STEELWATCH
Bringing climate urgency to steel

Sunsetting Coal in Steel Production

June 2023

Acknowledgements

SteelWatch is an emerging organisation with a vision for a steel industry that underpins a zero-emissions economy and enables the environment, communities and workers to thrive. Our mission is to turbo-charge the transformation to a decarbonised steel sector by raising ambition, supporting civil society advocacy, and campaigning for stronger commitments and faster action internationally. This is our first report, laying the groundwork for future work.

Primary authors include Caroline Ashley, Evan Gillespie and Margaret Hansbrough. Major contributors include Zoë Adams, John Cooney, Ariana Criste, Alastair Jackson, Valentin Vogl. Special thanks to all those who provided comments and input: Jimmy Aldridge, Chris Bataille, Molly Dorozenski, Leanne Govindsamy, Tom Hoskyns, Hilary Lewis, Cynthia Rocamora, Roger Smith, Caitlin Swalec, Chan Yang, Yumin Han. Additional thanks to the teams at Pooled Fund on International Energy (PIE), Industrious Labs, Solutions for our Climate (SFOC), Sunrise Project, and the numerous allies who have helped along the way.

Design and production provided by: Abbie Darley and Yuko Hirono

Translation: EcoNetworks and Hankuk University of Foreign Studies

Any inquiries can be directed to info@steelwatch.org

Title page photography by Matthew Kaplan

Citation: **SteelWatch, 2023; Sunsetting Coal in Steel Production**

Descriptor: This report calls for the end of coal in steel production. It shows how coal-based production is driving the huge and dangerous climate emissions of steel and frames the immense opportunity that now exists to transform steel investment and production away from coal.

Table of Contents

Executive Summary

The steel industry's climate impact is a global risk.

Emissions from the steel sector are driving climate change and jeopardising chances of stabilising at 1.5°C of warming. Currently, the steel sector contributes to at least seven percent of global greenhouse gas emissions, and without immediate and drastic action, this share will continue to rise.

Coal is the culprit.

The problem is not steel itself, it is how steel is made today. Globally, 70 percent of steel is new, primary steel that is produced from iron ore using coal-based processes. Each tonne of primary steel requires 0.77 tonnes of metallurgical coal, which is used in a blast furnace as iron ore is made ready for steel production.

While the risks associated with investing in thermal coal for power generation are well-known, the threat of metallurgical coal for steel production has yet to be sufficiently recognized. Mining it unlocks vast methane emissions, burning it drives pollution and ill health, and using it in steelmaking drives the climate footprint of steel. As the sun sets on outdated and polluting practices, it is imperative to shift our focus towards ending investment in metallurgical coal-based steelmaking.

Each tonne of steel produced through the coal-based blast furnace route is responsible for 2.3 tonnes of CO_2 emissions and for over 3 tonnes of CO_2e when the methane from coal mining is included. This little-known fact is a cause for concern and a call to action.

The next two decades will make or break the future of steelmaking and our climate.

Around 400 steel facilities globally are responsible for most of the coal-based steel production in blast furnaces. Over the next two decades, the majority of existing blast furnaces will require reinvestment, known as 'relining' In addition, there are around 125 new projects that involve new coal-based blast furnaces. Companies will face critical decisions to either lock in decades more of this emissions-intensive pathway or begin to transition away from coal-based steelmaking and toward more sustainable pathways.

These decisions will determine whether steel gets on track for a climate-safe future. If steel is not on track, it is virtually impossible to limit warming to 1.5°C: should coal-based steel production persist on a 'business as usual' trajectory, it would consume almost a quarter of the remaining global carbon budget available - for all sectors and societies - between now and 2050 to give us half a chance of staying within 1.5°C of global warming.

But there is hope.

Clean alternatives to coal-based steelmaking are rapidly emerging from recycled steel to new technologies that replace coal with green hydrogen. By transitioning to coal-free steel production, we can preserve a livable climate and build a stronger steel industry. This is a not-to-be-missed opportunity to build a transformed steel sector that offers quality jobs while eliminating toxic emissions.

Now is the time to phase out coal in steelmaking.

We call for a red line on coal-based steel production: no relining of existing blast furnaces, no investment in new blast furnaces, and a phased transition out of existing ones. Organisation for Economic Co-operation and Development (OECD) countries and companies headquartered in those countries must lead the way, starting today, modelling a just transition beyond coal-based steelmaking and enabling emerging economies to leapfrog to new technology as well.

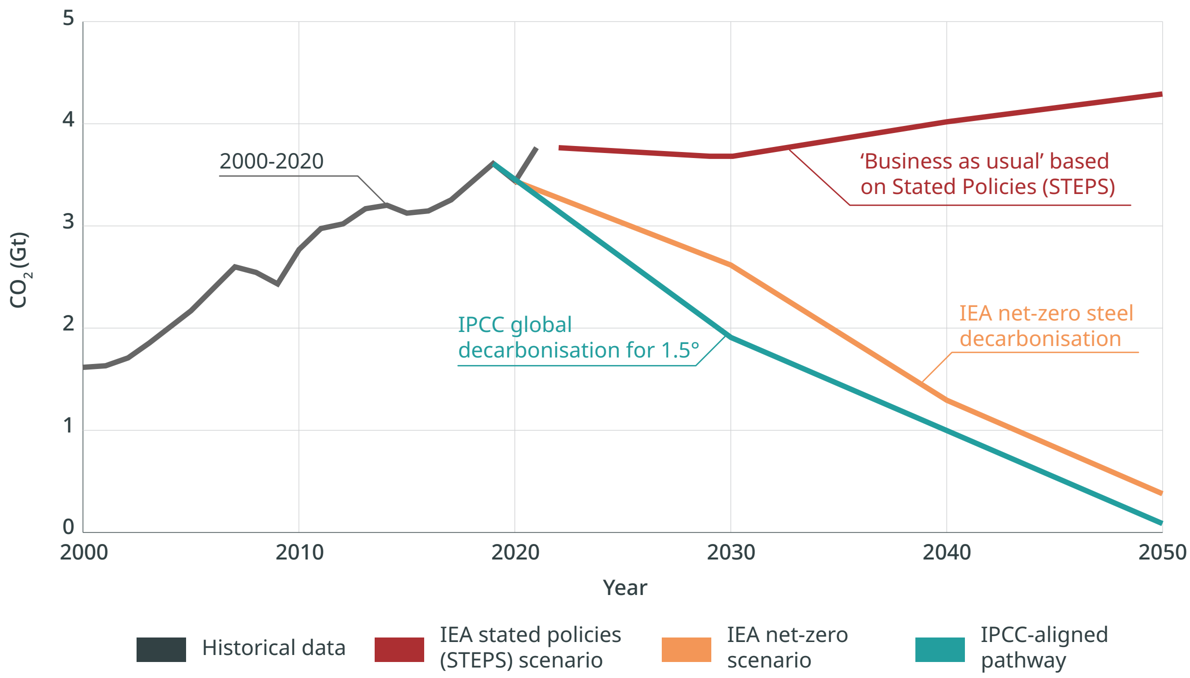
1. Context: steel climate emissions are a global threat

