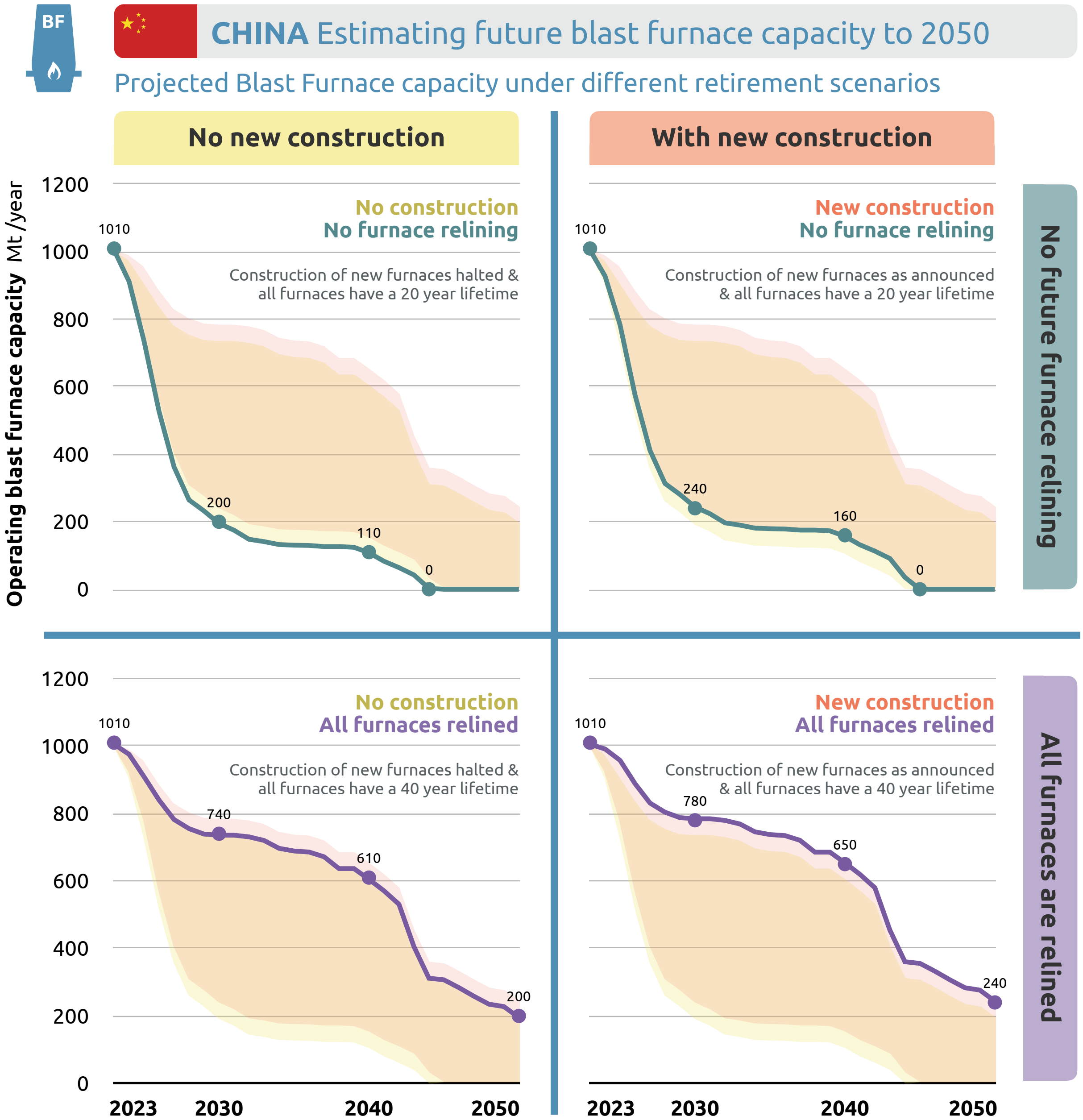

Figure 5 China's projected blast furnace capacity under different construction and retirement scenarios (2023-2050) (calculated based on data from Steel Plant Tracker by Global Energy Monitor)

Scrap recycling through EAF has huge potential to cut carbon emissions in China's steel industry, but it depends on clean energy. Decarbonising steel production is therefore closely tied to decarbonising the power sector China needs to achieve by 2040 to be compatible with the global 1.5°C goal (Climate Action Tracker, 2023b).

China's coal phaseout and renewable build-out both need rapid acceleration. Despite progress in renewable energy adoption, coal remains predominant (60%) in China's power sector, requiring a drastic reduction to 7-9% by 2030 and a complete phase-out by 2040 for a 1.5°C compatible scenario (Climate Action Tracker, 2023a, 2023b).

China still needs to take further measures to get rid of its reliance on coal for power generation and increase its renewable electricity consumption to fully unlock the decarbonisation potential of an electrified steel sector.

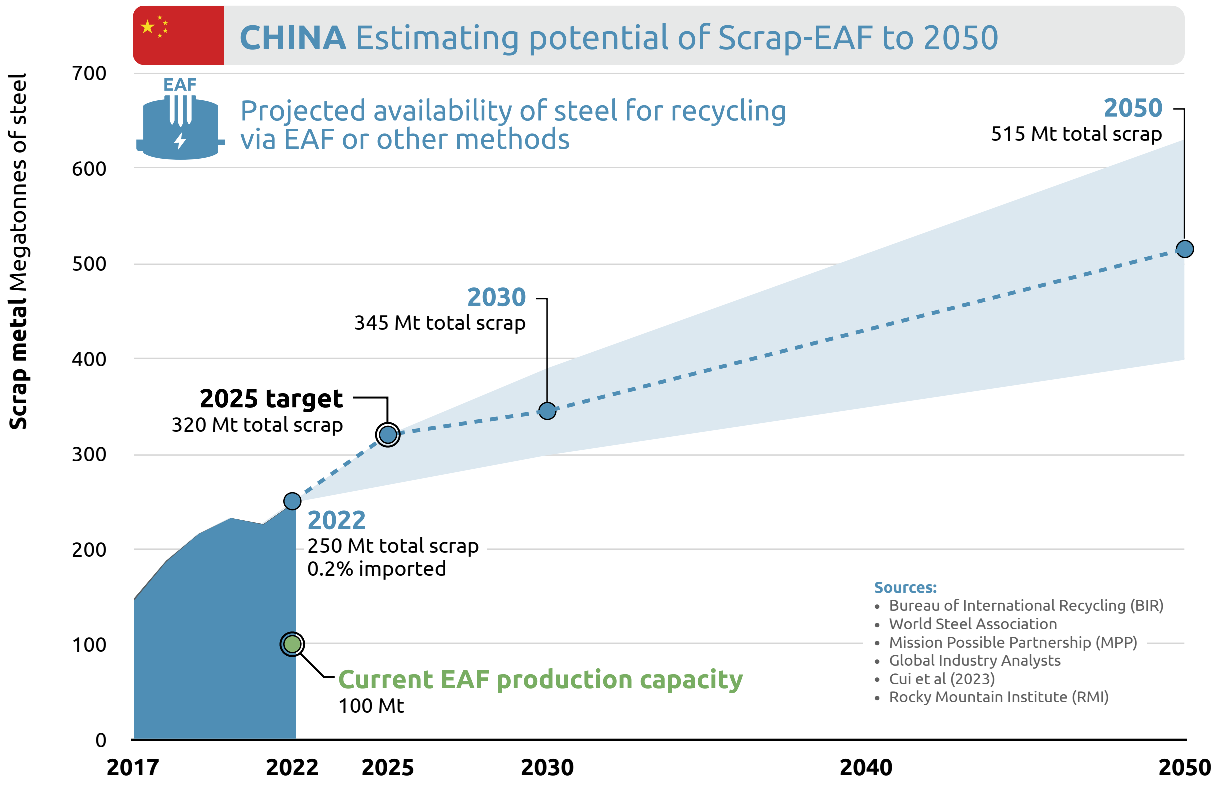

Figure 6 China's scrap production and projected scrap availability

The future of DRI-EAF steelmaking and its decarbonisation

The expansion EAF capacity brings opportunities for DRI production in China.

