Pedal to the Metal

2023

IT'S TIME TO SHIFT STEEL DECARBONIZATION INTO HIGH GEAR

Global Energy Monitor

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The Global Steel Plant Tracker (GSPT) provides information on global crude iron and steel production plants, and includes every plant currently operating at a capacity of 0.5 million tonnes per year (mtpa) or more of crude iron or steel. The GSPT includes all plants meeting the 0.5 mtpa threshold that have been proposed or are under construction since 2017 or retired or mothballed since 2020.

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The cover photo shows the site of the steel factory of Tata Steel in the Netherlands. © Marten van Dijl/Greenpeace

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FURTHER RESOURCES

For additional data on proposed and existing steel plants, see Summary Data of the Global Steel Plant Tracker (GSPT). For links to reports based on GSPT data, see Reports & Briefings. To obtain primary data from the GSPT, see Download Data.

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2023 Pedal to the Metal

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Caitlin Swalec and Astrid Grigsby-Schulte

EXECUTIVE SUMMARY

- **The transition away from coal-based steelmaking is underway but moving far too slowly:** new developments indicate a growing proportion of electric arc furnace (EAF) steelmaking compared to blast furnace-basic oxygen furnace (BF-BOF) steelmaking. In March 2022, the proportions of planned capacity nearly matched the existing operating capacity (67% BF-BOF vs 68% BF-BOF and 33% EAF vs 32% EAF), which would lead to no change in future operating capacity shares. As of March 2023, plans have shifted significantly and 43% of planned capacity now uses largely gas and electricity-based EAF while only 57% of planned capacity uses the coal-based BF-BOF route.

  However, the International Energy Agency's (IEA) Net Zero by 2050 scenario indicates that over half (53%) of steelmaking capacity needs to use EAF technology by 2050 and 42% of primary steelmaking alone needs to use EAFs in a hydrogen-based direct reduced iron or iron ore electrolysis configuration to meet that goal. Current capacity plans will result in a mere 32% of total capacity using EAF in 2050, far less than what is needed. While the growing proportion of EAF in planned capacity is promising, existing BF-BOF capacity must be closed and planned BF-BOF capacity cancelled.

- **Global steelmaking overcapacity remains a persistent issue:** The OECD reported a 26% global excess capacity (632 million tonnes) in 2022. The industry has remained at a high level of overcapacity for several years, and the Global Steel Plant Tracker indicates that it is increasing slightly, with an 11 million metric tonnes (Mt) net capacity gain in 2022 and a slight fall in capacity utilization rates of top producers from 75% in 2021 to 72% in 2022. While overcapacity presents a challenge to steelmakers in terms of profitability, it also creates an opportunity to shift investments in the sector to support the green steel transition.

- **Asia holds steady as the hub of new steelmaking capacity, particularly coal-based BF-BOF:** Three-quarters of steelmaking capacity under development is in Asia, with 55% from China and India. Considering the BF-BOF route in isolation, Asia is responsible for 99% of new developments and, as with general steelmaking, China and India hold the majority of those developments (79% together).

- **India surpasses China as the top developer of coal-based capacity:** While China accounts for 49% of operating BF-BOF capacity and India holds 5%, India is developing much more rapidly. India's share of new developments (27%) has nearly reached that of China (28%). India is now the world's largest developer of new coal-based (BF-BOF) capacity, holding 40% of BF-BOF capacity under development, while China is responsible for 39%.

- **Stranded asset risk is growing:** The steel industry could face as much as US$ 554 billion in stranded asset risk as countries work towards their carbon neutrality commitments while simultaneously building out coal-based BF-BOF capacity. From 2021 to 2022, BF-BOF assets under development in countries with net-zero carbon commitments increased approximately 7% (36 mtpa).

ABOUT THE GLOBAL STEEL PLANT TRACKER

Since 2021, GEM has provided a publicly-accessible database that identifies, maps, and records plant-level details such as plant ownership, production capacity, production process/technology, and geolocation for all crude iron and steel plants with capacity of 0.5 million tonnes per annum (mtpa) or greater, covering over 92% of global capacity. GEM's dataset provides a robust view of the current and developing global iron and steel plant fleet, and the opportunity to examine the status of the iron and steel sector compared to global decarbonization roadmaps and corporate and country level net-zero pledges.

ACRONYMS

BF	blast furnace
BOF	basic oxygen furnace
DRI	direct reduced iron
EAF	electric arc furnace
IF	induction furnace
Mt	million metric tonnes
MTPA	million tonnes per annum
OHF	open hearth furnace
SAF	submerged arc furnace
TTPA	thousand tonnes per annum

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INTRODUCTION

The majority of operating steelmaking capacity relies on conventional, coal-based steel production processes. In order to align with mid-century net-zero emissions goals, new investments and reinvestments in coal-based steel production must be stopped and steel production capacity must be transitioned to lower emission steel production technology. Based on current steel capacity development plans, the steel industry is not on track to meet goals to shift the fleet away from coal-based blast furnace-basic oxygen furnace steelmaking. Immediate action must be taken to shift steel decarbonization efforts into high gear.

This report serves to provide an assessment of the global iron and steel plant fleet, including capacity that is operating and capacity under development, based on the March 2023 update of the Global Steel Plant Tracker.[1] For an overview of the global steel fleet and a more detailed explanation of steel decarbonization roadmaps please visit GEM's previous reports, Pedal to the Metal '21: No Time to Delay Decarbonizing the Global Steel Sector and Pedal to the Metal '22: It's Not too Late to Abate Emissions From the Global Iron & Steel Sector. For a summary of the main steel production processes, see Appendix A of this report.

BACKGROUND

The climate movement is finally beginning to shine a light on the iron and steel industry, which is responsible for 11% of global carbon dioxide emissions and 7–9% of global greenhouse gas emissions. The heightened focus on the iron and steel sector is evidenced by the incorporation of heavy industry decarbonization targets and technology investments at the national, international, and corporate levels in the past year. Still, as 2030 decarbonization targets and 2050 net zero targets draw near, the urgency of mitigating the carbon footprint of the global iron and steel industry grows even more quickly than the current ambition from governments and the private sector. The momentum to decarbonize the iron and steel industry must shift into high gear.

Society will continue to rely on steel for engineering, construction, medical, and energy applications as it builds new energy projects, replaces and develops infrastructure, and innovates for a bright future. As economies develop, the global demand for steel will continue increasing. In the recovery from the COVID-19 pandemic, steel demand grew by 2.8% in 2021, bouncing back from a decline of 0.2% in 2020.[2] However, in 2022, Russia's war in Ukraine and challenges related to global inflation led to a contraction in demand of approximately 2.3%.[3] Looking ahead, the World Steel Association projects a rebound of 2.3% in steel demand for 2023, followed by additional growth of 1.7% in 2024.

The continued dominance of fossil fuels in steel production processes in operating and developing plants must be challenged and emissions reduced through a combination of strategies including material efficiency to lessen demand, increased reuse and recycling, and production decarbonization through retrofits and advanced technology.

1. Plants "under development" include iron and steel plants 0.5 mtpa and over that are in any stage of planning or construction prior to starting crude iron/steel production. Announcements or plants under construction that have not made any reported or physically observable advancement towards operations in the past five years were considered to be "cancelled."

2. Although preliminary reports of global crude steel production estimated a 0.9% decline in 2020, final production data from the World Steel Association show that the annual average global crude steel output actually held steady from about 1,875 mtpa in 2019 to 1,880 mtpa in 2020.

3. Based on worldsteel's predictions in October 2022.

COAL, FOSSIL FUELS, & STEEL

Steel is produced via two main production routes: the blast furnace-basic oxygen furnace route (BF-BOF) and the electric arc furnace (EAF) route. In the traditional BF-BOF route, iron ore is first reduced in a blast furnace (BF) using coke and pulverised coal. Coke is produced from coking coal in coking ovens, whereas pulverised coal is directly injected into blast furnaces. Then the pig iron from the BF is moved to a basic oxygen furnace (BOF), where oxygen blown into the unit lowers the carbon content of the hot metal and transforms it into liquid steel. In addition to the coal products used in the BF phase of BF-BOF steelmaking, BF-BOF units require large amounts of energy, which may further involve coal or other fossil fuels.

EAF production uses an electrical current to melt shares of scrap metal and/or direct reduced iron (DRI) to produce molten steel. EAFs may involve coal or other fossil fuels through the source of electricity used to power the EAF, but the EAF process alone is largely coal-free. In DRI production, which is a form of primary ironmaking comparable to a BF, iron ore is reduced in a DRI plant using a reducing gas (typically carbon monoxide and/or hydrogen). The reducing gas used in DRI plants is made from reformed natural gas, syngas, or coal, with more recent developments using electricity-based electrolyzers to produce fossil-fuel-free hydrogen. Again, the source of electricity used to power a DRI plant may involve fossil fuels or coal. While commercial scale DRI plants currently rely on coal and fossil fuels, DRI plants can be designed to switch over to fossil-free production as fossil-free hydrogen becomes available.

(Modern large) blast furnaces are designed to take advantage of the unique mechanical properties of (fossil) coke, which means that the BF-BOF steel production route can never be fully decarbonized, even when full decarbonized electricity is used to power the process. Scrap-based EAF production and DRI-EAF production do not exhibit this in-built dependence on fossil fuels by design and can be transfigured to fossil-fuel-free production in the near future, while also operating with fewer emissions at the present. In addition to the two main production routes, BF-BOF and scrap/DRI-EAF, some steelmakers have started using submerged arc furnaces (SAF) to create new technology combinations of DRI-SAF-BOF, which can lower the emissions of and eliminate the need for coal in the ironmaking portion of BOF based steel production.

In this report, we use the term "coal-based" steel production to refer to the BF-BOF production route. Whenever relevant, we mention coal-based DRI explicitly. We use the term "metallurgical" coal to describe all coal used for steel production. Whenever relevant we distinguish between different types of coal used in steel production, the main ones being coking coal and coke, pulverised coals for injection into the blast furnace, and other coals used to generate heat.

PATHS TO NET ZERO FOR THE STEEL INDUSTRY

Once thought of as an industry without feasible decarbonization options (i.e., "hard-to-abate"), the steel industry now has a range of technologies and tools that can enable a meaningful shift to a low-emission sector. Because of the diverse needs of the steel sector, a combination of approaches including changes in production methods and consumption patterns is essential. Through these changes in demand and production, several viable pathways exist to steel decarbonization by 2050.[4] However, the steel industry is currently not on track for any of these net zero scenarios, let alone 1.5 degree alignment. The primary challenge lies in effectively implementing these policies on a large scale and injecting the appropriate sense of urgency into stakeholders to act on carbon reduction plans.

The coal-based technologies prevalent in iron and steel production today are not sustainable in net zero emissions scenarios. Blast furnace-basic oxygen furnace (BF-BOF) steelmaking needs to be phased out in favor of scrap and DRI-based electric arc furnace (EAF) production.[5] EAF steelmaking only produces 10–20% of the carbon dioxide emissions of BF-BOF steelmaking, depending on the input material (scrap, pig iron, direct reduced iron and so on). While scrap-based EAF steelmaking should be prioritized to lower industry emissions, scrap supplies are finite, and alternative iron production methods must be implemented to further eliminate emissions from the sector. New technologies such as green hydrogen-based direct reduced iron (DRI) hold promise for achieving net zero compliant steel production if the necessary investments in development—including clean energy and hydrogen production—are made.