The ability of the global community to meet the Paris Agreement hinges on the steel sector transitioning away from coal-based steelmaking. Steel sector emissions are too significant for the planet to stabilise without decisive action. The steel industry is often reported as responsible for seven percent[1] of annual greenhouse gas emissions (GHG), equivalent to the entire country of India,[2] or the third-largest emitting country. Yet, as other sectors have begun the pivot towards zero-emission technology, greenhouse gas emissions from the steel sector have risen sharply.

Direct steel sector CO_2 emissions have doubled since 2000[3], making steel the industrial sector with the fastest-growing CO_2 emission levels.[4]

The steel sector is simply not on track to decarbonise at the rate needed to keep global warming to 1.5°C. As Figure 1 shows, steel is late to start emissions reductions and should be on a steep downward pathway by now.

Figure 1: Business-as-usual steel sector emissions are way off track



Note: The 'historic' data[5] and 'business as usual'[6] pathway estimate total CO_2 emissions from steel production based on emissions intensity[7] and shares in the production of different production methods. The IEA Net Zero[8] and IPCC pathways[9] show the reduction in steel sector emissions required from 2019 based on the rate specified in IEA net-zero scenario for steel and the IPCC-aligned pathway for 1.5°C for global emissions. Drawing on World Steel data, IEA 2020 and IPCC 2023

[1] Steel sector GHG emissions are 4.12 Gt CO_2e per year according to Wang (2021) which includes some scope 3 but not coal mine methane. Global emissions are 59 +/- 6.6 Gt CO_2eq (Dhakal et al., 2022). So steel accounts for 7 percent of annual GHG at least - and even more if coal mining methane is included.
[2] Rhodium Group (Rivera et al., 2022, p2) shows India to account for 7 percent of world emissions over 2017-2020, the most recent years.
[3] As per IPCC (Bashmakov et al., 2022): from 2000-2010 emissions increased by 5.62 percent p.a and for 2010-2019 by 2.28 percent p.a.
[4] IPCC (Bashmakov et al., 2022).

While the sharp emissions increase of recent decades is levelling off, available data indicates that the steel sector has not yet even peaked let alone begun to reduce emissions, which is essential. A 'business as usual' approach, based on stated policies assessed by the International Energy Agency (IEA) (as the 'STEPS' or 'Stated Policies' Scenario) in 2020, will keep the sector far from the required trajectory.

With each passing year, the industry is projected to fall further behind. The longer decarbonisation is delayed, the smaller the chance of stabilising climate change at 1.5°C of warming and the steeper the necessary change in steel becomes.

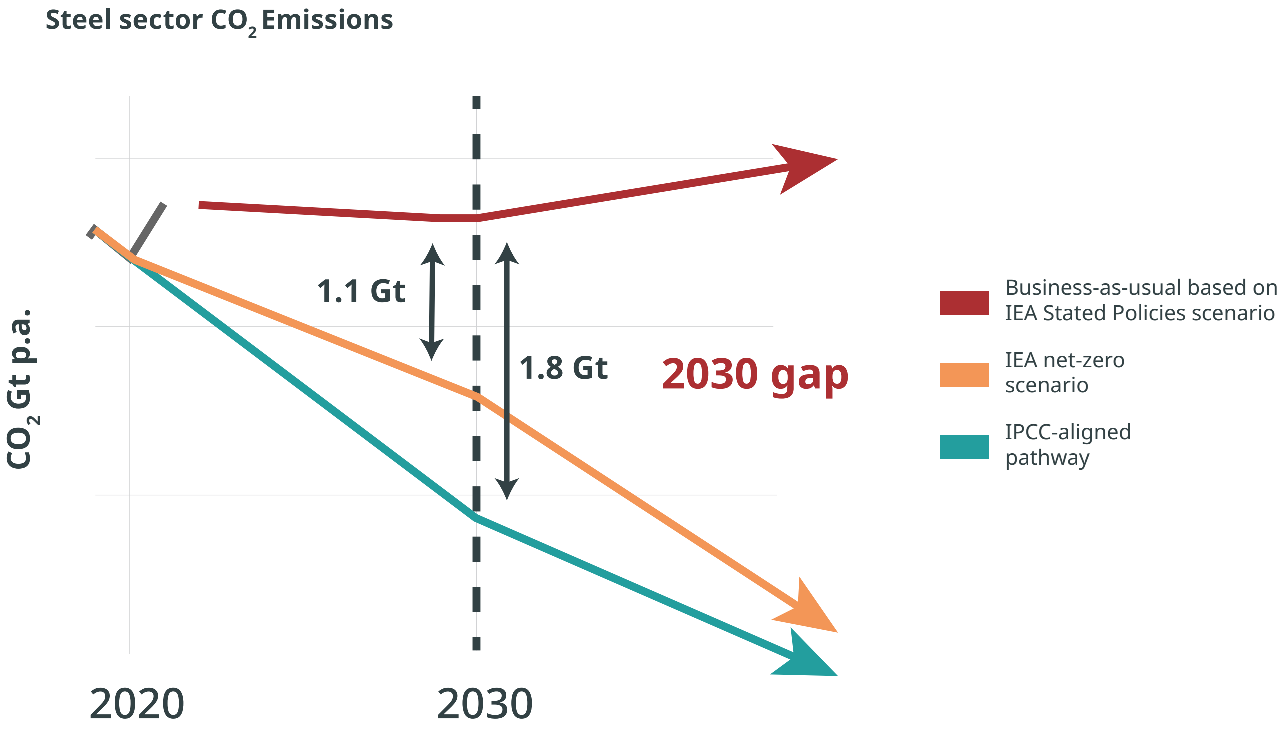
The urgency of cutting steel emissions by 2030 is not getting the attention it needs. A number of decarbonisation pathways for steel have been published, calling for emissions cuts ranging from 24-37 percent of direct emissions from 2019 to 2030 and up to 49 percent if indirect emissions from electricity use are included.[10] But most commitments made by the industry so far have focused on cuts by 2050, ignoring the urgency of 2030.