There is currently around 100 Mtpa of EAF capacity in operation, predominantly utilising scrap as a feedstock to produce low-carbon secondary steel (Swalec and Grigsby-Schulte, 2023). As the demand for primary steel persists, the integration of DRI into EAFs is crucial (Zuo and He, 2024). Based on that, replacing fossil gas with green hydrogen as the reducing agent aligns with the goal of reducing carbon emissions. The primary obstacles hindering the expansion of clean DRI-EAF steel production primarily revolve around raw material availability, particularly DR-grade iron ore and green hydrogen.

The decreasing DR-grade iron ore available on the global market poses challenges for China to expand its DRI production.

As the world's leading steel producer, with an annual steel output of more than 1 billion tonnes, China's current DRI production is negligible - only a few hundred thousand tonnes - falling below the threshold for inclusion in the World Steel Association's statistics (WSA, 2023b).

In contrast to the requisite high-grade iron ore with a minimum iron content of 67% for direct reduction, domestically sourced iron ore registers an average iron content of 34.5% (Zuo and He, 2024). Due to the relatively low-grade iron ore available domestically, China imports over 80% of its iron ore, mainly from Australia (WSA, 2023b). Iron ore pellets currently available on the Chinese market usually contain 65% or less iron and can therefore only be used for blast furnace ironmaking. (Fastmarkets, 2021). Unfortunately, China is facing the challenge of importing enough iron ore with high iron content for DRI production due to the declining overall quality of iron ore globally over the past two decades (IEEFA, 2022c).

The lack of high-grade iron ore is a global challenge. Processing low-grade iron ore to improve its iron content – known as beneficiation – could help to address this challenge. Beneficiation is already used in practice but could be further enhanced and expanded with additional research and regulation.

China is expected to boost the production of green hydrogen and its integration into the DRI-EAF steelmaking route, provided it establishes more ambitious goals and ensures effective implementation.

Despite being the world's largest hydrogen producer, generating 33 million tonnes annually, the majority of this output relies on coal and fossil gas (Zhou, 2023). To increase the production of green hydrogen via water electrolysis—a zero-emission process feasible with renewable electricity—the Chinese government has outlined targets. However, these targets are far from ambitious, with no priority on the steel sector.

But change has already begun, driven by the private sector. Although primarily in the R&D phase, certain hydrogen-DRI initiatives have achieved industrial-scale DRI production. For example, Tenova, an Italian firm specialising in sustainable metal production, has partnered with HBIS Group and Sinosteel, two leading steel manufacturers in China, to establish DRI plants powered by hydrogen-enriched fossil gas with a combined production capacity of 1.6 Mtpa (Tenova, 2020, 2022, 2024).

Summary: priorities for decarbonising China's steel industry

As the largest steel maker and the home of the most blast furnaces in the world, China's action greatly determines the pace of decarbonisation in the global steel industry. China's steel production has roughly stabilised and is expected to decline from 2025. The reduced production will be mainly driven by the reduced demand for steel in the building sector. However, reducing production alone is not enough to achieve a 1.5°C compatible steel industry, and the decarbonisation of the steel production chain is more critical.

The retirement of the emissions-intensive blast furnaces will be in the centre, with a halt to new coal-based steelmaking plants as an important step. 80% of the currently operating BF-BOF capacity in China was commissioned in the last 40 years and is still within the average life expectancy. Early retirement of these steel plants poses a significant stranded asset risk but will be necessary to some extent in order to stay in line with the Paris agreement (Swalec and Grigsby-Schulte, 2023).

A holistic strategy is imperative to achieve a net zero steel sector in China by 2050 - the capacity gap resulting from the BF-BOF phase-down will be addressed by the construction of EAFs running on clean energy.

Increasing supplies of scrap steel and expanding green hydrogen production provide opportunities for this transition. Simultaneously, China must reduce its dependence on coal for power generation and explore alternative sources for high-grade iron ore.

India

National targets and government priorities

India has emerged as the world's second-largest producer of crude steel since 2019, surpassing Japan and second only to China. The steel sector contributes about 12% to the country's total CO_2 emissions, having an emissions-intensity of 2,150 kg CO_2/tcs in 2019, compared to the global average level of 1,850 kg CO_2/tcs (Hasanbeigi, 2022; WSA, 2022). Despite an updated NDC target to reach net zero by 2070, India has yet to establish a specific quantitative target for decarbonising its iron and steel manufacturing sector.

The Indian government has taken initiatives to decarbonise the steel sector, including the Steel Scrap Recycling Policy 2019 to boost domestic scrap production for recycling; the Perform, Achieve and Trade (PAT) scheme to improve energy efficiency; and the approval of 13 task forces for developing a green steel roadmap (Government of India, 2016, 2019).

Simultaneously, the government initiated the National Green Hydrogen Mission, allocating 30% of the pilot project budget (USD 177m) to the Ministry of Steel to promote the use of green hydrogen in steelmaking (Government of India, 2023b). It should be noted that, propelled by the ambitious goal of doubling its steel production capacity by 2030, India's steel decarbonisation plans seemingly assign minimal attention to the transition away from BF-BOF technologies, which currently serve as the predominant choice for newly-constructed or announced steel plants in the country (Government of India, 2023a).

Demand and infrastructure

India has a great potential of growth in steel demand and capacity.

In 2022, India produced 125 Mt of steel, reflecting a 4.5% annual growth rate over the past decade (Figure 7). Remarkably, among the top five steel-producing nations globally, India stands out as the sole country to exhibit growth in steel production during 2022 compared to the preceding year. India's current per capita consumption of steel, at 77 kg in 2022, is considerably lower than the global average of 233 kg, highlighting a substantial growth potential within the Indian steel industry (Government of India, 2023c).

To satisfy the increasing domestic need for steel, the Indian government has articulated its commitment to large-scale augmentation efforts, aiming to double the current steel production capacity from 150 Mtpa to an ambitious 300 Mtpa by 2030 (Government of India, 2023a). Stimulated by both market and policy, India's steel capacity and production is expected to keep growing, with one industry leader anticipating 300 Mt by 2030 and up to 500 Mt by 2050 (Periwal, 2023).

The emission-intensive BF-BOF route accounts for half of India's steel production, while the remaining half is contributed by coal-fed DRI, which also carries a high carbon footprint.

85% of energy inputs to steel production is coal (IEEFA, 2022a; Swalec and Grigsby-Schulte, 2023). Regarding the pipeline capacity, India has surpassed China to be the world's largest developer of new coal-based steel plants, holding 40% (153 Mtpa) of BF-BOF steel production capacity under development (Figure 8).

The future of BF-BOF steelmaking and its decarbonisation

In India, the BF-BOF steelmaking route is in the early stages of rapid development.

Three-quarters of the country's blast furnace capacity has been developed within the past decade, so the capacity is very young (Figure 9). With an additional 130 Mtpa BF-BOF capacity in the pipeline, there is a growing risk of stranded assets, estimated to range between USD 153-230bn (Swalec and Grigsby-Schulte, 2023).