However, it is important to avoid excessive dependence on certain technologies that overlook the need for fundamental changes in coal-based production methods. Key examples lie in emerging carbon capture, usage, and storage (CCUS) technologies, which are frequently integrated into decarbonization models. While the inclusion of CCUS in planning is critical, it is essential to exercise caution to prevent it from encouraging steelmakers to invest more resources into carbon-intensive production equipment when CCUS alone cannot serve as a comprehensive decarbonization solution. Furthermore, the economic viability of CCUS in BF-BOF steelmaking has been seriously called into question since the CO_2 emissions in BF-BOF emissions are distributed among many different point sources (coke ovens, sinter plant, power plant, BF, BOF, etc), which increases capture costs and system complexity.

Transitioning the steel industry towards a circular economy model is crucial to maximize resource efficiency, minimize waste generation, and promote sustainable practices. Structural and wide-scale changes are needed, emphasizing reduced consumption, creative reuse, increased scrap collection and recycling, and the remanufacturing of steel products to expand the material's lifetime. For an overview of the main solutions available for the steel industry, see Appendix B.

While key BF-BOF alternatives like DRI-based EAFs have been on the rise for decades, the adoption of these alternatives needs to accelerate substantially through enforced policy and economic incentivization. Current international efforts to decarbonize the steel industry include the Clean

4. Recently published steel sector decarbonization roadmaps include IDDRI's Net Zero Steel project; the IEA's Iron and Steel Technology Roadmap and Net Zero by 2050 report; McKinsey & Company's Decarbonization challenge for steel and The net-zero transition, The future of the European steel industry, and Tackling the challenge of decarbonizing steelmaking reports; OECD's Low and Zero emissions in the steel and cement industries issue paper; Mission Possible Partnership's Net-Zero Steel Initiative; World Steel Association's Climate change and the production of iron and steel policy paper; and various scientific journal articles.

5. Some steelmakers are also investigating and planning new technology combinations that use a submerged arc furnace (SAF) to feed DRI into a BOF (DRI-SAF-BOF route), which is another technology route that could eliminate metallurgical coal use and reduce steelmaking emissions.

Energy Ministerial's Industrial Deep Decarbonization Initiative (IDDI), which aims to develop a global strategy to decarbonize the steel industry by 2050 through public procurement policies and government commitments, SteelZero, a net-zero steel procurement pledge led by the Climate Group, and ResponsibleSteel, one of many steel standard and certification initiatives. While governments will play an important role in this adjustment, consumers in key markets like the automotive and construction sectors also have the power to shape steel production investments and direct the course of the transition. One example of such an effort is the First Movers Coalition, a group of companies that seek to use their purchasing power to accelerate the market for green steel, among other materials.

Importantly, the actions of some countries, particularly China and India, have a more pronounced impact on climate goals due to the current and projected size of their domestic iron and steel industry.

Around half (49%) of the operating capacity of the global steel fleet is located in China, including 59% (819 mtpa) of the capacity that generates higher emissions, coal-based BF-BOF technology. This means that, without substantial change from China, international efforts to get the industry on track will fall short.

While China has announced policies to curb emissions, these are far behind what is needed to transform the industry in the 2020s. China's slow decline in industrial emissions coupled with ongoing investments in coal-based steel production also highlights a large gap between their actions and their stated 2060 neutrality goal.

India currently operates 112 mtpa (5.3%) of global steel capacity, of which 71 mtpa is BF-BOF steelmaking. While their capacity is only a fraction of that in China, India has raised alarms with plans to build out an additional 153 mtpa of BF-BOF steelmaking capacity by 2030, representing the largest share (40%) of BF-BOF steelmaking capacity under development in any single nation and an 11% increase to currently operating BF-BOF steelmaking capacity. This buildout of emissions intensive BF-BOF technology will add to the emissions intensity of India's steel sector and quadruple emissions from 2021 to 2050 if significant action is not taken to bring the country in line with their stated 2070 neutrality goal.

China and India must ramp up efforts significantly in order to meet global decarbonization targets, as well as their own.

STEEL SECTOR EMISSIONS ARE HARD TO QUANTIFY, BUT SUBSTANTIAL

Though neither companies nor governments have converged on a common scope or methodology for calculating emissions from the sector, global estimates undeniably confirm that iron and steel production is responsible for a huge share of emissions.

GEM calculations show that steel sector CO_2 emissions have averaged approximately 3.7 Gt per year since 2019,[6] with an upward trend as production rises. This is more than the emissions generated from all passenger cars on earth. In order to align with the IEA's Net zero by 2050 scenario, direct CO_2 emissions from the global iron and steel industry need to be lowered to 1.8 Gt CO_2 by 2030 and 0.2 Gt CO_2 by 2050.[7]

A benchmarking report for steel emissions shows that approximately 86% of steel emissions came from BF-BOF steel production and 14% from EAF steel production. In the BF-BOF steelmaking route, coal used in the BF is the single biggest contributor to CO_2 emissions in the process. According to data from Climate TRACE, China accounted for approximately 60% of CO_2 emissions in the steel sector in 2022, with India a distant second at 10%.[8] However, the aforementioned rapid development of India's BF-BOF capacity means that its share of global emissions is likely to rise in coming years as more emissions-intensive technology comes online in the country.

Further, high levels of unaccounted emissions from coal mine methane have not been factored into steel industry emissions assessments.[9] Coal used in (iron and) steel production is commonly referred to as metallurgical coal or steelmaking coal. Steel production consumes both coke, which is made from coking coal, as well as a range of non-coking coals of very similar quality to thermal coals. Thus decarbonizing the industry depends on both shifting away from coal-based processes and sourcing clean energy. Global thermal coal operations emit significant amounts of methane, as do metallurgical coal operations and mixed thermal/metallurgical coal mines. Accounting for methane emissions from metallurgical coal mining could increase the reported carbon footprint of the steel industry by up to 27%.[10] This reinforces concerns about relying on carbon capture technology without transitioning away from coal-based steel production for effective decarbonization.

6. In 2019 the global steel industry emitted over 3.6 Gt CO_2 emissions, including 2.6 Gt of direct CO_2 emissions per year and nearly 1.1 Gt of indirect CO_2 emissions from the power sector and combustion of steel off-gasses. Using production data since 2019, the value has risen.

7. SteelWatch finds that alignment with the 1.5 degree pathway from the Intergovernmental Panel on Climate Change (IPCC) requires even further emissions reductions from the global iron and steel sector beyond the IEA's Net-zero by 2050 pathway.

8. Uses emissions quantities from Climate TRACE's manufacturing sector steel asset emissions dataset, which were estimated by TransitionZero based on Global Energy Monitor's Global Steel Plant Tracker and satellite technology.

9. For more information on underreported methane emissions please refer to GEM's 2022 Pedal to the Metal report.

10. Based on 2021 estimates of steel production through the BF-BOF route the global steel industry and coal mine production, we assume that the steel industry consumes approximately 84% of all of the total combined production from metallurgical and mixed metallurgical/thermal coal mines.

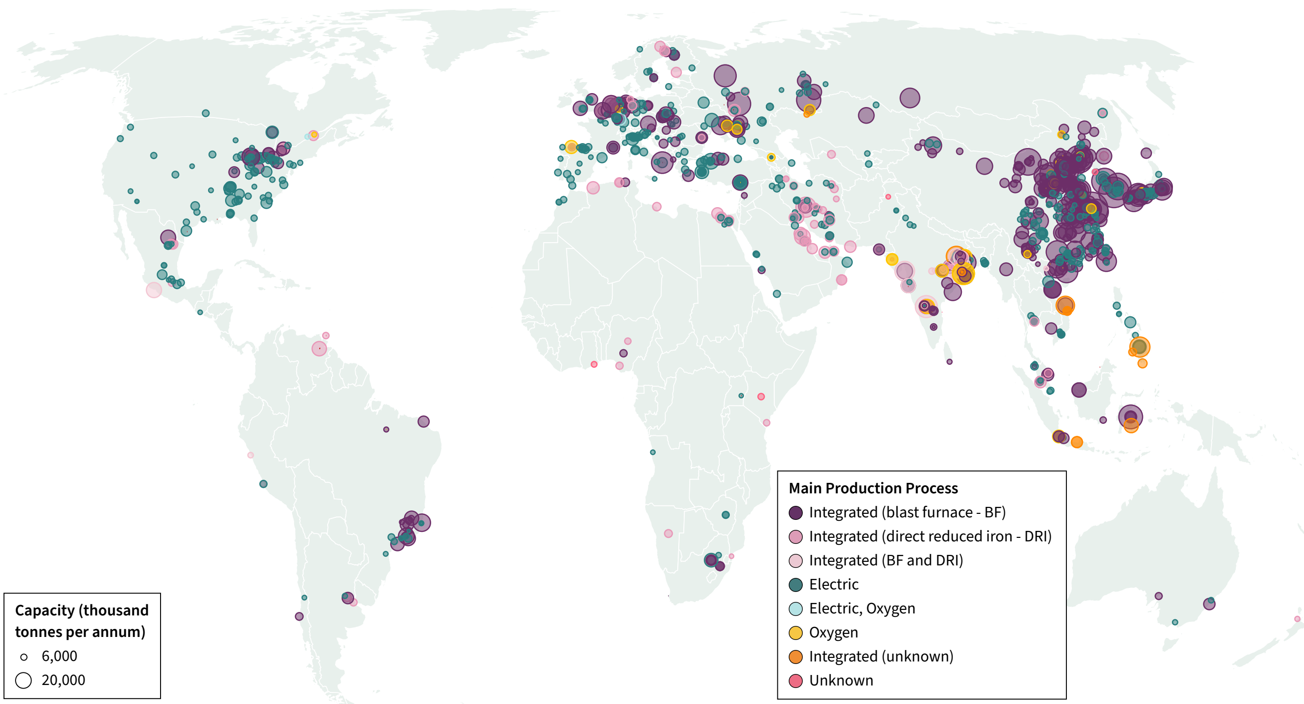
CURRENT STATUS OF GLOBAL IRON AND STEEL PLANT FLEET

Global steelmaking capacity

The GSPT covers 2,271 mtpa of operating crude steelmaking capacity, or 92% of global capacity according to OECD estimates.[11] The GSPT also includes 1,486 mtpa operating blast furnace capacity and 144 mtpa operating DRI capacity, representing 93% and 99% of world capacities, respectively, or 93% of operating ironmaking capacity altogether.[12] Additionally, the GSPT covers all crude iron and steel plants under development as of March 1, 2023, making this the most up-to-date comprehensive tracker of changes in global steel capacity.

According to the GSPT, 62% (1,397 mtpa) of global crude steel capacity currently uses the BOF route,[13]

Figure 1: Global operating steelmaking capacity by type



Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes steel plants with capacity of at least 0.5 mtpa.

11. GEM Global Steel Plant Tracker, March 2023. The OECD reported 2,463 mtpa crude steelmaking capacity in 2022.

12. Global estimates of operating blast furnace capacity are limited and opaque, but recent estimates based on a combination of private and public sources estimate 1,600 mtpa. Global estimates of operating DRI capacity are also limited and difficult to find because of the high number of small rotary kiln operations, but recent estimates report approximately 145 mtpa. Global ironmaking capacity is estimated here as a sum of these process capacities.