Figure 2 zooms into Figure 1 in more detail to show just how far off-track the industry will be by 2030. The gap between a business-as-usual trajectory (orange line) and what the IEA says (green line) is required to achieve net zero is over 1 Gt CO_2 by 2030. Business-as-usual emissions in 2030 will be 42 percent higher than they should be if steel were on track for IEA net zero, and 96 percent higher than if steel were in line with IPCC decarbonisation pathways for 1.5°C of warming. The alarm bells could not be louder for how dramatically the steel industry must change course, and do it immediately. Emissions need to slump as sharply now as they have sharply risen over recent decades. That requires urgent action from CEOs to investors to policymakers.

Caroline Ashley, "View of ArcelorMittal Steel Plant in Gent, Belgium" February 2023

[5] Historical data: sum of emissions for each production route, based on emissions intensity per production route x share of total production. Taken from World Steel data (2022a).
[6] 'Business as usual' pathway is represented by multiplying the World Steel emissions intensity by the 'stated policies' or STEP pathway in IEA (2020).
[7] In the historic and STEPS pathways, emissions intensity per production route from World Steel (2022a) is assumed constant, given it has levelled out in recent years. Other sources provide higher emissions intensity estimates so would result in higher total emissions from steel, but this method provides comparability across scenarios.
[8] The slope of the net-zero pathway is based on the IEA Net Zero pathway (2021).
[9] The slope of the IPCC 1.5°C pathway is based on a 48 percent reduction from 2019 by 2030 and 99 percent reduction from 2019 by 2050 detailed by the IPCC (2023)
[10] IEA, 2021; E3G, (Yu et al., 2021); IDDRI, (Bataille et al., 2021); MPP, 2021 (to note, in MPP the reference year is 2020 not 2019).

Figure 2: Zooming in on the 2030 gap



Over the next decade, the steel industry faces a critical choice: whether or not to reinvest in coal-based steelmaking or pivot to renewable energy-based production. Attention must be focused on this question: ***will steel companies invest billions of dollars retrofitting their existing facilities and building new blast furnaces, eating up the remaining carbon budget, or will they instead spend those funds transforming their production towards technologies that are fossil free?*** The steel industry's present and past climate damage is already written, but the future can still be altered.

The threat that the steel industry's emissions present to the planet is the cornerstone of this report. In order to align the steel industry with the necessary emissions trajectory, we must identify the leading drivers of emissions from steelmaking and determine which interventions can shape a better future for both steelmaking and the planet.

This report delves into why coal-based blast furnace production is the central driver of the industry's climate pollution problem and how we can leverage key decisions in the next five to seven years to shift away from coal towards renewable energy-based production in time to keep 1.5°C alive.

2. The fundamental problem is reliance on coal in steel making

2.1 Primary production depends on coal

To build a future beyond coal-based steel production, it is crucial to understand the current production process. Seventy percent of steel output globally comes from 'primary steel production' or virgin steelmaking, as it is sometimes referred to. This primary steel is produced in 397 steel mills[11] that use coal-based blast furnaces.

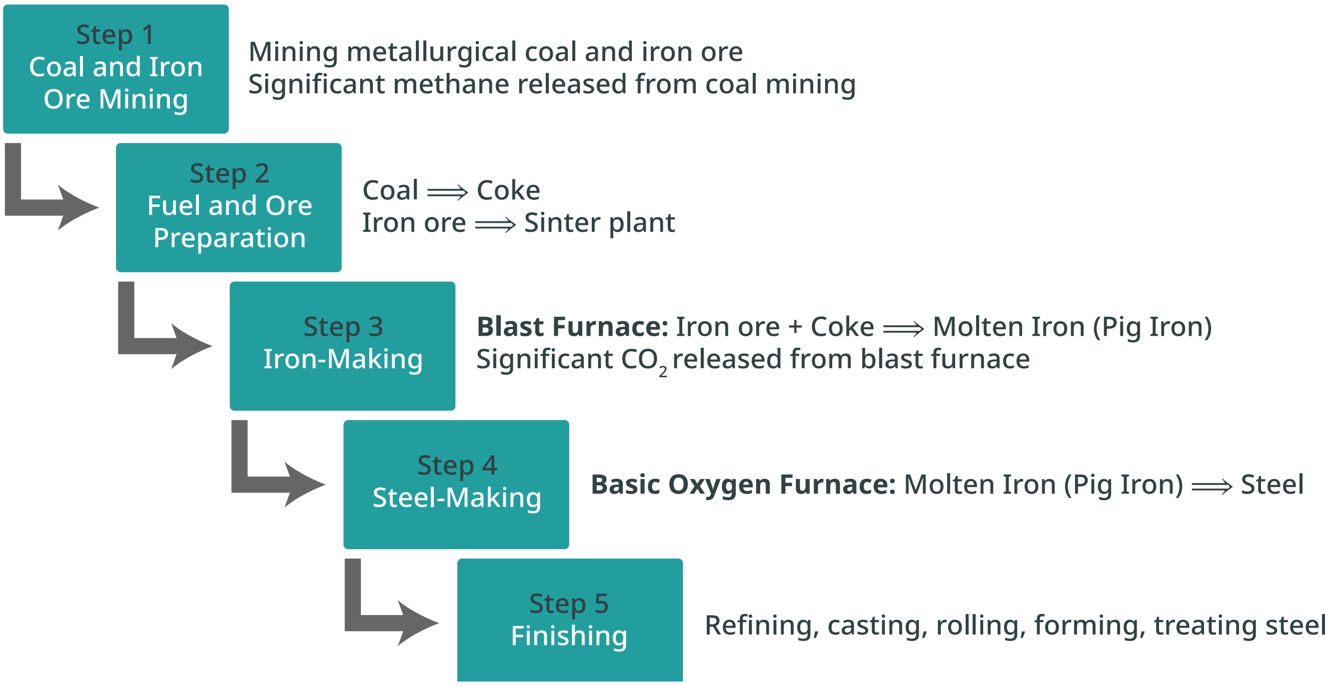
The standard primary steel production process is known as BF-BOF, relying on a blast furnace (BF) and then a basic oxygen furnace (BOF). It can be summarised in five steps: (i) mining, (ii) fuel and ore preparation, (iii) ironmaking, (iv) steelmaking, and (v) finishing.

Coal is centre-stage: in Stage 1, metallurgical coal is mined. In Stage 2, coal is converted into coke. During Stage 3, the blast furnace consumes massive amounts of coke to produce iron. Inside the high-temperature blast furnace, coke reacts with the iron ore to strip it of oxygen to provide pure molten iron, known as pig iron. From there, iron is transformed into steel in the basic oxygen furnace in Stage 4, then shaped and finished for distribution in Stage 5.