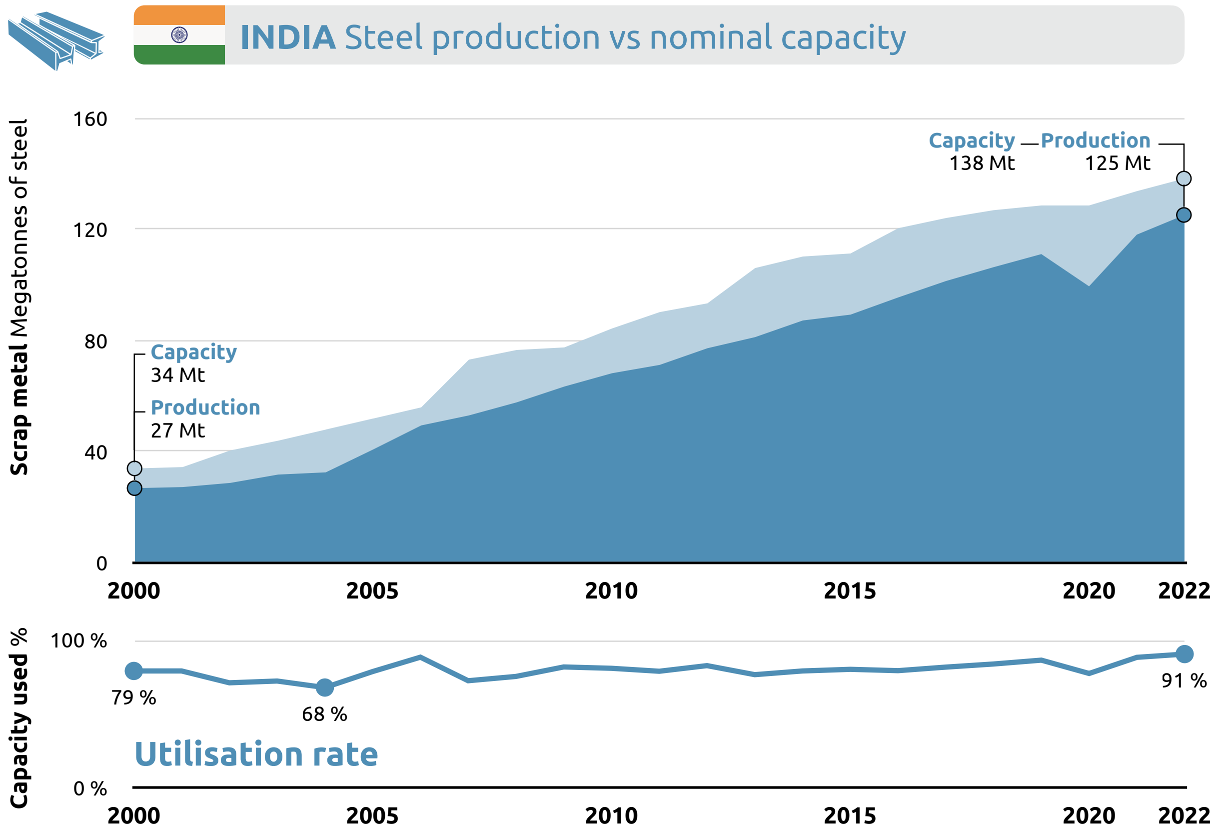

Figure 7 Crude steel production, capacity, and utilisation rate in India (source: OECD.Stat, World Steel Association)

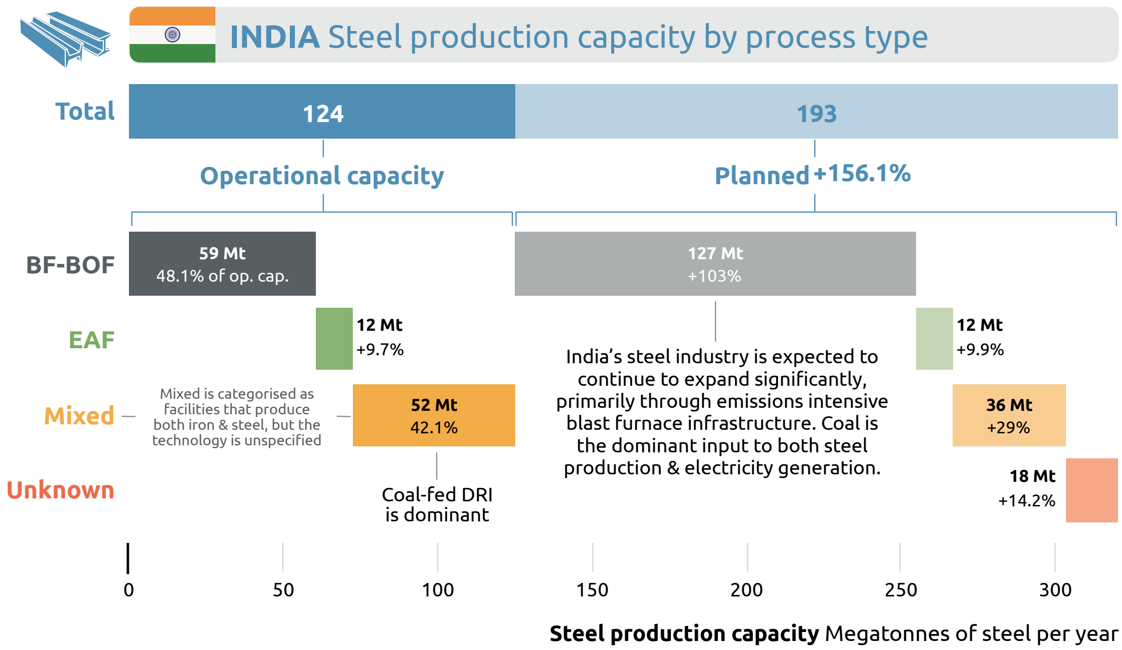

Figure 8 Steel production capacity by different production process in India (Source: Steel Plant Tracker by Global Energy Monitor)

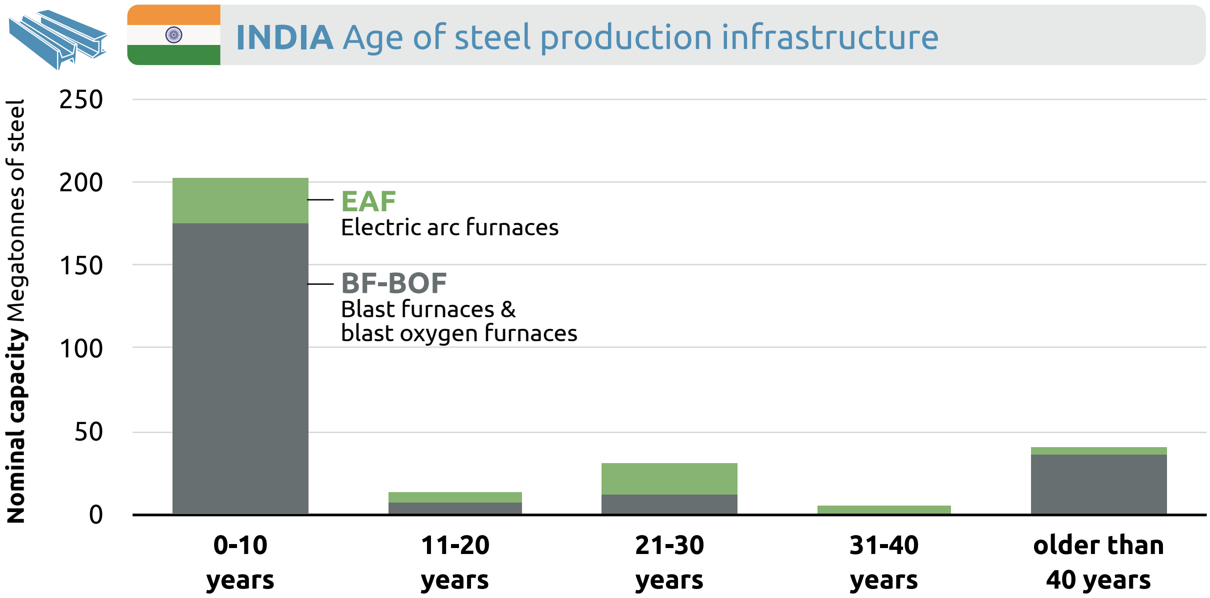

Figure 9 Capacity of Steel Plants of different Age in India (Source: Steel Plant Tracker by Global Energy Monitor)

While there is currently no definitive phase-out plan for blast furnaces in India, it is imperative to explore the potential impacts of various pathways for retiring them.