13. The BOF steel capacity captured in the GSPT predominantly uses the BF-BOF route, though some steelmakers are now considering alternative routes to feed DRI and scrap into BOFs. Thus, BOF steelmaking will be referred to as the coal-based BF-BOF steelmaking route throughout this report, unless otherwise noted.

29% (665 mtpa) uses EAF steelmaking, and <1% (<6 mtpa) uses open hearth furnace (OHF) steelmaking. The remaining 9% (204 mtpa) of capacity has not been distinguished between these routes.[14] From the steelmaking capacity of known technologies, 68% is BF-BOF, 32% is EAF, and <1% is OHF.

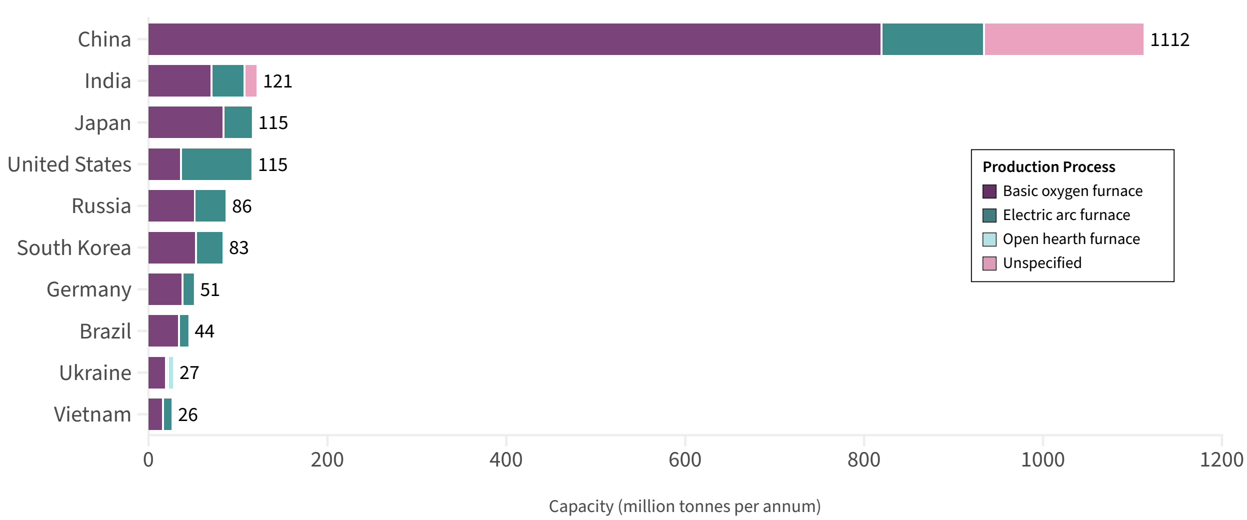
Over two-thirds of current steelmaking capacity is in Asia; China accounts for 49% (1112 mtpa) of the operating capacity in the GSPT, followed by India at 5.3% (121 mtpa) and Japan at 5.1% (115 mtpa). Outside of Asia, Europe has the most operating capacity at 13% (297 mtpa) while the United States holds another 5.1% (115 mtpa). When only BF-BOF steelmaking is considered, China accounts for 59% (819 mtpa) of global capacity. (See Appendix C for full list of operating steelmaking capacity by type and country.) (Figure 2a)

Global ironmaking capacity

Asia also holds most of the world's operating iron capacity with around three-quarters of global ironmaking belonging to the region. China accounts for 55% (897 mtpa), followed by India (122 mtpa) and Japan (95 mtpa). Europe, as in steelmaking, comes in second for regional ironmaking, representing 10% (158 mtpa) of global operating capacity; Germany (33 mtpa) and Ukraine (30 mtpa), representing 2.0% and 1.8% of global capacity respectively, lead the region. Other notable countries include Russia (65 mtpa), the United States (34 mtpa), and Brazil (34 mtpa). Iran not only has a sizable operating ironmaking capacity overall (44 mtpa), but also has the highest operating DRI capacity in the world (38 mtpa).

Per the GSPT, 91% (1,486 mtpa) of global crude iron capacity currently uses BF technology and 9% (144 mtpa) uses DRI technology, mainly a mix of natural gas-based and coal-based DRI. Less than 1% (9 mtpa) of iron capacity in the GSPT has not been distinguished as BF or DRI technology.

Figure 2a: Operating steelmaking capacity by technology type



Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes iron and steel plants with capacity of at least 0.5 mtpa. "Mixture" indicates unknown production route.

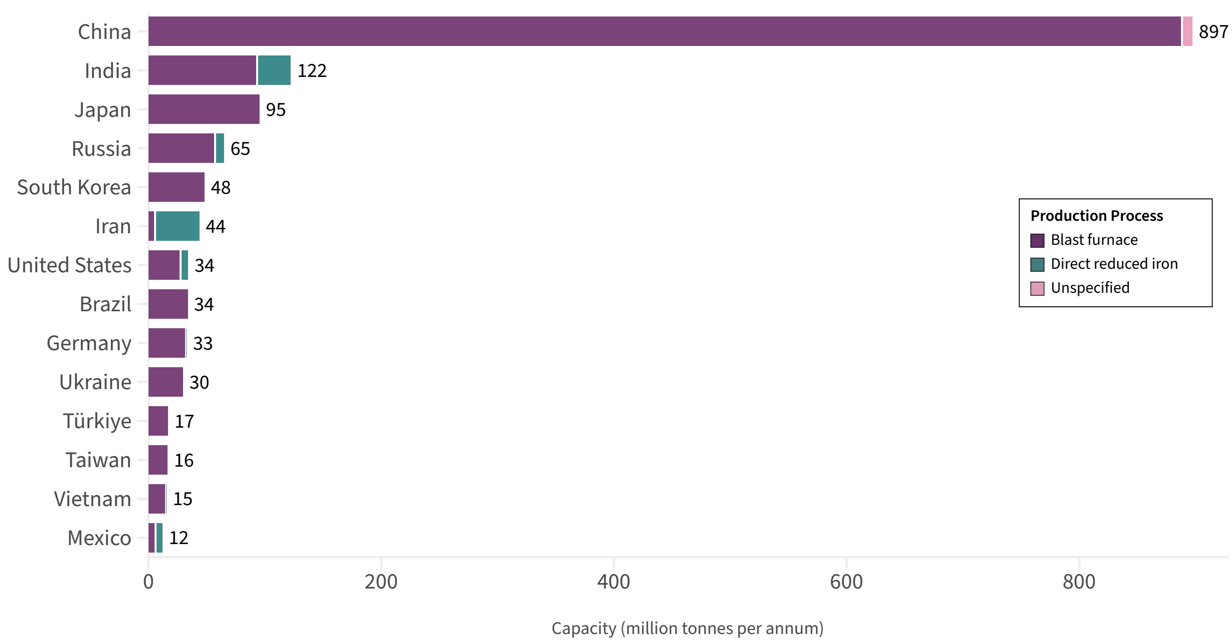
14. Open hearth furnace steelmaking combusts fuel to convert steel scrap and/or pig iron to crude steel. OHF steelmaking has been almost completely replaced by BOF and EAF steelmaking.

Ironmaking units typically operate for around 40 years, with lifetime-extending relinings every 15–20 years for BFs and every 20 or more years for DRIs. A typical BF relining costs approximately $200 million USD and represents 25–50% of the cost of a new blast furnace. Each of these cycles represents a chance for steelmakers to either double down on existing technology or else transition to cleaner production routes.

By 2030, 1090 Mt of existing coal-based BF capacity (73% of the fleet) will reach the end of their working life, requiring decisions on refurbishment or shutdown. Two-thirds of these reinvestment decisions will arise in China. As each BF unit comes up against its reinvestment cycle, a plan must be made for switching the unit to low-emissions steel production technology, whether that means an immediate, full retirement or replacement of BF capacity, or a limited maintenance plan to prolong the lifetime of the asset by no more than 2–5 years until it can be fully retired or replaced by low-emissions processes. By 2025, no further reinvestments in BFs should be made, in order to minimize long-term carbon lock-in and additional stranded asset risk. Given that each BF reinvestment cycle decision plan takes time to develop (one to several years), these plans need to be created immediately to ensure that the 2025 target of no further reinvestments in BFs be met.

Further insight into BF relining dates and investment cycles will be made possible with Global Energy Monitor's Global Blast Furnace Tracker.

Figure 2b: Operating ironmaking capacity by technology type



Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes iron and steel plants with capacity of at least 0.5 mtpa. "Mixture" indicates unknown production route.

CURRENT EVENTS IMPACTING THE STEEL INDUSTRY

Ukraine

The war in Ukraine has caused substantial disruptions to the steel industry, both in and outside the region, since Russia's invasion of Ukraine in February 2022. According to the Global Steel Plant Tracker, approximately 12 mtpa of capacity—30% of Ukraine's total 39 mtpa capacity—was shut down entirely, including the Azovstal Iron & Steel Works, which became a symbol of the Ukrainian resistance after an 80-day siege by Russian forces destroyed the plant.

The extent of the loss of operating capacity in Ukraine is hard to pinpoint, as other plants are operating at severely reduced levels. Furthermore, at some operational plants, transporting the steel to market has resulted in significant interruptions in shipping and supply chains. Overall, Ukrainian steel production dropped by 71% (15 Mt) from 2021 to 2022, meaning that capacity utilization as well as operable capacity decreased. Additionally, of the country's 37 mtpa of pig iron capacity, around 54% (20 mtpa) was mothballed or retired due to infrastructure damage or operational issues caused by the war.[15]

Beyond the direct impacts on Ukrainian steel production, the war sparked political tensions and triggered economic shifts that affected the steel industry globally. In the European Union specifically, the conflict has led to decreased supply of fuels and higher energy prices, halting or reducing production at numerous plants due to unprofitability.[16] Production in the EU fell by 11% in 2022.

Additionally, the war has impacted the global coal trade, including both thermal and metallurgical coal. Countries including the United States, United Kingdom, and Japan placed bans on Russian coal imports, leading to a reconfiguring of imports of Russian coal to China, India, and Turkey, particularly. The war also led to an unprecedented turnaround in the coal market where thermal coal became (and still is) priced higher than metallurgical coal. This led coal miners to sell metallurgical coal into thermal coal markets. Coronado, one of the largest metallurgical coal producers globally, made headline news in Australia by selling metallurgical coal to European coal-fired power plants.

China

In an effort to tackle overcapacity and instability in its steel industry, China has implemented policies and guidelines in recent years to curb the establishment of new production capacity. The current plans focus on closely monitoring the steel industry to prevent the creation of new production capacity, avoid the resurgence of previously halted projects, and implement structural reforms on the supply side of the national steel economy. China also launched an environmental product declaration (EPD) platform for the steel industry in January. This platform provides a method for calculating, reporting, and comparing product-level emissions for finished products from China's iron and steel industry.

As the world's largest steel producer, these policies have the potential to significantly influence production and capacity developments on a global scale, provided they are consistently enforced. As detailed later in this report, these policies are operating with limited success. While there is a noticeable slow down in new Chinese developments, the country is still a global frontrunner in both existing and emerging steel production capacity.