Metallurgical coal, also known as 'met coal' or coking coal, is higher quality than thermal coal. It accounts for approximately 23% of the annual global coal output.[12] The vast majority of the world's supply of metallurgical coal is used by the steel sector. Inside the blast furnace it acts both as a form of energy providing heat, and as a reducing agent - reacting with iron oxide to take the oxygen out. It also provides physical structure support inside the furnance.

[11] Latest GEM data for operating steel plants including a blast furnace, updated in 2023
[12] IEA (2022b, p66)

Figure 3: The 5 steps of conventional coal-based blast furnace steel production



The remaining 30 percent of annual steel output is 'secondary production,' in which scrap steel is recycled and reprocessed in an electric arc furnace (EAF).[13] There are various technical variations and some overlap between the two fundamental ways of making steel.

Steel decarbonisation pathways often emphasise increasing the share of secondary production and cutting total demand. Both are necessary but insufficient. Through incremental technological improvements, secondary steel continues to cut into the market for primary steel, especially in the auto sector, which historically has used premium, primary steel. However, since all secondary production comes from steel produced through primary steelmaking, there is only a limited amount of scrap available, and the global recycling rate is commonly assumed to be around 85-90 percent. And it is primary production that accounts for the vast majority of steel sector emissions.

Unfortunately, shifting the balance to secondary production while reducing overall demand for steel through more efficient usage will not offer significant enough emissions reductions in the time span needed. These measures should not be used as an excuse to evade action on primary production.

Additionally, it is critical that as the economy grows cleaner through electrification, that the steel needed for EVs, wind, transmission, and other critical items is not driving demand for more coal-based steel. Therefore, while there may be some debate regarding the balance of primary versus secondary steel and the potential to curb demand in coming decades, the world will still require significant quantities of primary steel, which means it must be decarbonised.

[13] MPP (2021, p11). Notably, the United States is reversed: 70 percent of production is via EAF.

2.2 Emissions from this coal-based route are huge and even underestimated

World Steel reports that BF-BOF production accounted for 3.2 Gt CO_2 in 2021, which is an estimated 86 percent of the entire steel sector's annual GHG emissions.[14]

The blast furnace's large carbon footprint stems from its heavy reliance on metallurgical coal. Producing one tonne of steel through the BF-BOF method requires 0.77 tonnes of coal.[15] This is what drives the emissions intensity of steel produced through the BF-BOF route, which World Steel estimates to average 2.32 tonnes of CO_2 per tonne of steel. Huge as these figures are, they are minimum figures, given how they are calculated.

The climate emissions start at the metallurgical coal mine, where methane leaks are a frequent byproduct of mining. A 2022 report by the IEA estimated that methane leakage from metallurgical coal mining is significant, estimated to represent 1 Gt CO_2e per annum,[16] and the vast majority of this supplies the steel sector.[17] However, World Steel and other conventional data on emissions from coal-based steel production ignore these methane emissions. When that 1 gigatonne is accounted for, the total sector emissions are higher, and so is the share of steel sector emissions from BF-BOF production.

With methane emissions correctly included, we estimate **that steel production via the BF-BOF route emits 4.2 gigatons of CO_2e per year** and 90 percent of emissions for the entire industry. The implication is a huge **emissions intensity of over 3 tonnes of CO_2e per tonne of steel[18] produced via the blast furnace route,** as Figure 4 shows.

[14] From World Steel 2022a and 2022b
[15] BHP (Date Accessed 24th April 2023)
[16] GEM (Swalec, 2022, p19) and EMBER (Campbell, 2023). As explained by EMBER (p10), 'the IEA estimates that mining of coking coal (which is the primary metallurgical coal) emitted 11.98 million tonnes (Mt) of methane in 2021, equivalent to 988 Mt of CO_2-equivalent annually using the IPCC's 20-year global warming potential (GWP) of 82.5 times more than CO_2.' Thus the steel industry's environmental impact may be as much as 1 Gt CO_2-e higher than the reported figures.
[17] Considering the production of steel through the BF-BOF route and coal mine production in 2021, it's estimated that the steel industry consumes around 84 percent of all the total combined production from metallurgical and mixed metallurgical/thermal coal mines as per Global Energy Monitor (Swalec, 2022)
[18] SteelWatch estimates this number based on secondary sources; GEM (Swalec, 2022) and World Steel (2022a). For total steel sector emissions, SteelWatch has used World Steel Association average BF-BOF emissions per tonne of steel as a proxy (2.32 t CO_2 per tonne of steel) and added a proportional amount of emissions from upstream methane emissions, based on IEA and GEM analysis which attributes 1 Gt CO_2e of methane emissions to global BF-BOF steel production. Annual (2021) BF-BOF steel accounted for 1.3 billion tonnes of steel meaning around 0.7 t CO_2e from methane can be attributed to each tonne of BF-BOF steel leading to a total of 3.04 t CO_2e per tonne of steel produced via BF-BOF.

Figure 4: GHG emissions by stage in coal-based blast furnace production with methane included

Stage	Mt CO_2e p.a.	t CO_2e/t crude steel	Share of emissions by stage
1: Mining metallurgical coal	1,000	0.72	SIGNIFICANT METHANE FROM COAL MINING 24%
2: Input preparation (making coke, sintering, pelletisation)	643	0.45	15%
3: Iron making in blast furnace	2,217	1.6	SIGNIFICANT CO_2 FROM BLAST FURNACE 53%
4: Steel making	354	0.26	8%
Total	**4,214**	**3.04**	

Notes and sources: Mt CO_2e p.a. is million tonnes of carbon dioxide equivalent per annum.
T CO_2e/t cs is tonnes of carbon dioxide equivalent per tonne of crude steel. Estimates include methane emissions from coal mining.[19]

As these figures show, the use of coke in a typical integrated steel production process drives the industry's climate emissions. Replacing blast furnaces with cleaner ironmaking technology that does not rely on coal would eliminate the need for metallurgical coal mining and coke producing. Blast furnaces are the cornerstone of coal dependency in steel-making, driving emissions throughout the value chain. Phasing out blast furnaces is the only way the sector can successfully align to a 1.5°C pathway by 2030.

Blast furnaces are the cornerstone of coal dependency in steel-making, driving emissions throughout the value chain.

[19] Figures show CO_2e emissions in total and per stage for steel produced via the BF-BOF production route. Methane emissions from coal mining are included, but other scope 3 emissions including from iron mining are not. Adapted from GEM (2023), Swalec (2022), World Steel Data (2022a), IEA (2020) and Sohn et al. (2019). Further analysis by Steelwatch.