This consideration becomes particularly relevant as India contemplates a more profound decarbonisation strategy for its steel industry on its way towards net zero.

The anticipated capacity of blast furnaces in India is largely affected by two decisions - the relining of existing steel plants and the ongoing construction of new projects.

Figure 10 shows the expected blast furnace capacity by 2050 under four distinct scenarios based on the two decisions:

- The first two scenarios arise from the decision to reline operating blast furnaces, which influences the lifespan of steel plants.
- The other two scenarios stem from the decision to stop planned BF-BOF projects that have been announced but not yet constructed.

The worst-case scenario predicts an increase in blast furnace capacity to 60 Mtpa by 2030 and a stabilised level of over 70 Mtpa by 2050 if the operating plants can last up to 40 years and all announced blast furnace projects are completed on schedule. This estimate is still optimistic, assuming no new blast furnace projects are approved in India, which is unlikely to happen.

Without further relining and reinvestment in the operating steel plants, which currently stand at 59 Mtpa, the total blast furnace capacity is expected to decrease by 7 Mtpa by 2030 and by 40 Mtpa by 2050. Additionally, if the newly announced but unconstructed BF-BOF projects, totalling 50 Mtpa, were not built, the projected capacity would decline by 29 Mtpa by 2030 and by 38 Mtpa by 2050.

In the best-case scenario, where no new blast furnaces are constructed and the lifespan of existing plants is as short as 20 years, the total capacity of emissions-intensive blast furnaces is projected to decline significantly to 22 Mtpa by 2030 and then to an insignificant level of 3 Mtpa before 2044.

CCUS should not serve as an excuse for constructing new coal-based steel plants.

Neither relining operating blast furnaces with CCUS facilities nor building new integrated coal-based steel plants with CCUS functions demonstrates economic feasibility and emission reduction efficiency. CCUS installations do not provide the best solution globally, and its potential in emerging economies, such as India, is even more limited (IEEFA, 2024). The commercialisation of CCUS in India by 2050 is essentially unlikely without significant R&D incentives as well as international financial support (Stranger et al., 2023).

Meeting the projected demand for steel in India in line with the Paris Agreement implies a major shift in the construction pipeline to alternate, low or zero carbon technologies.

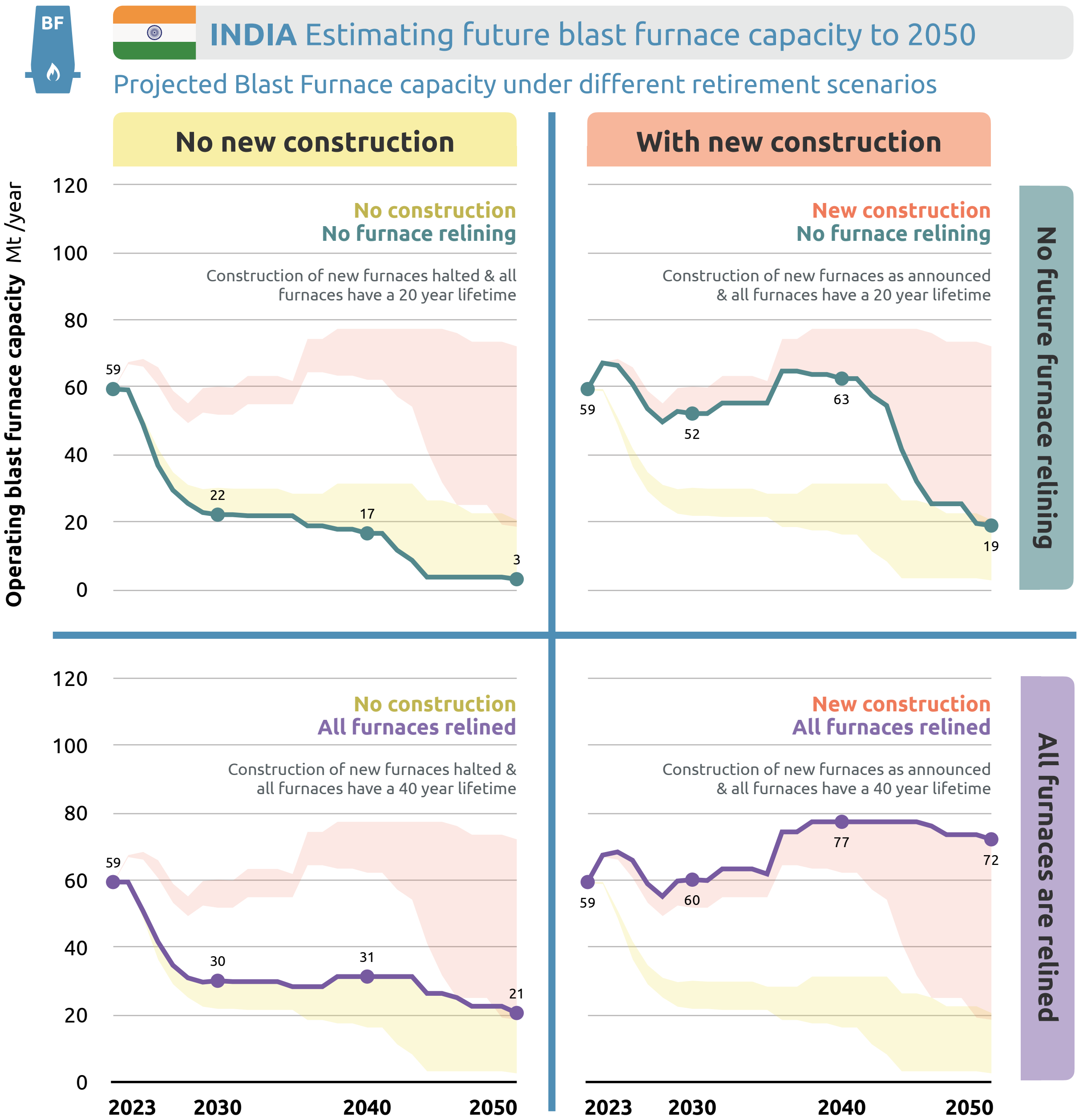

Figure 10 India's projected blast furnace capacity under different retirement scenarios (2023-2050) (Calculated based on data from Steel Plant Tracker by Global Energy Monitor)

The future of scrap-EAF steelmaking

The availability of scrap steel is a challenge to shifting production toward the scrap-EAF route, especially for India, an emerging economy with a relatively new infrastructure where 70% remains to be built (Kouamé, 2024).