15. Based on GEM's Global Blast Furnace Tracker, which tracks blast furnace capacity at the unit-level rather than plant-level.
16. Several plants in Germany, Italy, Spain, and other countries either shut down or reduced production due to the spike in energy prices.

India

Since 2014, India has pursued a "Make in India" initiative, a set of policies aimed at boosting domestic manufacturing. The country thus aims to double its steel production over the next decade, reaching 300 MTPA by 2030. In line with this, in 2021, India approved the Production-Linked Incentive (PLI) scheme to reshape the steel industry and work toward industrial self-reliance. The scheme invests over over $800 million USD over five years targeted at increasing production of specialty steel, with consecutive rounds of funding underway.

Simultaneously, India's steel decarbonization plans emphasize greater efficiency and renewable energy, with little mention of any shift away from BF-BOF technologies. Thus, a significant expansion of the country's BF-BOF capacity is ongoing. At the same time, India has joined the UN-level Leadership Group on Industry Transition as a founding member, which may provide the opportunity for international collaboration to help India leap-frog to cleaner technologies.

STEELMAKING CAPACITY UNDER DEVELOPMENT

Persistent global overcapacity provides opportunity for green steel transition

The Global Forum on Steel Excess Capacity (GFSEC) was formed in 2016 to address the overcapacity that has challenged the steel industry since the global financial crisis of 2008. Overcapacity presents serious risks to steelmakers as they struggle to operate profitably with lower capacity utilization rates.[17] GFSEC has found that overcapacity is largely driven by market-distorting government subsidies and support measures, which can keep inefficient steel assets operating past their lifetime. Removing such subsidies and support measures would not only stabilize the steel market, but also create opportunities for companies to invest in low-emissions steel production technologies, rather than maintaining uneconomic capacity.

In 2022 the OECD reported a global excess capacity of 632 million tonnes of crude steel, approximately 26% of operating capacity in excess of current production levels. Though this gap narrowed briefly in 2021 to 544 million tonnes, excess capacity has remained at or around 25% since 2018. This trend is set to continue and become more pronounced. Current development plans and investments in crude steel capacity (totaling 736 mtpa per the 2023 GSPT) indicate that the global trend of overcapacity will continue unless expansion plans are cancelled or scaled back.

The top ten steel producers in 2022 averaged 72% capacity utilization (see Figure 3), decreasing from 75% in 2021. However, India, which seemingly has a very high capacity utilization rate (97%), has a high level of induction furnace (IF) capacity and lacks transparency around these units. Accounting for IFs could add around 30 mtpa to Indian steelmaking capacity, which would bring their actual capacity utilization rate to a more realistic 79% and would lower the top 10 average utilization rate further to around 70%.

Global crude steel capacity increased slightly (0.4%) from 2021 (2454 Mt) to 2022 (2463 Mt) according to OECD estimates. According to the GSPT, 43 Mt crude steel capacity was closed in 2022 while 54 Mt started operating, representing a 11 Mt net gain. Of the 43 Mt of capacity retired or mothballed in 2022, 65% (28 Mt) was in China, 27% (12 Mt) was in Ukraine,[18] and the remainder was from one 1 Mt plant in Peru, one 2 Mt plant in Italy, and one 1 Mt plant in the U.K.

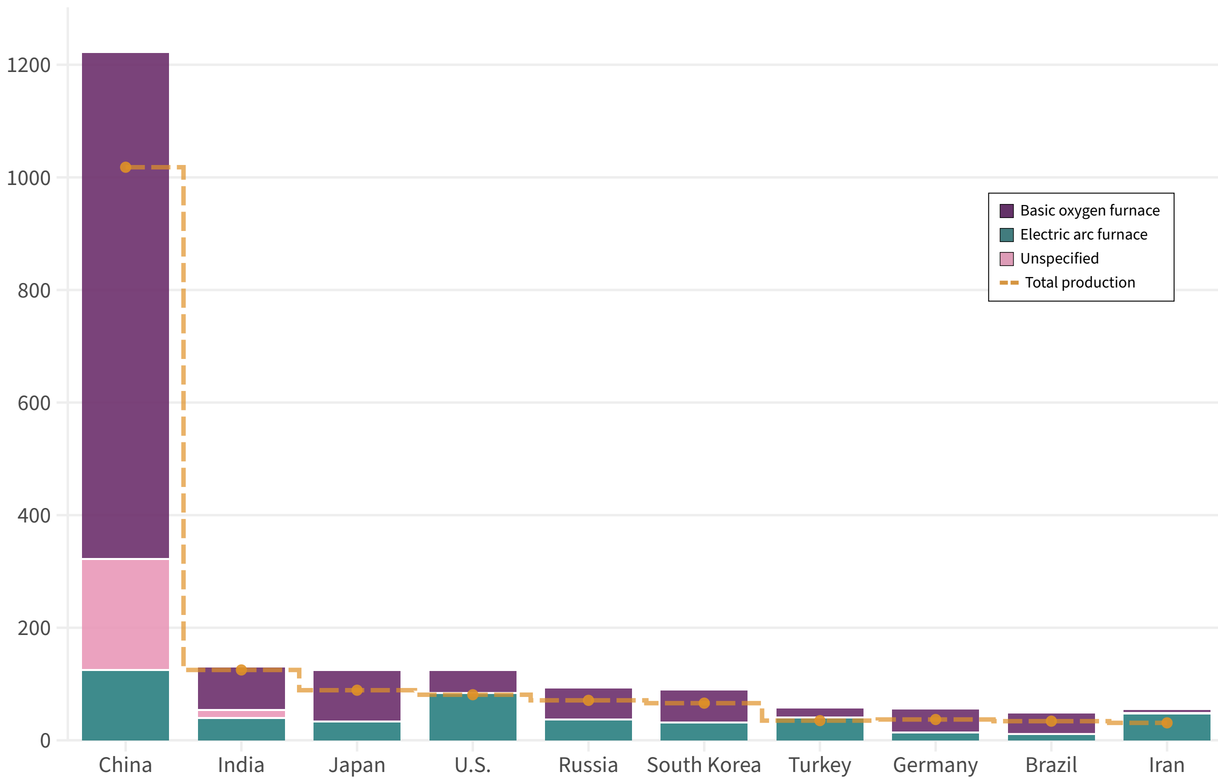
17. Typically capacity utilization rates of 80% to 90% are required for a steel plant to remain profitable. Steel capacity exceeding more than 90% of demand is considered to be overcapacity.
18. This high Ukrainian retired capacity is due to damage caused by the war in the region.

Of the closures for which the production method of the plant was known, 86% of capacity was BF-BOF and 14% EAF. 13% of closures were capacity with unknown technology. Of the steelmaking capacity that came onboard in 2022, 68% is in China (37 Mt), 11% is in the United States (6 Mt), 9.2% is in India (5 Mt), 5.5% is in Iran (3 Mt), and the remainder is in Türkiye (1 Mt), Iraq (1 Mt), and Kenya (1 Mt). 64% of new capacity in 2022 uses BF-BOF, with the remaining 36% using EAF.

Beyond the crude steel capacity that is known to have started operations in 2022, an additional 42 Mt (61.3% BF-BOF and 39.7% EAF) of capacity was under development with an intended start date of 2022. As of the end of 2021, 58% of this capacity under development had entered the construction phase, while the remaining 42% had not demonstrated any progress beyond the initial proposal stage. Delays in plant operation and changes to construction or proposal plans may be due to the ongoing impacts of the COVID-19 pandemic, shifting pressures on global supply chains, changes to capacity restriction policies, and general construction delays.

Figure 3: Overcapacity in top steel producers remains consistent

Steel production by type (mtpa)



Source: Production data from World Steel Association (2022). Capacity data from Global Energy Monitor's 2022 and 2023 Global Steel Plant Tracker, CarbonBrief (2020), and the OECD (2022).
Note: Includes iron and steel plants with capacity of at least 0.5 mtpa. "Unspecified" indicates unknown production route.

Still behind target on shift away from coal-based BF-BOF steelmaking

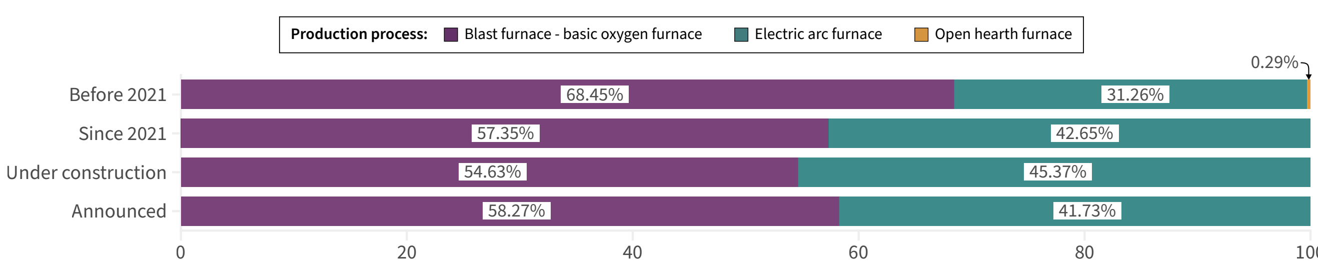
According to the GSPT, approximately 731 mtpa steelmaking capacity is under development worldwide, of which 52% (380 mtpa) uses the BF-BOF route, 39% (286 mtpa) uses EAF, and 9% (65 mtpa) is unknown. Of these new developments with known production processes, 57% are BF-BOF and 43% EAF. While still primarily coal-based BF-BOF, the steel industry is beginning to face the reality of decarbonization: when the first Pedal to the Metal report was released in 2021, 68% of operating capacity used the BF-BOF process, 31% EAF, and less than 1% HF. Of projects that have commenced operation since then, 57% have been BF-BOF and 43% EAF. The higher percentage of deployed EAF steelmaking signals that some progress is being made in the shift away from BF-BOF and toward EAF.

Further breaking down the new capacity under development reinforces this observation. This includes both projects that have been announced with no concrete advancements and construction phase projects that have broken ground. Of new development capacity announced before 2021, 78% uses BF-BOF technology and 22% EAF, whereas those announced since 2021 are 48% BF-BOF and 52% EAF. Projects that have progressed to the "construction" phase are 55% BF-BOF-based and 45% EAF.