2.3 Marginal efficiency gains can't shift the climate footprint of blast furnace production

The climate impact of coal-based blast furnace production cannot be resolved by further increases in blast furnace efficiency. Decades of engineering refinement mean that blast furnace ironmaking is one of the most efficient heavy industry processes known. Most blast furnaces operate close to maximum theoretical efficiencies, which means steel plants are already very good at maximising energy use, and only marginal gains can typically be made year over year. Traditional efficiency improvements with the same technology will not hit the reduction targets needed to reduce emissions. Small variability exists among emission intensities at blast furnaces. However, most blast furnaces production emits between 1.8-2.3t CO_2 per tonne of steel produced, as Figure 5 shows. With the possible exception of India, the scope for efficiency gains is small and would make a fractional impact on the climate damage of the sector.

Figure 5: The emissions intensity of coal-based blast furnace production varies little, from high to very high

Sources: Based on ETC (2021) and GEI (Hasanbeigi, 2022)

2.4 The mitigation efforts are less effective than assumed

Industry has long suggested that decarbonisation approaches should include carbon capture use and storage with blast furnaces. However, to be credible for aligning with net-zero and a 1.5°C trajectory, carbon capture, utilisation, and storage (CCUS) must capture and store 90-95 percent of emissions.[20] For storage, no commercial post-combustion carbon capture and storage (CCS) technology is available at the scale and capture rates needed to decarbonize existing or future blast furnaces.[21] CCUS cannot be considered a credible solution for coal-based steel facilities in the near or mid-term for the steel industry.

While research and development of CCUS technology may still offer valuable lessons, it is clear that other solutions (i.e. green hydrogen direct reduced iron (DRI), material efficiency) are much more viable in the near and mid-term, and they are more likely to outcompete CCUS as solutions for steel. Readiness assessments of these technologies by the International Energy Agency (IEA) and other institutions are not optimistic about the near and medium-term viability of CCUS. The IEA currently grades the most potentially impactful technology readiness level (TRL) for CCUS for blast furnaces[22] at a 5 on a scale of 1-10. However, of the projects being graded to determine this TRL, there is a lack of adequate transparency and performance targets to assess the pace of change of viability and scalability.

Some of the best-in-class research and development out of Japan for the potential for post-combustion CCUS for blast furnaces is far off-track from delivering a viable and affordable solution. The Renewable Energy Institute (REI) of Japan recently assessed the state of this potential solution and found that capture rate targets were below 20 percent, and even that low target has not yet been achieved. The same report found major roadblocks domestically for Japan that make CCUS impractical for steel and pointed out that CCUS for blast furnaces is very unlikely to compete with other more viable global mitigation pathways as forecasted by Bloomberg New Energy Finance in 2021.[23]

The problem is not just that CCS technology will not be ready at the speed and scale needed. The physical properties of a blast furnace site have emissions escaping from multiple points, making effective capture deeply problematic, and the methane emissions at mine sites add further challenges. Even if companies retrofit existing mills they would still have a massive source of emissions from the coal mines. True technology shift at existing steel facilities is what is needed to keep jobs in place while transitioning away from coal-dependent production. Some of the steel sector decarbonisation pathways published in recent years included carbon capture use and storage, including those by IEA. But these pathways are based on criteria defining 'what needs to be true' to reach net zero.[24] They should not be the basis for any investment in blast furnaces with the hope that CCS will be implemented; effective CCS must be a precondition for investment. Unless and until 90-95 percent of emissions can be permanently stored, CCS on a blast furnace is an inadequate solution.

---

[20] IDDRI (Bataille, et al., 2021, p2)

[21] We acknowledge using both CCS and CCUS, though the terms are distinct and imply different outcomes for the captured CO_2. Our concern is chiefly about the feasibility of capturing the CO_2 in the first place. The question of utilisation or storage is secondary in our minds to the first order challenge of capturing the CO_2 during the production process. Here, our use of the terms is simply driven by narrative consistency: where the relevant research (for example, IEA) being discussed uses the term CCUS, we use the term CCUS in discussing the research.

[22] IEA (2022a)

[23] REI (2022, p25-28)

[24] The 2021 net zero pathway analysis points out there is only one 90 percent mitigation primary steel technology that is currently commercial - that is methane-based DRI EAF with CCS (Bataille, et al. 2021, p2). That is fundamentally different from CCS on a blast furnace. Emissions sources in existing BF-BOF are relatively spread out across an integrated facility, making CCS retrofits difficult and only maximum 50 percent capture possible on existing facilities (Bataille, et al. 2021, p4, sourced from Fan and Friedmann, 2021).

There should be no investment in new blast furnaces that lock in coal-burning technology and do not have current and credible CCUS mitigation technology available. Credible in the view of this report means that it is on track to be cost-competitive with other clean technology, will ensure 90 percent capture rates by the early 2030s, and addresses the full scope of impact from metallurgical coal, including coal mine methane. Beyond climate, credible mitigation solutions should also address air and water pollution impacts as they are significant quality-of-life factors in communities where coal-based steelmaking occurs.

> *"Reaching net-zero requires crystal clear communication to steel makers that no more BF-BOFs without 90% CCS can be built past 2025 and that they should be planning for near zero emissions alternatives."*
>
> Net Zero Steel, Bataille et al 2021

Mikulas Jaros, "Bulga Coal mine located near Broke NSW Australia", April 16, 2019, iStock.com

2.5 The negative impacts go well beyond carbon

Mining and burning metallurgical coal is not just a driver of climate change. It also drives air pollution, water pollution, and conflict over land rights, human rights, and worker rights. The negative impacts of metallurgical coal mines, coking plants, and blast furnaces are increasingly documented and challenged by the communities who are on the front line.

In order to assess the associated health and economic impacts, the Centre for Research on Energy and Clean Air and Solutions for Our Climate analysed air pollution from three integrated steel plants in Korea: POSCO Pohang plant, POSCO Gwangyang plant, and Hyundai Steel Dangjin plant.[25] When all three plants operate simultaneously, their emissions can cause the annual near-surface concentration of nitrogen dioxide, sulphur dioxide, and particulate matter to increase by 1.5 $\mu g/m^3$, 1.22 $\mu g/m^3$, and 0.4 $\mu g/m^3$, respectively. Air pollution from the same three plants accounted for the premature death of approximately 506 people in 2021, with an additional 19,400 cumulative premature deaths predicted between 2022 and 2050 under South Korea's Current Policy scenario (without additional emission control interventions).