In 2019, steel makers in India utilised around 32 Mt of scrap steel, with over 20% being imported, mainly from China (International Trade Administration, 2021). As China increases its scrap-EAF capacity, India faces a growing reliance on domestic scrap, which currently falls short of demand. To boost its scrap and recycling market, the Indian government is working towards ambitious plans such as the 2020 Self-Reliant India campaign.

In comparison to its targeted annual steel production of 300 Mt by 2030 and 500 Mt by 2050, the consumption of scrap steel is projected to surge to around 50 Mt by 2030 and 110 Mt by 2050, constituting roughly 20% of total anticipated production (Figure 11).

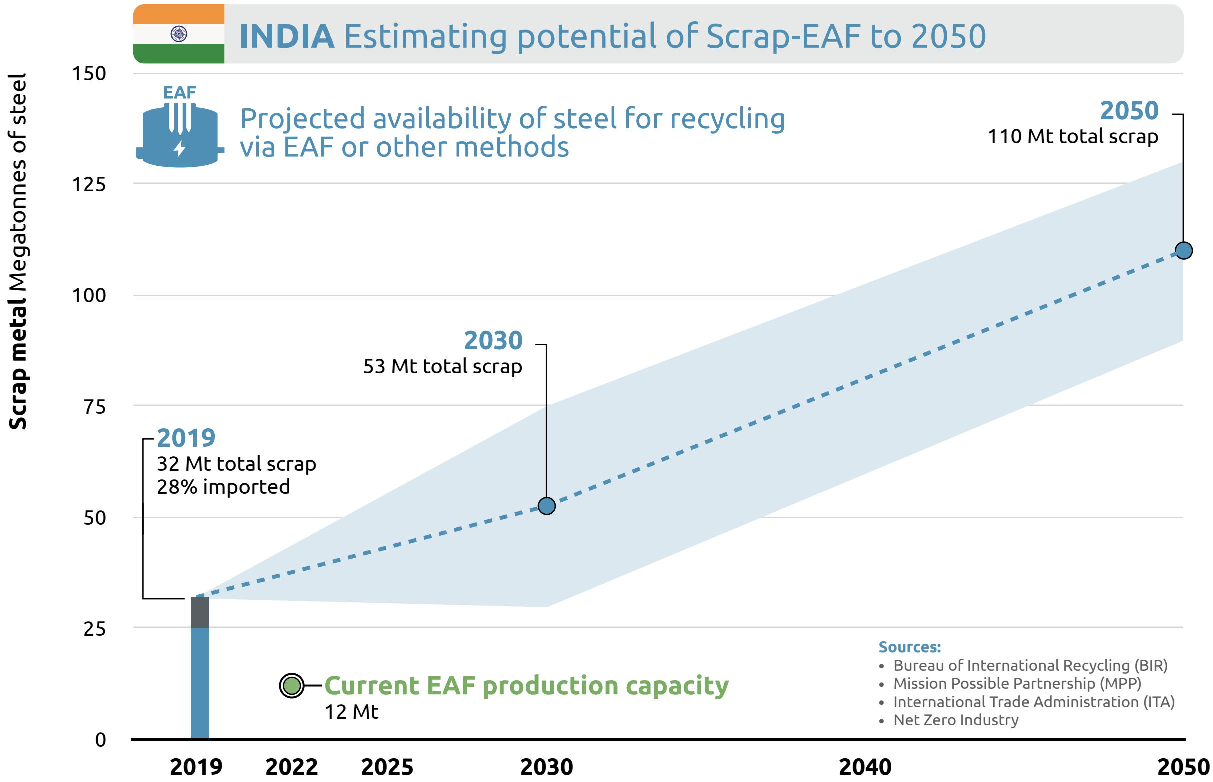

Figure 11 India's scrap production and projected scrap availability.

Greater electrification with significant integration of renewable energy is essential.

India's electricity generation is heavily reliant on coal power, which represents over 70% of the country's current generation. To be 1.5°C compatible, India's coal power generation would need to reduce significantly by 2030 to reach 17-19% of total generation and be phased out entirely between 2035-2040 (Climate Action Tracker, 2023c, 2023b).

Despite India's leadership in global new renewables development, their growth rates are insufficient for 1.5°C compatibility: 70-75% of India's electricity generation should come from renewables in 2030, escalating to 94-100% by 2050 (Climate Action Tracker, 2023b). International support will be indispensable for India to achieve this transition.

The future of DRI-EAF steelmaking and its decarbonisation

Replacing coal with green hydrogen for DRI-EAF steelmaking is a priority for the Indian government.

India, as the top DRI-producing country for the past two decades, produced 42.3 Mt of DRI in 2022 (WSA, 2023b). However, its DRI production heavily relies on coal, contributing to its overall emissions-intensity being 40% higher than the global average. Green hydrogen presents an opportunity to decrease coal reliance, with estimates suggesting a drop from 92% in 2021 to 70% by 2030 if green hydrogen is ready to commence commercial-scale operations by then (IEEFA, 2023).

India possesses an advantage in domestic access to high-grade iron ore, ranking seventh among countries with abundant iron ore resources, primarily of medium to high-grade quality. With over 85% of its iron ore boasting a iron content surpassing 62%, India possesses substantial potential to enhance the beneficiation of its iron ore for DRI production (Government of India, 2022). India can therefore expand the utilisation of the DRI-EAF steelmaking route while concurrently decarbonising it through the introduction of green hydrogen, thereby moving the steel sector on a 1.5°C compatible track.

The promotion of green hydrogen in steelmaking production requires increased support both domestically and internationally.

India consumes nearly 6 Mt of grey hydrogen annually, mainly in fertilisers and refineries, but not in the steel industry (Stranger et al., 2023). The primary barrier to the adoption of green hydrogen in India is the high cost of producing hydrogen using renewable electricity. However, the transition from coal-based DRI-EAF to green hydrogen-based DRI-EAF is feasible, supported by several pilot projects since 2020, alongside the implementation of the National Green Hydrogen Mission, which channels financial resources to promote green hydrogen utilisation in steelmaking (Government of India, 2023b). International climate finance and private sector investments are crucial to accelerate India’s transition and its application of emerging technologies such as green hydrogen.

Summary: priorities for decarbonising India’s steel industry

Given India's rapid economic development, urbanisation, and infrastructure construction, the steel industry is poised to assume a significantly more vital role in the country. However, the exponential growth in capacity and production raises concerns about a potential quadrupling of carbon emissions from India's steel sector by 2050 if coal still dominates. Meanwhile, this growth presents India with a unique opportunity to foster a low-carbon steel sector by minimising new BF-BOF and coal-based DRI builds and transitioning to electrified steelmaking.

Prioritising the adoption of cleaner EAF technology for future steel production capacity growth is imperative, alongside decarbonising the power sector. To achieve significant decarbonisation and reduce reliance on the coal-based BF-BOF route, halting new project constructions is essential.

India has an advantage in terms of abundant domestic high-grade iron ore reserves and has the potential to prioritise DRI-EAF steelmaking, which can be decarbonised by green hydrogen. Scarcity of scrap limits the expansion of secondary steelmaking. Through government efforts to incentivise scrap recycling and formalise the scrap market, scrap-EAF has the potential to satisfy around 20% of India’s future steel demand.

Currently, available technologies for steel decarbonisation are still in a nascent stage in India. Global climate finance, private sector investments, and technology support are therefore crucial to accelerate India’s transition towards a Paris-aligned steel sector.