While these developments indicate a notable movement toward greener technology, this shift is nowhere near the scale of change needed to meet carbon neutrality goals by 2050. The IEA's Net-zero by 2050 scenario puts the share of global EAF steelmaking capacity at 37% by 2030 and 53% by 2050.[19] Given the heavy presence of BF-BOF steelmaking today (67%), even the shift toward EAF in new developments leaves the industry far from this timeline. To meet the IEA's 53% EAF threshold by 2050 (while accounting for a projected 12% increase in global steel demand over this time period) approximately 347 Mt of BF-BOF capacity would need to be retired or cancelled and 610 Mt of EAF capacity would need to be added to the current fleet.[20]

In this scenario, the share of planned steel capacity using EAF technology would need to reach 64% and BF-BOF reduced to 36% (and all equipped with CCUS). However, current development plans would add 380 Mt of known BF-BOF capacity and only 286 Mt of EAF (57% BF-BOF and 43% EAF), which would result

Figure 4: Share of steel capacity operating and under development by technology



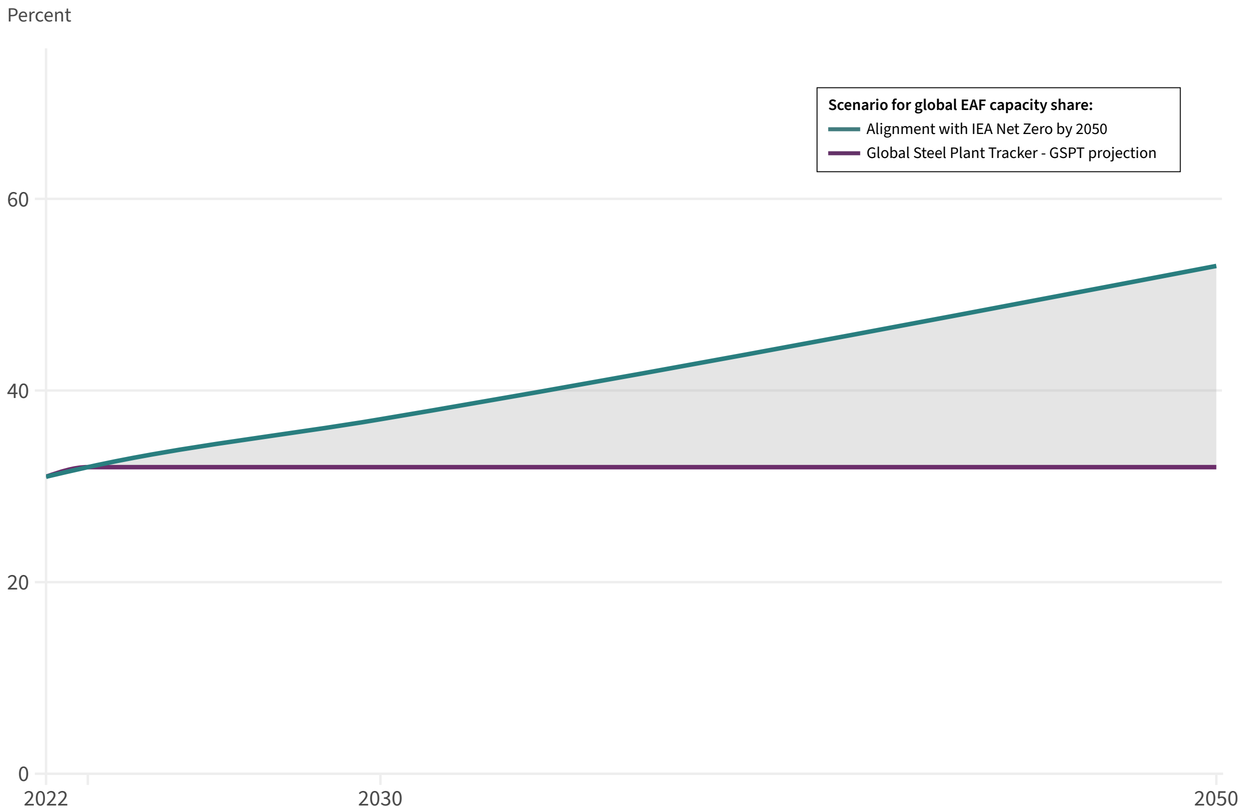
Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes steel plants with capacity of at least 0.5 mtpa.

19. Additionally, 42% of primary steelmaking alone needs to use EAFs by 2050 in a hydrogen-based direct reduced iron or iron ore electrolysis configuration. The IEA's Net-zero by 2050 Scenario allows for only 5% of primary production to use unabated BF-BOF production and no more than an additional 53% fully equipped with CCUS. Especially since the potential of CCUS to serve as an economically viable solution to decarbonizing BF-BOF steelmaking has been recently called into question, there is no doubt that BF-BOF steelmaking capacity needs to be reduced.

20. These calculations are made assuming that all existing OHF capacity (6 mtpa) is retired by 2050 and current capacity utilization rates remain the same (and thus, current overcapacity rates also remain the same).

in the percent of production using EAF technology remaining at 32% and BF-BOF at approximately 68% through 2050 (see Figure 5). Thus, significant action needs to be taken to change this trajectory by retiring existing BF-BOF capacity, cancelling BF-BOF capacity under development, and replacing BF-BOF plans with alternatives, mainly DRI-EAF.

Figure 5: Global shift towards EAF steelmaking well behind decarbonization targets

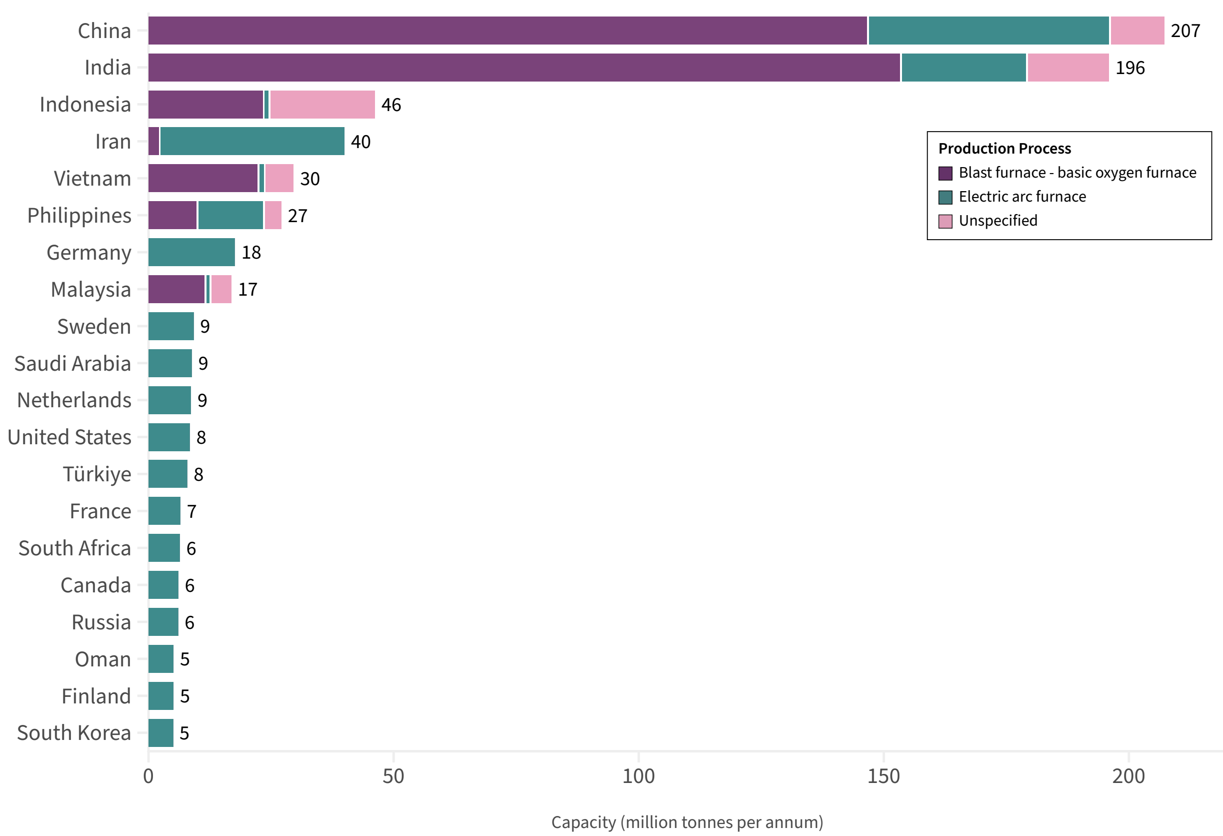


Source: EAF capacity projection data from Global Steel Plant Tracker, Global Energy Monitor, March 2023. EAF capacity net-zero projection from 1.5C pathway in IEA Net Zero by 2050.

Asia hotspot for new steel capacity

53 countries currently have new steelmaking capacity[21] planned or underway. As with operating capacity, most (75% or 545 mtpa) of this capacity comes from Asia, and a majority (55%) from just two countries—China and India (see Figure 6). However, the share of global development attributed to China and India is shrinking (down to 55% this year from 66% in 2021), with Chinese projects making up 28% (207 mtpa) of global developments and Indian projects 27% (196 mtpa). New steel capacity in Asia is particularly heavy in the BF-BOF route, with 99% of new BF-BOF developments planned in Asia.

Figure 6: Steelmaking capacity under development



Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: Includes steel plants with capacity of at least 0.5 mtpa. "Unspecified" indicates unknown production route.

21. Including plants over 0.5 mtpa

India ramps up plans to add emissions-intensive BF-BOF steelmaking capacity

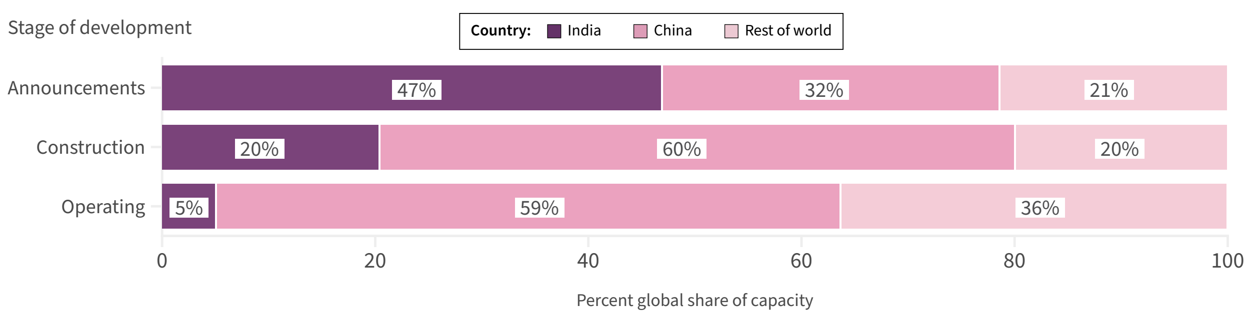
India is now the world's largest developer of new coal-based steel capacity, holding 40% (153 mtpa) of BF-BOF steelmaking capacity under development. China, the previous frontrunner, is a close second with 39% (147 mtpa), making the two countries responsible for over three-quarters of BF-BOF development globally. This is despite the fact that both countries have made pledges to achieve carbon neutrality, China by 2060 and India by 2070. Other countries with new BF-BOF capacity under development are Indonesia (24 mtpa), Vietnam (22 mtpa), Malaysia (12 mtpa), the Philippines (10 mtpa), Myanmar (4 mtpa), Cambodia (3 mtpa), Iran (2 mtpa), Bangladesh (2 mtpa), and Nigeria (1 mtpa), many of which have net zero commitments of their own (see Table 1).

EAF steelmaking capacity expands as China's share slows

While BF-BOF developments are led by a few key actors, global distribution of new EAF capacity is expanding, with 286 mtpa under development in 49 countries this year as opposed to 170 mtpa in 32 countries the year before—a 68% worldwide increase. China accounts for 17% (49 mtpa) of EAF developments, and although the country's overall tonnage has remained largely unchanged from 2021, the global share this represents has decreased almost 12 points from 29% in 2021. This decline reflects the expanding distribution of EAF steelmaking. Other leading countries developing EAF capacity include Iran with 13% (38 mtpa), India with 9.1% (26 mtpa), Germany with 6.3% (18 mtpa), and the Philippines with 4.9% (14 mtpa) (see Appendix E for a complete list).