South Africa's legacy of apartheid and current steel industry impacts are intertwined. ArcelorMittal S.A. (majority owned by ArcelorMittal Group) has been repeatedly criticised and challenged for pollution of air, water, and soil at its Vanderbijlpark plant,[26]which has changed hands from being state-owned to owned by Arcelor. The company faced criminal charges[27] for its toxic air pollution on the grounds of infringing the constitutional right for everyone 'to have an environment that is not harmful to their health or wellbeing.' The company is also criticised for patterns of ignoring informed consent with Black fenceline communities.[28]

In the power sector, thermal coal has been a central focus of community action for decades. Impacted communities have organised to challenge coal power plants and shut them down in many cases to protect their air, water, land, and their very lives. This challenge is now beginning with metallurgical coal. The paradox with steel is that the communities impacted by the toxic pollution from coal use in an integrated steel facility are sometimes the same communities that benefit from having a large source of stable, well-paying jobs. But no community should have to choose between their lives or their livelihoods. Some steel communities today are organising behind the green transition.

For example, the Ohio River Valley is home to some of the communities most affected by soot pollution from steel plants, according to the American Lung Association.[29] Advocates are starting to call for a green transformation and make a compelling case that it's imperative to ditch coal to keep and grow local jobs and protect people and the planet.[30] A report by the Ohio River Valley Institute estimates that the transition to fossil fuel-free steelmaking could grow total jobs supported by steelmaking in the region by 27 percent to 43 percent by 2031, stemming the tide of decades of job losses as regional jobs supported by traditional steelmaking are expected to continue to a decline by 30 percent in the same period.[31]

The damage to air, water, health, and community rights wrought by metallurgical coal-based production is not often quantified in the way that GHG emissions are, but it is a powerful case to drive change and a reminder that technical 'solutions,' such as CCS, do not remove some of the major harms that occur at the mining and firing stages of the production process.

[25] Centre for Research on Energy and Clean Air and Solutions for Our Climate (2021)
[26] Center for Environmental Rights (2019)
[27] Business and Human Rights Resource Center (2019)
[28] Center for Environmental Rights (2022)
[29] The Guardian (Lakhani, N., 2023)
[30] Canary Media (Myers, K., 2023)
[31] Ohio River Valley Institute (Ebner et al., 2023)

3. A clear and present danger is looming

3.1 New build and relining investments are looming

There are 397[32] steel production facilities that rely on blast furnace production and over a thousand blast furnaces in operation.[33] They are already driving greenhouse gases into the atmosphere. Going forward, there are two grave and imminent risks:

- First, 71 percent of global blast furnaces face a relining decision by 2030. If they are relined, at the cost of hundreds of millions of dollars each, this risks locking in high-emission technologies for another 20 years.[34]

- Second, the steel industry has over 125 new projects with one or more blast furnaces announced or under construction.[35] These new facilities could have potential lifespans of 40-50 years, blowing past carbon neutrality in 2050.

Blast Furnace Relining

Blast furnaces must be periodically relined due to wear and tear of the refractory bricks lining the interior. Relining cycles, known as "campaigns", historically occured every 15 to 25 years, but modern improvements in refractory materials can extend the time between relining projects. Blast furnace relining projects often involve upgrades or repairs to downstream units and can add capacity to the furnace. These projects can cost hundreds of millions of dollars and typically represent 25-50% of the cost of a new blast furnace.

[32] GEM (2023) lists 397 operating steel plants with blast furnace production.
[33] Based on GEM's GSPT data (March 2022 release), as of March 2022, there were an estimated 1,060 blast furnaces in operation. This is based on their data that covers an estimated 89 percent of global blast furnace capacity and assumes 1 blast furnace for mills that have an unknown number of blast furnaces. Thus, it could be an underestimate. GEM updates forthcoming in 2023 will provide further detail on furnace-level information. We expect the total number of blast furnaces in operation to be similar - ie just over 1,000.
[34] Agora Industry (2021)
[35] Latest GEM data for under construction and announced steel plants including a blast furnace, updated in 2023.

The steel industry is making commitments for relining this year that will lock in coal and emissions for decades. In one example from the Midwestern United States, primary steel producer Cleveland Cliffs, which bought several legacy plants from ArcelorMittal and AK Steel in 2020, has just announced that it is doubling down on coal-based production and is planning to reline a blast furnace at one of its Indiana facilities on Lake Michigan in 2025.[36] Despite growing evidence that any new relining will risk becoming stranded assets or blowing the 1.5°C carbon budget, industry continues to invest in coal-based steel.

Of the new-build projects, more are ‘proposed’ than in construction. This gives an extra window for reconsideration and redesign. A further set of steel investment projects do not disclose the technology used. For example, in India, a joint venture between ArcelorMittal and Nippon Steel has already begun constructing two new blast furnaces at Hazira, Gujarat, and is also planning two new integrated steel plants in Odisha state. The steelmaking technology under consideration for these new sites has not been disclosed. It is essential that new sites are developed as an opportunity for leapfrogging from coal to the green economy.[37]

There are furnaces operating today that were built or relined only recently and whose owners expect to run 20 or more years before additional investments are required. These furnaces and their emissions will be the most difficult to shift. Therefore, to meet net-zero decarbonisation targets by 2030, 2040, and 2050, avoiding building new blast furnaces or relining existing ones is essential.

Investment decisions at 397 steel facilities that operate blast furnaces will determine whether the steel sector – and our planet – can get on track for a 1.5 degree pathway.

Igor Groshev, “Industrial landscape in South Korea Gwangyang Bay”, Adobe Stock

[36] Northwest Indiana Times (Pete, 2023)
[37] IEEFA (Nicholas and Basirat, 2023)

3.2 Continued business as usual throws the industry and the planet off course

To retain a 50 percent chance of limiting global warming to 1.5°C, the IPCC estimated a remaining carbon budget of c. 500 Gt between 2019 and 2050. As of January 2023, Carbon Brief estimates we now have 380 Gt left until 2050.[38] We have estimated the CO_2 emissions from a 'business as usual' approach to blast furnaces, based on the 'stated policies scenario' for steel which was assessed by IEA in 2020.[39] As the name suggests, the scenario is based on actual policies announced globally rather than the more ambitious but vague non-committal targets. While there has been some marginal progress since then, it provides an indication of where we will be with business-as-usual rather than proactive change. By 2030, CO_2 emissions from coal-based blast furnace steel production would total 25 Gt; by 2050, they total 87 Gt CO_2.

This means a business-as-usual pathway for coal-based primary steel production would consume almost a quarter of the planet's remaining carbon budget for 1.5°C (all people, all industry, all countries).