The United States

National targets and government priorities

As the fourth largest steel producer in the world, the US annual steel production stabilised at 70-90 Mt in recent years (Figure 12). Given its high share of EAF (70%) in steelmaking and great scrap availability, the US has the lowest steel carbon intensity among the major producers, at 960 kg CO_2/tcs in 2019 (Hasanbeigi, 2022).

The US has set its NDC targets for reducing economy-wide emissions, aiming for a 50%–52% decrease below 2005 levels by 2030 and achieving net zero emissions no later than 2050 (Climate Action Tracker, 2023d). To further decarbonise its industrial production, the US launched the Buy Clean Initiative to promote the use of the use of domestically produced low-carbon products like green steel (Tilak et al., 2023).

Legislative efforts such as the Inflation Reduction Act (IRA) and the Bipartisan Infrastructure Law (BIL) stimulates the utilisation of steel in projects ranging from wind turbines and solar panels to electric vehicles, highways, and bridges. The IRA injects USD 370bn in the form of tax credits, grants and loans directed to develop and deploy the clean energy technologies that can be applied to decarbonise steel production such as green hydrogen (Alkaff, 2023).

Demand and infrastructure

The demand for steel in the US is expected to remain stable over the next decade, largely due to robust domestic construction demand sustained by the IRA and BIL.

Despite the nation's well-established infrastructure and high urbanisation rate, the construction sector, incentivised by IRA and BIL, will drive a 18Mt increase in steel demand by 2030 (Yermolenko, 2023).

Overcapacity presents a significant challenge for the US, a condition that has persisted since the 1970s, primarily stemming from a shift in priority from heavy industry to high-tech sectors.

This issue has intensified, evidenced by a utilisation rate as low as 67% in 2022 (Figure 12). Declining domestic production is attributed to rising production costs, notably in labour. The US is a now prominent steel importer, with net imports totalling 21 million metric tonnes compared to domestic production of 81 million metric tonnes in 2022 (WSA, 2023b).

The US steel industry boasts one of the highest shares of EAFs globally.

Two-thirds of the operational steel production capacity in the US utilises EAF technology, with the remaining third relying on conventional BF-BOF. Notably, all recently announced and under-construction steel production capacity in the US is powered by electricity (Figure 13).

Despite electricity's widespread use in the steelmaking process, cheap fossil gas remains the preferred option for heating treatment and iron production. Therefore, the deep electrification of the production process holds significant potential for further decarbonising the US steel industry (Kanthal, 2021).

The future of BF-BOF steelmaking and its decarbonisation

The US should phase out BF-BOF steel production, while also addressing potential social challenges to ensure a just transition towards a zero-emission steel sector.

Since 1980, the construction of blast furnaces in domestic steel plants has been hindered by its high cost and pollution, leaving the operating BF-BOF plants in the country at least 40 years old (Figure 14). As the industry moves towards EAFs that are cleaner, cheaper, and more flexible, only two companies, U.S. Steel and Cleveland-Cliffs, are still operating blast furnaces in the US (Taylor, 2022; Swalec and Grigsby-Schulte, 2023).

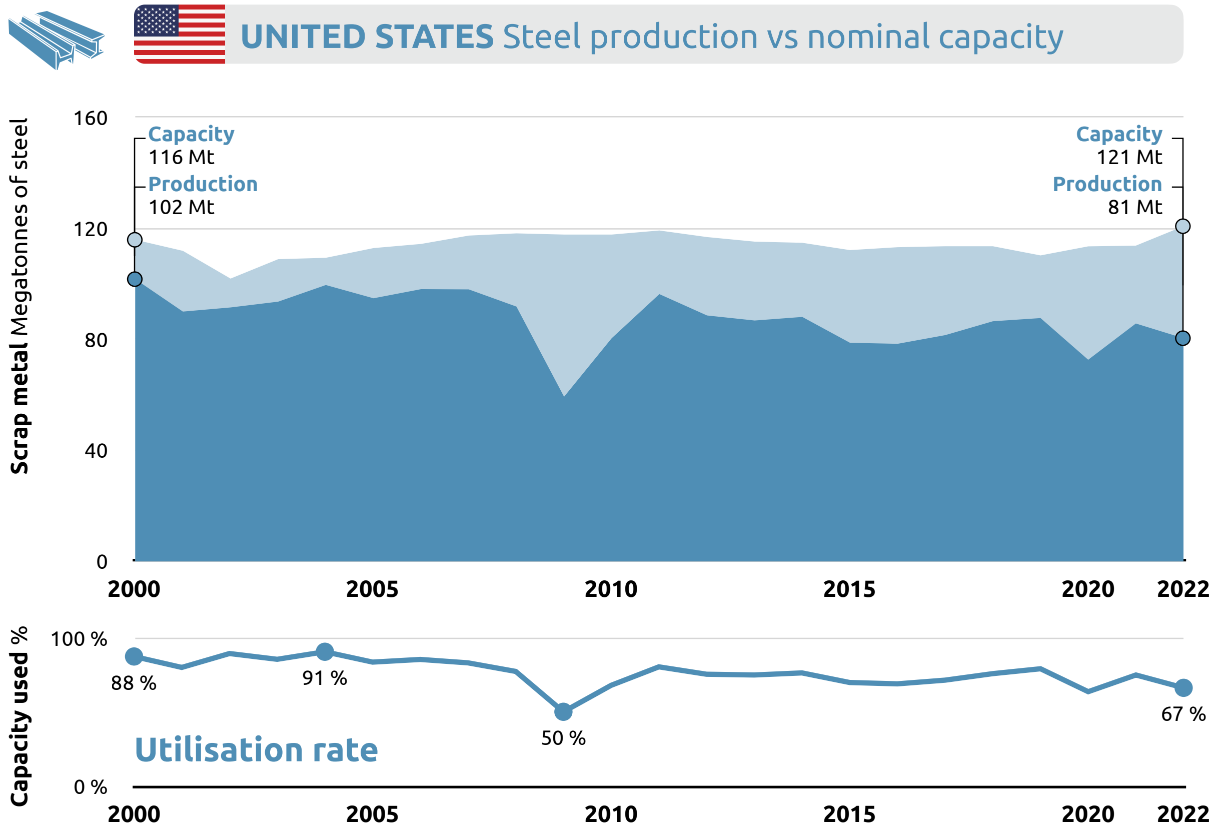

Figure 12 Crude steel production, capacity, and utilisation rate in the US (Source: OECD.Stat, World Steel Association)