While growth of EAF steelmaking capacity can be seen as a positive sign for the green steel transition, the source of electricity and EAF feedstock (scrap, pig iron, direct reduced iron, etc.) will determine the emissions intensity of the steel produced at these facilities.

Figure 7: China's and India's share of global coal-based blast furnace-basic oxygen furnace capacity



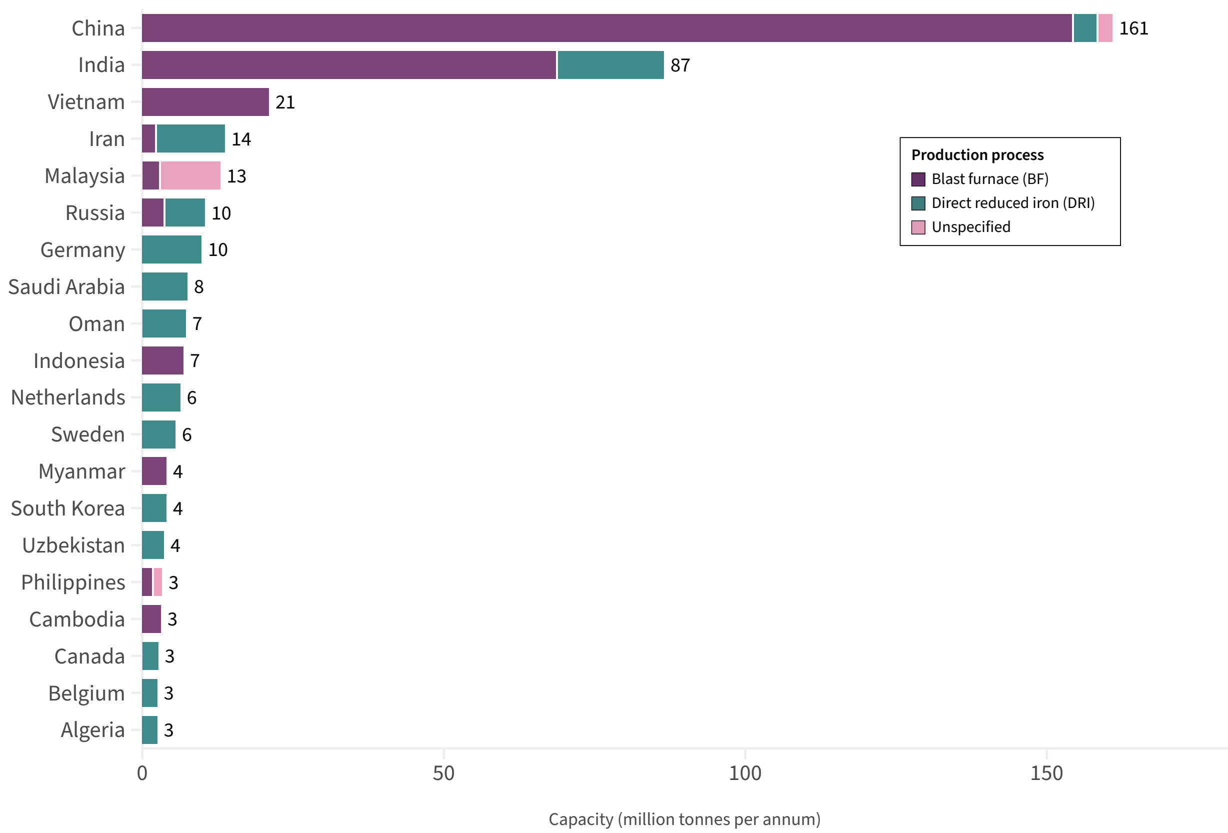
Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes steel plants with capacity of at least 0.5 mtpa.

IRONMAKING CAPACITY UNDER DEVELOPMENT

Of known capacities for ironmaking projects under development,[22] 71% (273 mtpa) will use BF technology and 29% (114 mtpa) will use the DRI process (see Figure 7). Relative to the current distribution of operating ironmaking capacity (91% BF, 9% DRI, <1% unspecified), ironmaking capacity is shifting towards a greater share being DRI production. Further, projects announced more recently (since 2021) have a higher proportion of DRI ironmaking (63% BF and 37% DRI) compared to projects announced before 2021 (84% BF and 16% DRI). Overall, DRI is gaining a larger share of ironmaking globally.

However, the emissions intensity of steel produced from DRI varies significantly depending on the DRI process. Much of the DRI capacity under development is in India (18 mtpa), where coal-based DRI production dominates the industry, resulting in the

Figure 8: Ironmaking capacity under development by technology type



Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes iron and steel plants with capacity of at least 0.5 mtpa. "Unspecified" indicates unknown production route.

22. Ironmaking developments are likely under-reported since proposals for integrated steel plants (BF-BOF technology) typically focus on final products, such as crude steel or finished steel products. Details on production capacity for raw materials processing (i.e., coking ovens, sinter plants, etc.) and ironmaking are often unavailable until the plant begins operating and reveals capital investments and facility upgrades through annual and investor reports. While it's possible to make rough estimates of the iron capacity required in a new integrated facility of a certain crude steel capacity, predicting how the expansion of crude steel capacity at an existing integrated facility will affect ironmaking capacity proves much more difficult since the facility may already have adequate ironmaking facilities or plans to source iron and/or scrap from other facilities. In order to estimate proposed additions to ironmaking capacity for these projects, iron and steel plant operators must provide more information and increased transparency about steel capacity expansions and the production and sourcing of upstream materials such as iron.

highest national average CO_2 emissions intensity for EAF steel production. Moreover, while DRI is most often associated with the lower emissions EAF steel production route, DRI plants can also feed BFs or BOFs to make steel. This means that the development of DRI technology on its own does not indicate a full scale shift away from coal-based steel production, but a significant reduction in emissions for one part of the iron and steelmaking process.

97% of global blast furnace capacity under development in Asia

While 13 countries have known plans[23] to develop blast furnace capacity, 97% (265 mtpa) of that capacity is located in Asia. The country with the largest global share is China with 56% (154 mtpa), followed by India with 25% (69 mtpa) and Vietnam with 8% (21 mtpa). Blast furnace capacity is a critical metric in the steel industry's decarbonization process; given that the blast furnace is the most carbon-intensive portion of steel production with limited, difficult, and high-cost decarbonization options, decisions about the refurbishment, retrofit, and retirement of existing blast furnace capacity and proposals and investments in new blast furnace plants vs direct reduced iron plants will determine whether the global steel sector aligns with the Net Zero by 2050 pathway. For a more in-depth look at blast furnace capacities and developments, you can visit GEM's new Global Blast Furnace Tracker.

DRI ironmaking capacity growing, but not quickly enough

Capacity using the direct reduced iron (DRI) process is more dispersed, with projects planned in 24 countries, though many smaller (<0.5 mtpa capacity) DRI projects are noted. Countries with the largest DRI capacities under development are India with 16% (18 mtpa), Iran with 10% (11 mtpa), and Germany with 9% (10 mtpa). As indicated earlier, the share of DRI in total global ironmaking capacity is growing but is still far from where it needs to be.

Steel decarbonization strategies point out that DRI development should be strategically planned in countries with ample renewable electricity generation potential and iron ore availability exceeding domestic needs.[24] The Net Zero Steel project identifies Australia, Brazil, Canada, South Africa, and Russia as good candidates for green hydrogen-based DRI production based on renewables potential and iron ore resources. An additional study that accounts for cost and worker wages, in addition to iron ore resources and renewable energy production, concludes that countries approximately 23.5 degrees north and south of the equator (near the tropics of Capricorn and Cancer) are best suited for green hydrogen-based DRI production.

23. Ibid.

24. While green hydrogen-based DRI technology is the route to achieve lowest-emissions steel production, some regions may have grid power available that is not yet fully renewables powered, but still provides a significant net-positive emissions impact for grid powered electrolyzer-based hydrogen production and DRI compared to BF-BOF steelmaking.

STRANDED ASSET RISK CONTINUES RISING

Stranded assets pose a significant economic risk to the iron and steel industry as more countries with major steel industries pledge to reach carbon neutrality but at the same time plan to build numerous large coal-based BF-BOF steel plants.

If all coal-based BF-BOF capacity proposed or under construction is fully developed, operated with unabated emissions, and historic overcapacity trends continue, the steel industry could face as much as US$554 billion in stranded asset risk as countries work towards their carbon neutrality commitments (see Table 1).

As this research continually expands its coverage of developing steel capacity and as countries further develop their decarbonization plans, a fuller picture of the increasing risk of stranded steel industry assets is available. As of June 2023, over 130 countries have announced net zero goals and the amount of BF-BOF capacity in development continues to grow. From 2021 to 2022 there was an increase of approximately 7% (36 mtpa) in BF-BOF assets under development in countries with net-zero carbon commitments, increasing the upper range of stranded asset risk estimations from US$518 billion to US$554 billion.

In addition to stranded asset risk from developing steel plants, a 2022 study of TransitionZero's Global Steel Cost Tracker estimated that 132 mtpa capacity at existing BF-BOF facilities will face stranded asset

Table 1: Coal-based BF-BOF capacity under development in countries with net-zero carbon commitments

Country	Carbon commitment	Coal-based BF-BOF steel capacity under development (ttpa)	Stranded asset risk (US$ billion)	
			Low range	High range
China	Net Zero 2060	146,764	147	222
India	Net Zero 2070	153,487	153	230
Indonesia	Net Zero 2060	23,500	24	35
Vietnam	Net Zero 2050	22,400	22	34
Malaysia	Net Zero 2050	11,600	12	17
Myanmar	Net Zero 2050	4,000	4	6
Cambodia	Net Zero 2050	3,100	3	5
Bangladesh	Net Zero 2050	2,000	2	3
Nigeria	Net Zero 2060	1,300	1	2
Total		**368,151**	**368**	**554**

Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes steel plants with capacity of at least 0.5 mtpa. Based on estimation that the capital cost of a new integrated BF-BOF steelmaking facility is approximately US$1–1.5 billion per million tonnes crude steel capacity.

STRANDED ASSETS IN THE STEEL INDUSTRY

Stranded assets are assets that have lost anticipated economic value as the result of changes in market conditions and regulations adopted as part of decarbonizing the global economy. Because decarbonization options for blast furnaces are limited and largely unproven, BF-BOF steel plants will be vulnerable to stranded asset risk if the cost of carbon is realized through carbon pricing (i.e., taxes) or emission standards, and a conventional steel plant may be unable to price competitively with low-carbon steel production plants. To avoid stranded asset potential, BF-BOF retrofits for low-carbon steelmaking would need to be developed and brought to market in a fraction of the time predicted in steel decarbonization roadmaps (see The risk of stranded assets.)

risk by 2030 and 514 mtpa by 2050 if we are to achieve net zero emissions by 2050.[25] Looking at stranded asset risk from existing plants and from plants under development together puts total capacity at risk at approximately 882 mtpa by 2050, equivalent to 36% of current global operating steel production capacity. It is thus increasingly clear that there are substantial financial risks associated with building new BF-BOF plants and extending the operational lifespan of existing BF-BOF plants.