Figure 6: Business as usual coal-based production will gobble 23 percent of the remaining global carbon budget

Remaining global carbon budget[1] for 2023 - 2050 is 380 Gt of CO_2

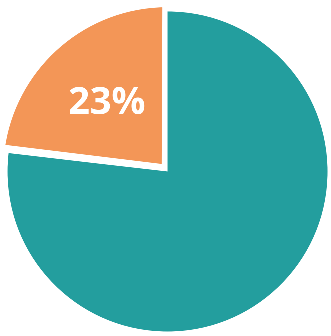
Business as usual steel production[2] via coal-based blast furnace would lead to:

By 2030: 25 Gt of CO_2 emitted

7% of entire budget used up by **coal-based steel-making** in just 8 years

By 2050: 87 Gt of CO_2 emitted

23% of entire budget used up by **coal-based steel-making** by 2050



[1] For a 50% chance of staying within 1.5 degrees of global warming (Carbon Brief; Forster et al., 2022)
[2] Based on Stated Policies (STEPS) scenario modelled by IEA (2020)

[38] Carbon Brief (Forster et al, 2022)
[39] Our estimates are based on IEA assumptions for relatively steady steel output per year. Carbon budgets are expressed in CO_2 not CO_2e so we calculate only CO_2, using the emissions intensity factor for BF-BOF from World Steel (2022a) for t CO_2/t crude steel.

4. The opportunity: a future for steel without coal

4.1 Alternatives are growing, much work to be done

Primary steel production will still be needed for decades to come, even if demand for steel declines or is increasingly met by secondary production with recycled scrap. An alternative two-step process of making iron and steel known as 'direct reduction iron' has the potential to eliminate climate pollution.

Direct reduction of iron ore (producing direct reduced iron, or DRI) has been used for making iron since the 1970s. Oxygen is removed from the iron ore at a temperature below the melting point. Pure metallic iron is then fed into a furnace to make steel, typically an EAF, often alongside scrap steel. Conventionally, fossil gas or sometimes coal is used to reduce iron ore in the DRI process and to supply the electricity that powers the EAF. So this approach to steel production still has a significant carbon footprint, albeit less than BF-BOF.

By using green hydrogen instead of fossil gas to reduce the iron ore, there is a pathway to eliminate fossil fuels in steelmaking. Iron produced through DRI can be fed into electric arc furnaces or used in basic oxygen furnaces via an additional smelter unit. Alternatively, green hydrogen can transform iron ore into hot briquetted iron (HBI)[40] for shipping to the steel plant. So long as the hydrogen is made with an electrolyzer powered by renewable energy, iron-making transforms into a fossil fuel and emissions-free process. And, powering EAFs with 100 percent renewable electricity removes most of the carbon footprint of the steelmaking phase. This two-step process—replacing fossil fuels with green hydrogen to make iron and converting iron to steel in an EAF powered by renewable energy—makes fossil-free steel possible.

In addition, emerging pre-commercial technologies like molten oxide electrolysis (MOE) can potentially remove the need for fuels entirely and pave the way toward the direct electrification of ironmaking.

In summary, renewable energy—at a huge scale—can dramatically lower the carbon footprint of steel, displacing the role of coal and gas in steelmaking. Fossil-free steel is within our reach if we act.

[40] International Iron Metallics Association (Date Accessed 25th May 2023)

Some plants are already beginning this transformation. For example, at the ArcelorMittal Dofasco plant in Canada, the BF-BOF setup will be phased down as the new DRI-EAF production route gets up and running by 2028 – totally phasing out coal.[41] In some cases, iron produced using DRI may flow into an existing BOF, perhaps via an intermediate smelter. In other cases, a hydrogen-ready DRI plant is set up but awaiting green hydrogen infrastructure.

In one of the most high-profile examples, an integrated network of prototype facilities across the steel value chain are brought together under a public-private partnership in Sweden known as HYBRIT, which has already produced green steel for Volvo prototype trucks and is set to go commercial by 2026. The transition will take more than one step, with different configurations by location, but choosing to invest away from coal-based steelmaking is central.

This transformation should be an opportunity. All major steel-producing countries must grapple with the history and politics of domestic steel-producing regions. Heavy industrial production and the consumer manufacturing that derives from it helped create a middle class in many countries. Additionally, domestic steel production is considered critical to national security for major economies worldwide. The case for investing in a greener steel industry to stabilise the planet is strong but relies on building the social and political momentum for a transformed economy. This means full dialogue and participation of affected communities in defining that pathway and major investment in a fair and future-fit economy.

Mathew McDermid, "View of POSCO's Gwangyang steel mill", May 2023

[41] Canadian Broadcasting Company (Hristova, B., 2022)

4.2 Decision points and red lines

Today, we face an incredible opportunity to correct the direction of steel emissions and, thus, the pace of global warming. Instead of relining emissions-heavy blast furnaces and prolonging coal-based steel production, companies and investors can and must change course. The power sector is already in the middle of a fundamental shift to cleaner renewable electricity. It is time for the steel sector to change course too.

The next seven years will make or break a 1.5°C climate trajectory for the steel sector. Many complex issues will need action (see Box), but the central point is clear. The synthesis of available credible research shows that continued investments in coal will force us further and further away from that critical threshold for a livable planet.

Keeping the prospect of a 1.5°C pathway for steel alive means staying within these goalposts:

No investment in any new or relined coal-based blast furnace facilities in OECD countries or by OECD based companies, from today.

No investment in relining existing or building new coal-based blast furnace facilities that go on-line from January 2028, in emerging economies.[42]

[42] Agora Industry (2023) Report cites 2043-45 as target for total coal based steel sunset/phaseout to ensure 1.5C alignment.

Defining the parameters for transition out of coal-based steel production

Several key parameters will need continuous attention, exploration, and action in order to ensure an effective and just transition out of coal-based steel production. These items must be the focus for decision-makers in the coming months and years.