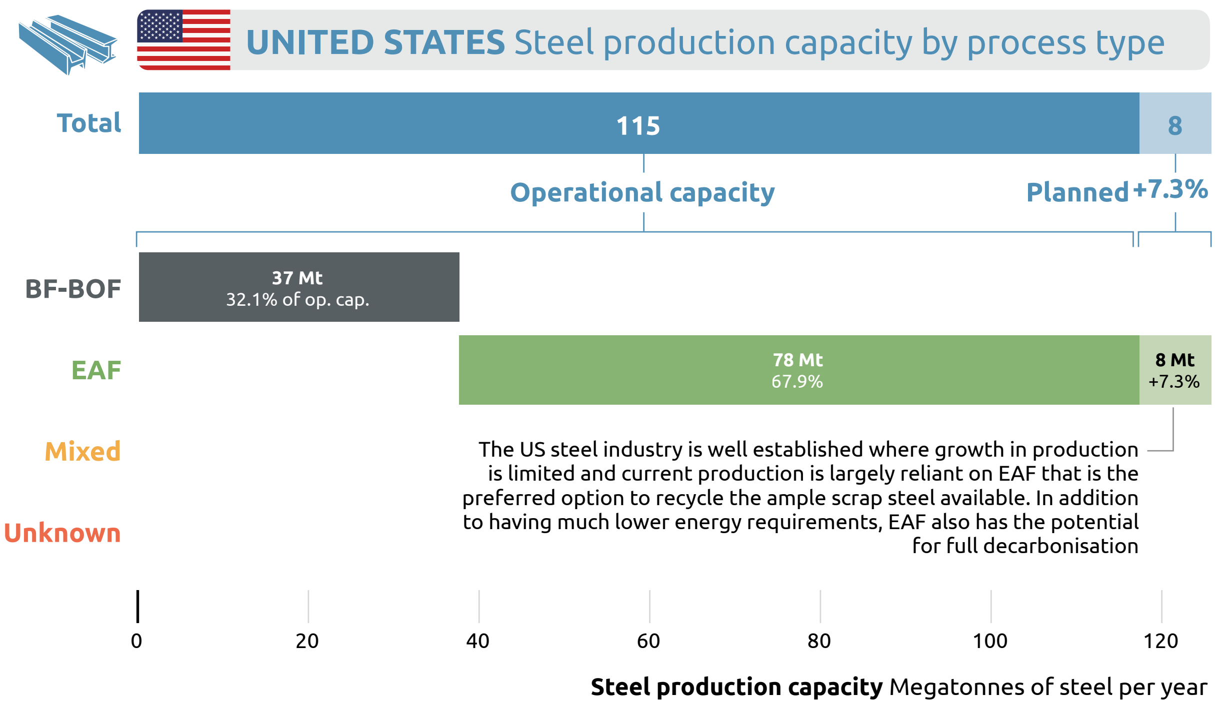

Figure 13 Steel production capacity by different production process in the US (Source: Steel Plant Tracker by Global Energy Monitor)

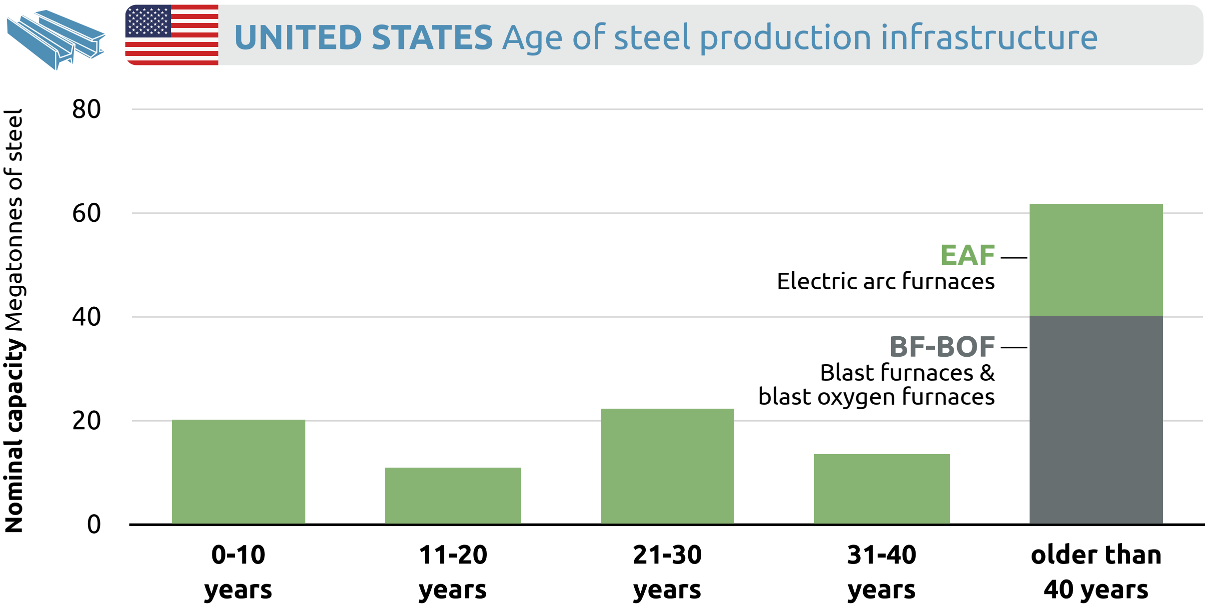

Figure 14 Capacity of Steel Plants of different Age in the US (Source: Steel Plant Tracker by Global Energy Monitor)

US Steel aims to shut down its remaining BF-BOF plants due to rising energy costs and declining demand but is facing opposition due to potential job losses. Conversely, Cleveland-Cliffs seeks to preserve its operating blast furnaces through acquisitions, aiming to reduce overall production costs by maintaining a high market share, arguing that EAFs may not meet the steel requirements of certain car manufacturers (Binnie and Flowers, 2023).

CCUS technology in steelmaking remains challenging and economically prohibitive.

None of the 15 CCUS projects in operation in the US are installed specifically for steelmaking purposes. This is due to the insufficient capture rates as well as the high costs associated with CCUS in steel production, ranging from USD 55-100 per metric tonne of CO_2 captured (U.S. Congressional Budget Office, 2023). These expenses are notably higher compared to CCUS applications in other sectors, such as fossil gas processing, where costs range from USD 15-25 per metric tonnes of CO_2 captured (U.S. Congressional Budget Office, 2023).

The future of scrap-EAF steelmaking

Scrap-EAF steelmaking will remain at the centre of the steel industry in the US.

Over the past decade, the US has consistently maintained an impressive scrap recycling rate, averaging between 80% and 90% (BIR, 2022). The US generates a substantial 60-80 Mt of steel scrap every year, of which 50-60 Mt undergo domestic recycling into new products. Another 15-18 Mt steel scrap is exported to international markets, such as Canada and Mexico (Figure 15).

The availability of scrap for recycling is anticipated to remain high in the future, with a likelihood of increased domestic consumption, particularly as China and India emerge as competitors for scrap exporters on the global market (Global Industry Analysts, 2023).

Decarbonising the power sector will be a primary objective for decarbonising EAF-based steel production.

The Biden Administration has announced a target of a carbon-free electricity system no later than 2035. The goal of carbon-free power supply by 2035 is aligned with the Paris Agreement, based on the benchmarks defined by the CAT, which necessitates the replacement of the current shares of coal (20%) and fossil gas (39%) with renewable energy sources by 2030 and 2035 respectively (Climate Action Tracker, 2023d, 2023b). Although the goal is Paris-aligned, current policies are insufficient to meet that goal.