Insufficient action from top steelmaking companies

While the majority of countries possessing significant steel production capacity have made explicit pledges towards achieving carbon neutrality, most of the top steel production companies are yet to demonstrate similar commitments. According to the GSPT, out of the 20 companies that hold the largest shares of global steel production capacity (28.9% total), less than half (45%) have formulated concrete plans to reach net zero by 2050.[26] Even among those with net zero 2050 goals, the average proportion of capacity reliant on the coal-based BF-BOF production route stands at 84%, while only 16% uses EAF. This highlights the need for greater engagement in the private sphere as well as the public, including widespread accountability mechanisms to incentivize corporate climate action.

CONCLUSIONS

- **The last year was pivotal for heavy industry decarbonization.** Steel has moved from inertia to progress. We saw the first set of blast furnace relining investment decisions made, and the pipeline of coal-based blast furnace-basic oxygen furnace production has somewhat changed for the positive. Coal-based steel production is on the decline, but not quickly enough. Further challenges arise in ensuring that the steel transformation strives for fully decarbonized production routes, rather than other fossil fuel-based alternatives.

- **The market is changing.** Governments are handing out subsidies for green steel now, notably the European Union, United States, and Australia. Plans for new steel capacity reveal a small but distinct shift in steel production towards low-emissions steel production. The green steel transformation is becoming a race, and governments subsidizing uneconomic capacity using the coal-based blast furnace-basic oxygen furnace route will be left behind.

- **South East Asia continues to lead in development of steel production capacity and is now emerging as a stranded assets hotspot.** Capacity development plans in South East Asia need to be redesigned in alignment with net-zero plans, meaning no new coal-based blast furnace-basic oxygen furnace steelmaking developments and plans to retire and replace blast furnaces with fossil-fuel-free alternatives.

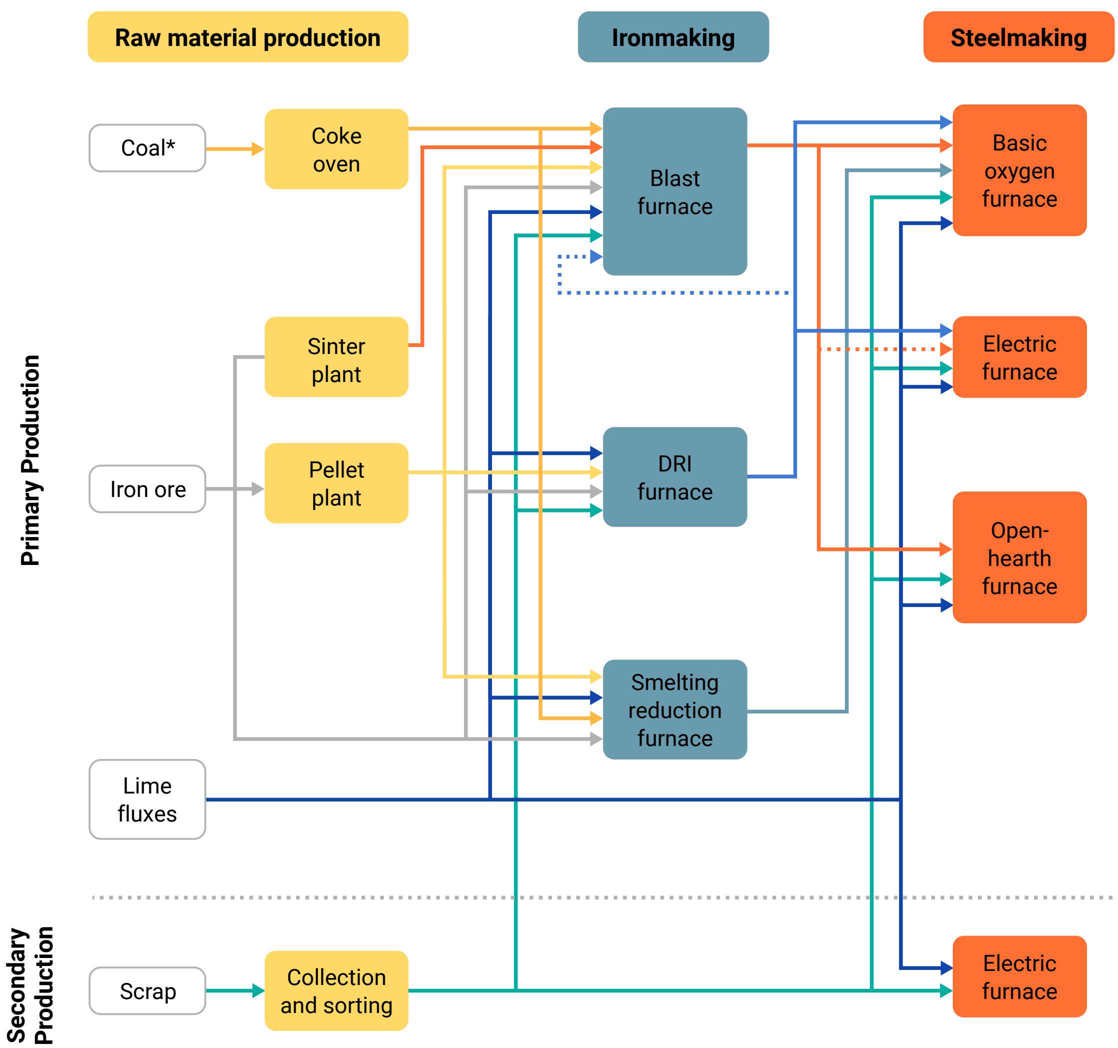
25. The countries with the highest production costs in BF-BOF production would face stranded asset risk first. This 132 mtpa BF-BOF capacity facing closure by 2030 would come from Japan, Germany, China, Italy, and the United States.

26. Calculated by cross-referencing GEM's Global Steel Plant Tracker (2023) and Transition Pathway Initiative's database of net zero commitments.

APPENDICES

Appendix A: Main steel production pathways

Steelmaking currently uses two main production routes: (1) integrated blast furnace-basic oxygen furnace (BF-BOF) and (2) electric arc furnace (EAF) steelmaking, which typically uses a feedstock of direct reduced iron (DRI) and/or steel scrap. Open-hearth furnaces (OHF) are less commonly used, accounting for <1% of global steel capacity. The figure below displays the main steelmaking pathways.



Source: Iron and Steel Technology Roadmap, IEA, October 2020 as modified by Global Energy Monitor.
*Coal is a key material input to coke ovens for conversion into coke; while not represented here, it is also an energy input into other process units, alongside other energy inputs like natural gas and electricity.
Notes: Iron ore includes concentrate, lump and fines. Electric furnace includes both EAFs and induction furnaces. DRI input into blast furnace and blast furnace input into EAFs are less common (dashed lines).

BF-BOF steelmaking

In blast furnace-basic oxygen furnace (BF-BOF) steelmaking, iron ore is converted to pig iron (aka hot metal, crude iron) with the help of coal in the blast furnace. Crude steel is produced in the basic oxygen furnace, which uses pig iron and steel scrap as its primary feedstocks, though small amounts of direct reduced iron (DRI) may be used as a supplemental input. The BF-BOF steelmaking process often includes pelletization and sintering of iron ore and production of coke from coking coal as preliminary processes for iron and steelmaking. Producing one tonne of steel through the BF-BOF steelmaking route emits around 2.2 tonnes of CO_2 and requires roughly 20.8 GJ of energy, assuming global average electricity carbon intensity. Options for decarbonizing the BF-BOF steelmaking route are difficult and limited because of the reliance on coke in the ironmaking process. In the blast furnace process, coke is needed to guarantee the stability of furnace operations. As coke reacts with iron ore to form pig iron, CO_2 is inevitably released as a byproduct, so-called process emissions. Given that process emissions are an inherent part of BF ironmaking, the abatement potential is limited, with the use of zero carbon electricity in the BF-BOF steelmaking process reducing emissions by just 7.4%. Hydrogen can be used to partially substitute metallurgical coal as a reductant in the BF-BOF steelmaking process, with a maximum carbon emissions reduction of 21.4% per tonne of steel. Together, zero carbon electricity and hydrogen injection can abate a maximum of 28.8% of CO_2 emissions in BF-BOF steelmaking, based on current estimates.

EAF steelmaking

Electric Arc Furnace (EAF) steelmaking uses steel scrap, DRI (aka sponge iron), or a combination of these materials as the primary feedstock. DRI production turns iron ore into iron using a reducing gas such as carbon monoxide (produced from natural gas or coal) or hydrogen (produced from natural gas, coal, or using an electrolyzer that relies on electricity to split water into hydrogen and oxygen). Scrap-based EAF production results in approximately 0.3 t CO_2 / t crude steel (not including embodied emissions), while natural gas-based DRI-EAF production results in approximately 1.4 t CO_2 / t crude steel. Coal can also be used in DRI-EAF production, with average emissions ranging from 1.3–1.8 t CO_2 / t crude steel for the COREX/FINEX process and 3.2 t CO_2 / t crude steel for the rotary kiln process. Hydrogen-based DRI-EAF production results in an average of 0.71 t CO_2 / t crude steel, though actual emissions vary widely depending on the production route of the hydrogen and electricity source. Producing one tonne of steel through the EAF steelmaking process requires 9.0 GJ of energy on average globally. The average energy intensity for EAF steelmaking drops to 6.2 GJ/t crude steel if China and India are excluded from estimates. EAF energy intensity for these countries is high due to the high use of DRI and pig iron as feed materials.

It is important to note that the emissions intensities of EAF steelmaking processes vary based on electricity sources and feed materials, particularly the choice of reductant in the DRI process. In both BF-BOF and EAF steelmaking, the iron production portion is responsible for the majority share of emissions in the steelmaking process.