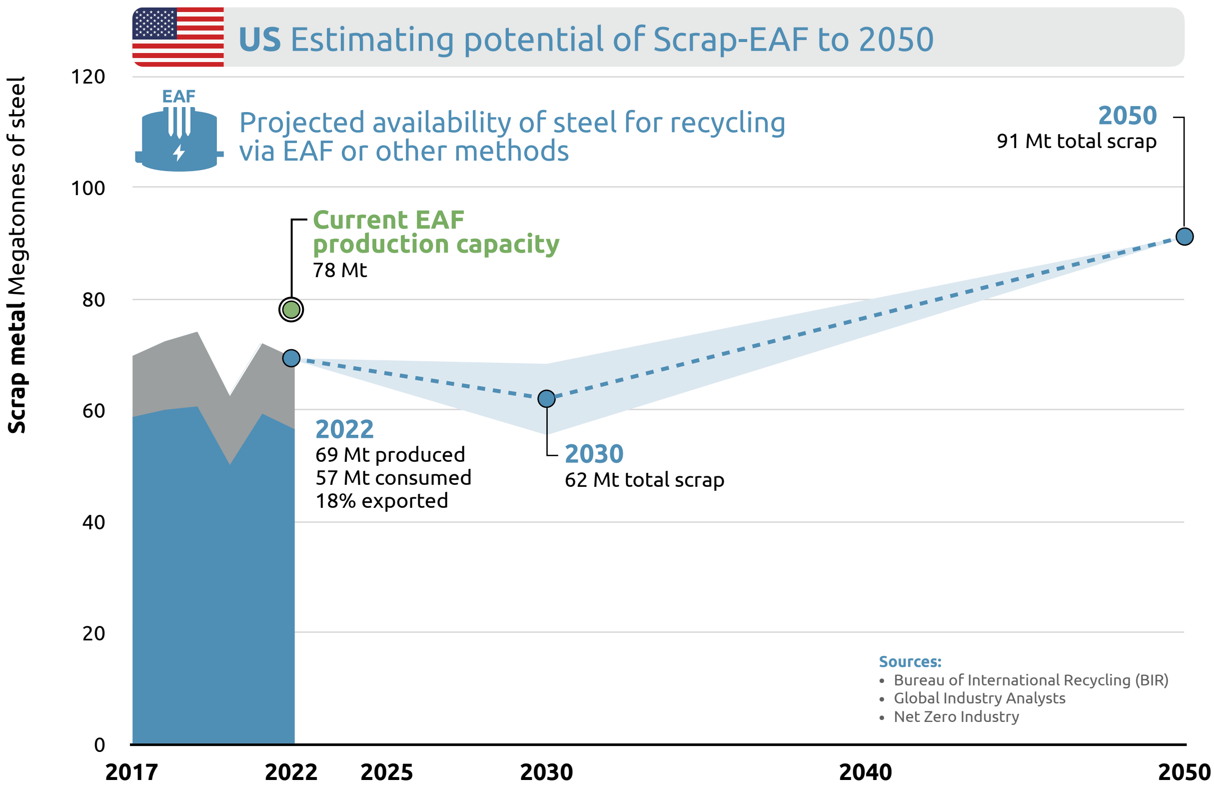

Figure 15 US's scrap production and projected scrap availability

The future of DRI-EAF steelmaking and its decarbonisation

DRI-EAF will be the main route for primary steelmaking as secondary steelmaking alone cannot fully meet the steel demand.

In 2022, the US produced 5 Mt of DRI, primarily utilising fossil gas as a fuel source (WSA, 2023b). Recognising the increasing need for DR-grade iron ore, U.S. Steel is making investments in new DR-grade pellet capacities in Minnesota (Kuykendall, 2022; U.S. Steel, 2022).

To bolster clean energy initiatives, the Biden administration has announced plans to produce over 3 Mt of green hydrogen generated from electrolysis using renewable energy sources. This initiative includes the allocation of USD 7bn in funding from the BIL to establish seven regional green hydrogen hubs (The White House Briefing Room, 2023).

With a combination of policy incentives and private sector efforts, the integration of green hydrogen-based DRI-EAF, alongside scrap recycling and current import levels (20%), holds the potential to meet the steel demand in the US.

Summary: priorities for decarbonising US's steel industry

The US, benefiting from ample scrap availability, holds a leading position in steel decarbonisation endeavours, positioning it to lead the global transition towards a fully decarbonised steel sector. Further decarbonising steel production in the United States requires ambitious actions and concrete measures. While initiatives like the IRA and the BIL are boosting the US steel market, they also create openings for emerging technologies such as green hydrogen, which can significantly reduce emissions.

Priority should be given to deepening electrification and achieving the goal of a carbon-free electricity system by 2035, considering the substantial share of EAF capacities in the US. As scrap-EAF remains central to steelmaking, EAFs are also used for primary steelmaking with DRI. Transitioning from natural gas to green hydrogen for DRI production offers considerable potential for decarbonisation. Addressing societal and employment pressures by either decommissioning high-emission blast furnaces or retrofitting them with CCUS facilities is crucial.

Key takeaways

The electrification of steelmaking and decarbonising the power sector are fundamental to ensuring the carbon neutrality of the steel sector by 2050.

The steel sector's significant carbon emissions predominantly stem from its heavy reliance on fossil fuels, particularly coal. Steel sectors with substantial coal dependence, such as China (75%) and India (85%), exhibit emission intensities more than two times higher than that of the US, which relies on EAF for steelmaking.

It is imperative to recognise that, since electric arc furnaces derive their energy from electricity, any initiative aimed at cleansing the steel industry of its environmental footprint must ensure a dependable commercial supply of clean electricity.

While transitioning from heavily emitting BF-BOF routes to EAFs, governments should also prioritise the decarbonisation of the power sector to align with the Paris Agreement and thus reduce carbon emissions throughout the production process, including indirect emissions.

Maximising scrap recycling through EAF stands as a paramount strategy for the decarbonisation of the steel sector.

However, expanding scrap-based steel production requires a robust domestic scrap supply. Given the relatively stable yet uncontrollable volume of scrapped steel products such as automobiles, buildings, ships, and machinery, governments can enhance the supply of scrap for secondary steel production by boosting the capacity for scrap dismantling and processing, while also regulating the scrap market.

The US boasts a mature market for scrap processing and secondary steel production, serving as a significant exporter of scrap. With anticipated stable domestic steel production, scrap recycling in the US could maintain stability or even grow.

Conversely, China and India exhibit greater potential for growth in scrap recycling, given the expected rise in end-of-life steel products. Cleaner and more cost-effective secondary steel production will aid China and India in effectively decarbonising their steel sectors, provided they regulate their scrap dismantling and processing industries and domestic scrap markets to foster healthy competition.

Decarbonising DRI-EAF with green hydrogen presents varying prospects across regions.

This is influenced by factors such as access to high-grade iron ore and the ability to produce green hydrogen. As the overall grade of iron ore diminishes globally, there will be heightened competition among buyers for DR-grade iron ore, favouring countries endowed with large iron ore reserves. India stands out in this regard, benefiting from substantial reserves of DR-grade iron ore, positioning it to leverage hydrogen-based DRI-EAF as a primary alternative to coal-based steel production. International climate finance, technical support, and private sector investments are pivotal in facilitating India's transition towards this greener steelmaking route.

Phasing down BF-BOF capacity globally is a necessary step toward a 1.5°C compatible steel sector, given the insufficiency of CCUS for emission reductions.

CCUS technology, with its limited capture capacity, high costs, and relatively immature status, currently sees rare piloting in steel production processes and falls short of significantly decarbonising heavily emitting blast furnaces.

Both India and China should halt investment in new BF-BOF capacity promptly to align with the goal of achieving a net zero steel sector by 2050. Additionally, China is advised to implement an early retirement plan for its over 1,000 Mtpa of BF-BOF capacity, refraining from further relinings or reinvestment.

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Authors

NewClimate Institute
Norah Zhang
Louise Jeffery
Anna Nilsson

Editing
Cindy Baxter

Design
Designers For Climate

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CAT Consortium

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Climate Analytics is a non-profit institute leading research on climate science and policy in relation to the 1.5°C limit in the Paris Agreement. It has offices in Germany, the United States, Togo, Australia, Nepal and Trinidad and Tobago.

Contact: Dr. h.c. Bill Hare, +61 468 372 179

climateanalytics.org

NewClimate Institute is a non-profit institute established in 2014. NewClimate Institute supports research and implementation of action against climate change around the globe, covering the topics international climate negotiations, tracking climate action, climate and development, climate finance and carbon market mechanisms. NewClimate Institute aims at connecting up-to-date research with the real world decision making processes.

Contact: Prof. Dr. Niklas Höhne, +49 173 715 2279

newclimate.org