Appendix B

Comparison of IEA decarbonization roadmaps[27]

	Sustainable Development Scenario (SDS)	Faster Innovation Case	Net Zero by 2050 Scenario (NZE)
Report source	Iron and Steel Technology Roadmap	Iron and Steel Technology Roadmap	Net Zero by 2050
Energy system goal	2°C / net-zero 2070	1.5°C / net-zero 2050	1.5°C / net-zero 2050
Steel sector goal relative to 2019 CO_2 emissions	2.3 Gt CO_2 emitted in 2030 1.2 Gt CO_2 emitted in 2050 0.3 Gt CO_2 emitted in 2070 54% reduction in direct, process emissions by 2050	0.3 Gt CO_2 emitted in 2050 88.5% reduction in direct, process emissions by 2050[28]	1.8 Gt CO_2 emitted in 2030 0.2 Gt CO_2 emitted in 2050 92% reduction in direct, process emissions by 2050
Share of steel production using EAF	29% in 2019; 57% by 2050	Assumed same as SDS	24% in 2020; 37% by 2030; 53% by 2050
Scrap as share of input	32% in 2019; 45% by 2050	Assumed same as SDS	32% in 2020; 38% by 2030; 46% by 2050
Material efficiency	Responsible for 40% of cumulative emissions reductions relative to 2019 baseline by 2050	Reduces steel demand by 19% relative to 2019 by 2050	Reduces steel demand by 20% relative to 2020 by 2050
Technology performance improvements (BAT and best practices)	21% of cumulative emissions reductions by 2050		While the NZE cites the importance of installing BAT and optimizing operational efficiency of equipment, they do not provide estimated emissions savings from technology performance improvements.
Technologies still in development/prototype phase	Responsible for 30% of cumulative emissions reductions by 2050 Responsible for approximately 40% annual emissions savings in 2050	Introduced to market by 2026 Responsible for approximately 75% annual emissions savings in 2050	Responsible for 54% of cumulative emissions reductions by 2050[29]
Hydrogen-based DRI	Responsible for 8% of cumulative emissions reductions by 2050 15% of steelmaking capacity equipped by 2050 Introduced to market by 2030 One electrolytic hydrogen-based DRI plant built per month after market introduction	Introduced to market by 2026 Two 100% renewable hydrogen-based DRI plants built per month after market introduction	29% steelmaking capacity equipped by 2050
CCUS (including blue hydrogen-DRI)	Responsible for 16% of cumulative emissions reductions by 2050 Introduced to market by 2030 One 1 Mt CO_2 captured per year CCUS project installed every 2–3 weeks after market introduction Reaches 400 Mt CO_2 captured per year by 2050	Introduced to market by 2025 Two 1 Mt CO_2 captured per year CCUS projects built every month after market introduction	53% steelmaking capacity equipped by 2050 Reaches capture total of 670 Mt CO_2 by 2050
Iron ore electrolysis	Not deployed	5% of steelmaking capacity equipped by 2050 Introduced to market by 2030 One plant built every two months from 2030 to 2050	13% of steelmaking capacity equipped by 2050

27. The IEA reports that total direct emissions from the iron and steel sector were approximately 3.7 Gt CO_2 in 2019 (2.6 Gt CO_2 direct emissions and 1.1 Gt CO_2 indirect emissions). According to the IEA's NZE report, direct emissions in 2020 were 2.4 Gt CO_2. The NZE projected heavy industry (including steel, chemicals, and cement) emissions reductions of 20% by 2030 and 93% by 2050 relative to a 2020 emissions baseline. Emissions reductions for the NZE were recalculated relative to a 2019 baseline for comparison with the SDS and Faster Innovation Case.

28. IEA states that direct global emissions from the iron and steel sector "fall to reach a level in 2050 that is 75% lower than in the Sustainable Development Scenario."

29. Recalculated for 2019 baseline. Responsible for 60% of cumulative emissions reductions by 2050 relative to 2020 baseline.

Appendix C

Operating steelmaking capacity by country and production process

Country	Total Capacity	BOF	EAF	OHF	Mixture (BOF, EAF, and/or OHF)
China	1,112,318	819,075	114,803	0	178,440
India	120,573	70,555	36,885	0	13,133
Japan	115,381	83,923	31,458	0	0
United States	114,926	36,400	78,526	0	0
Russia	86,106	51,600	34,506	0	0
South Korea	82,710	53,000	29,710	0	0
Türkiye	52,080	14,400	37,680	0	0
Germany	50,550	37,700	12,850	0	0
Iran	50,100	5,100	45,000	0	0
Brazil	44,360	33,800	10,560	0	0
Italy	34,970	11,500	23,470	0	0
Ukraine	27,392	19,472	2,320	5,600	0
Mexico	26,440	6,000	20,440	0	0
Vietnam	25,700	16,340	9,360	0	0
Taiwan	22,080	16,100	5,980	0	0
Spain	19,440	5,400	14,040	0	0
France	16,350	10,750	5,600	0	0
Malaysia	16,150	3,500	11,950	0	700
Canada	15,049	8,600	6,449	0	0
Indonesia	14,275	9,100	5,175	0	0
Egypt	14,000	0	14,000	0	0
Saudi Arabia	12,680	1,180	11,500	0	0
United Kingdom	11,120	8,200	2,920	0	0
North Korea	10,720	0	0	0	10,720
Poland	9,690	5,000	4,690	0	0
Thailand	8,355	0	8,355	0	0
Belgium	8,050	5,000	3,050	0	0
Algeria	7,700	0	7,700	0	0
Austria	7,570	7,570	0	0	0
Netherlands	7,500	7,500	0	0	0
South Africa	7,150	6,400	750	0	0
Argentina	6,900	3,200	3,700	0	0
Sweden	6,810	3,800	3,010	0	0
Kazakhstan	6,800	6,000	800	0	0
Czech Republic	6,400	6,200	200	0	0
Australia	5,810	4,400	1,410	0	0
Romania	5,350	3,200	2,150	0	0
Bangladesh	5,220	0	5,220	0	0
Venezuela	5,100	0	5,100	0	0
Finland	4,663	2,600	2,063	0	0

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Operating steelmaking capacity by country and production process *— continued*

Country	Total Capacity	BOF	EAF	OHF	Mixture (BOF, EAF, and/or OHF)
Slovakia	4,500	4,500	0	0	0
Oman	4,250	0	4,250	0	0
Pakistan	4,100	3,000	1,100	0	0
United Arab Emirates	3,500	0	3,500	0	0
Greece	3,300	0	3,300	0	0
Belarus	3,000	0	3,000	0	0
Luxembourg	3,000	0	3,000	0	0
Hungary	2,840	1,600	1,240	0	0
Serbia	2,700	2,200	500	0	0
Qatar	2,575	0	2,575	0	0
Iraq	2,500	0	2,500	0	0
Syria	2,200	0	2,200	0	0
Peru	2,000	0	2,000	0	0
Chile	1,970	1,450	520	0	0
Bosnia and Herzegovina	1,940	1,140	800	0	0
Morocco	1,800	0	1,800	0	0
Libya	1,750	0	1,750	0	0
Portugal	1,700	0	1,700	0	0
Nigeria	1,300	0	1,300	0	0
Bulgaria	1,200	0	1,200	0	0
Kuwait	1,200	0	1,200	0	0
Bahrain	1,100	0	1,100	0	0
Azerbaijan	1,000	0	1,000	0	0
Kenya	1,000	0	1,000	0	0
Moldova	1,000	0	1,000	0	0
Uzbekistan	1,000	0	1,000	0	0
Ghana	800	0	0	0	800
Singapore	800	0	800	0	0
Slovenia	726	0	726	0	0
Albania	700	0	700	0	0
Norway	700	0	700	0	0
Switzerland	687	0	687	0	0
New Zealand	650	650	0	0	0
North Macedonia	550	0	550	0	0
Angola	500	0	500	0	0
Guatemala	500	0	500	0	0
Philippines	500	0	500	0	0
Uganda	450	0	450	0	0
Croatia	350	0	350	0	0
Georgia	120	0	120	0	0
World	**2,270,996**	**1,397,105**	**664,498**	**5,600**	**203,793**

Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes steel plants with capacity of at least 0.5 mtpa.

Appendix D

Operating ironmaking capacity by country and production process

Country	Total Capacity	BF	DRI	Mixture (BF and DRI)
China	897,205	888,025	300	8,880
India	122,084	93,375	28,709	0
Japan	95,358	95,358	0	0
Russia	64,713	57,013	7,700	0
South Korea	48,000	48,000	0	0
Iran	43,570	5,300	38,270	0
United States	33,911	27,511	6,400	0
Brazil	33,580	33,580	0	0
Germany	32,615	32,015	600	0
Ukraine	29,579	29,579	0	0
Türkiye	16,588	16,588	0	0
Taiwan	16,150	16,150	0	0
Vietnam	15,142	15,120	22	0
Mexico	11,692	5,832	5,860	0
Venezuela	11,320	0	11,320	0
France	10,900	10,900	0	0
Indonesia	9,590	8,240	1,350	0
Italy	9,500	9,500	0	0
Canada	9,114	8,114	1,000	0
Egypt	9,100	0	9,100	0
Malaysia	8,340	4,700	3,640	0
United Kingdom	7,770	7,770	0	0
Austria	6,650	6,650	0	0
Netherlands	6,310	6,310	0	0
Saudi Arabia	6,300	0	6,300	0
Algeria	6,200	1,200	5,000	0
South Africa	6,194	5,244	950	0
Sweden	5,405	4,105	1,300	0
Kazakhstan	5,125	5,125	0	0
Belgium	5,000	5,000	0	0
Slovakia	5,000	5,000	0	0
Poland	4,500	4,500	0	0
Argentina	4,430	3,220	1,210	0
Australia	4,200	4,200	0	0
Czech Republic	4,200	4,200	0	0
Spain	4,200	4,200	0	0
Romania	3,000	3,000	0	0
Finland	2,600	2,600	0	0
Qatar	2,493	0	2,493	0
United Arab Emirates	2,000	0	2,000	0
Serbia	1,900	1,900	0	0

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Operating ironmaking capacity by country and production process *— continued*

Country	Total Capacity	BF	DRI	Mixture (BF and DRI)
Oman	1,800	0	1,800	0
Libya	1,750	0	1,750	0
Bahrain	1,600	0	1,600	0
Trinidad and Tobago	1,600	0	1,600	0
Chile	1,482	1,482	0	0
Hungary	1,300	1,300	0	0
Pakistan	1,200	1,200	0	0
Uganda	1,200	0	1,200	0
Bosnia and Herzegovina	1,100	1,100	0	0
Nigeria	1,020	0	1,020	0
Georgia	725	725	0	0
New Zealand	650	0	650	0
Kenya	500	0	500	0
Peru	500	400	100	0
Syria	300	300	0	0
World	**1,638,254**	**1,485,631**	**143,744**	**8,880**

Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes iron plants with capacity of at least 0.5 mtpa.

Appendix E

Steel capacity under development by technology type.

Country	BOF capacity under development (ttpa)
China	146,764
India	153,487
Indonesia	23,500
Iran	2,280
Vietnam	22,400
Philippines	10,000
Malaysia	11,600
Bangladesh	2,000
Myanmar	4,000
Cambodia	3,100
Nigeria	1,300

Country	EAF capacity under development (ttpa)
China	49,390
India	25,719
Indonesia	1,200
Iran	37,700
Vietnam	1,300
Philippines	13,600
Germany	17,600
Malaysia	1,000
Sweden	9,200
Saudi Arabia	8,840
Netherlands	8,660
United States	8,441
Türkiye	7,900
Finland	5,100
France	6,500
South Africa	6,400
Canada	6,100
Russia	6,050
Oman	5,100
South Korea	5,000
Algeria	4,950
Bangladesh	2,500
Namibia	4,500
Ukraine	4,500
Romania	4100

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Country	EAF capacity under development (ttpa)
Czech Republic	3,500
Mexico	2,600
Belgium	2,500
Italy	2,500
Uzbekistan	2,500
Austria	2,450
Australia	2,400
Nigeria	1,000
Zimbabwe	2,200
Brazil	1,700
Spain	1,700
Egypt	1,600
Azerbaijan	1,250
Pakistan	600
Poland	1,000
United Arab Emirates	1,000
Japan	835
Morocco	800
United Kingdom	780
Hong Kong	700
Mozambique	500
Georgia	250
Luxembourg	250
Croatia	200

Source: Global Steel Plant Tracker, Global Energy Monitor, March 2023.
Note: includes steel plants with capacity of at least 0.5 mtpa.