- **Scale Clean Electricity:** As blast furnaces are replaced, the transition to green hydrogen direct reduced iron (DRI) for new primary steelmaking will likely pick up pace. Governments and steel companies need to coordinate with electric utilities and other stakeholders to ensure a sufficient supply of clean electricity to meet the rising demand associated with green hydrogen production. This cannot be at the expense of clean decarbonised power for other users.
- **Avoid Gas Lock-in:** Steel companies may look to delay the transition away from fossil fuels entirely by developing "hydrogen-ready" DRI that runs on fossil gas in the interim time period. New investments in fossil gas risk new infrastructure lock-in (pipelines to facilities being one such example) and stranded assets. Clear criteria will be needed to prevent misuse of the 'hydrogen-ready' label by plants that are not designed from the start to work with green hydrogen and have a clear binding timeline for transition away from fossil gas.
- **Worker Protections:** A transition to green steel that leaves unions and workers behind is a failed transition. Governments and companies need to work with unions, workforce training programs, and other stakeholders to minimize disruption for workers and communities that rely on the steel industry for jobs and tax revenue. Government incentives and policies need to ensure that existing mill sites and historic steel regions are an integral part of the wider transition to a thriving zero-carbon economy.
- **Environmental Clean Up:** Remediation and restitution plans for past and current air and water pollution impacts from the steel industry are needed, requiring full transparency and accountability from steel companies and direct engagement with local communities to settle terms for these pollution impacts. Going forward, green and responsible steel will need a transparent, accountable value chain upstream and downstream with free and prior informed consent (FPIC), and without any violent or coercive methods.
- **Green Buyers:** Formal commitments will be needed from steel buyers (i.e. car companies, wind power companies, government procurement) to bridge the cost gap for zero emissions pathways for steelmaking to ensure cost competitiveness by 2030.
- **Government Support:** Strong policy support and financial incentives from governments will drive the transition at pace, and should have clear conditions attached to ensure accountability for delivery of promises and manage unintended consequences. Companies need to use their considerable political power to constructively support such policy shifts, rather than to block and delay.

What does this mean in practice?

In OECD countries, current relining projects must be abandoned, while in emerging economies companies cannot plan for new relining projects. The no-building and no-relining red line requires commitment from both governments and companies.

No relining:

With approximately 71 percent of existing furnaces slated for relining over the next six and a half years, the most immediate and important priority is urgently developing alternative plans at these sites. Every potential relining must be scrutinised and challenged against a sector-wide 1.5°C climate emissions trajectory and carbon budget.

No new blast furnaces:

Building new coal-based facilities can no longer be justified. The vague prospect of CCS must not be used to justify more investment in blast furnaces. There should be no investment in coal-based technology that does not currently have credible CCSS mitigation technology available.

Decline of metallurgical coal:

Every investment in metallurgical coal needs scrutiny and challenge to halt the entire value chain. The tide has turned on thermal coal but is still only lapping at the shores of metallurgical coal.[43] The beyond-coal global economy is emerging fast, leaving behind coal as part of our fossilised past. It is time to ensure that metallurgical coal is also transitioned out.

OECD-based companies and countries lead the way:

A sunset provision on new coal-based production must be led by OECD countries and companies headquartered in OECD countries, given historic responsibility for emissions and capacity to invest in new technology. Rapid action is needed on timetables for transitioning existing coal-based production globally. As with the coal power phaseout, major economies like the United States and European Union must adopt firm red lines quickly. They should lead by example, develop the market for cleaner technologies, and directly support emerging economies to leapfrog to clean. Companies headquartered in OECD countries and operating in emerging economies must apply the same strict standards across their global operations and support technology leap-frogging.

The decline of coal-based blast furnaces for steel production is one of the biggest indicators of whether the steel industry can get on track for a 1.5°C warming trajectory. This is why a total halt on all blast furnace relining projects and new construction is needed. These real-time investment decisions will make or break the steel industry's ability to prevent its emissions from breaking the planetary climate boundaries.

[43] Some investors are starting to draw red lines. For example, in late 2022, British banking giant HSBC expanded their prohibition on new coal mine investments to include metallurgical coal.

Reference List

Agora Industry and Wuppertal Institute (2023). 15 *insights on the global steel transformation*
https://www.agora-energiewende.de/en/publications/15-insights-on-the-global-steel-transformation-1/

Agora Industry, Wuppertal Institute and Lund University (2021). *Global Steel at a Crossroads. Why the global steel sector needs to invest in climate-neutral technologies in the 2020s.*
https://www.agora-energiewende.de/en/publications/global-steel-at-a-crossroads/

Bashmakov, I.A., L.J. Nilsson, A. Acquaye, C. Bataille, J.M. Cullen, S. de la Rue du Can, M. Fischedick, Y. Geng and K. Tanaka (2022). I*ndustry in Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC.
https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter11.pdf

Bataille, C., S. Stiebert and F. G. N. Li (2021). *Global facility level net-zero steel pathways; technical report on the first scenarios of the net-zero steel project,* Net Zero Steel, IDDRI.
http://netzerosteel.org/wp-content/uploads/pdf/net_zero_steel_report.pdf

BHP (Accessed 24th April 2023). *Metallurgical Coal.*
https://www.bhp.com/what-we-do/products/metallurgical-coal

Business and Human Rights Resource Center (2019, June 7). *So. Africa: ArcelorMittal criminally charged for environmental pollution; company comments.*
https://www.business-humanrights.org/en/latest-news/so-africa-arcelormittal-criminally-charged-for-environmental-pollution-company-comments/ (Accessed 24th May 2023).

Campbell, C. (2023). *Why the steel industry needs to tackle coal mine methane, EMBER.*
https://ember-climate.org/insights/research/why-the-steel-industry-needs-to-tackle-coal-mine-methane /#supporting-material-downloads

Center for Environmental Rights (2019). *ASMA Full Disclosure; Fact sheet May 2019.*
https://cer.org.za/wp-content/uploads/2019/05/AMSA-Full-Disclosure-5-web-1.pdf

Center for Environmental Rights (2022, May 19). *Activists push dirty steel giant ArcelorMittal SA to stop pollution and accelerate transition to green steel.*
https://cer.org.za/news/activists-push-dirty-steel-giant-arcelormittal-sa-to-stop-pollution-and-accelerate -transition-to-green-steel (Accessed May 24, 2023)

Centre for Research on Energy and Clean Air and Solutions for Our Climate (2022). *Unveiling the Truth Behind Blast Furnace Pollution; Air Quality and Health Impact Assessment of South Korean Steel Plants*, CREA and SFOC.
https://forourclimate.org/hubfs/%5BCREA-SFOC%5D%20Unveiling%20the%20Truth%20Behind%20Blast%20Furnace%20Pollution_South%20Korea%20(ENG).pdf

Dhakal, S. et al. (2022). 'Emissions Trends and Drivers', in P. Shukla et al. (eds) *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (accepted version subject to final edits), IPCC.
https://www.ipcc.ch/report/ar6/wg3/

Ebner, J., K. Hipple, N. Messenger and I. Spector (2023). *Green Steel in the Ohio River Valley: The Timing is Right for the Rebirth of a Clean, Green Steel Industry,* Ohio River Valley Institute.
https://ohiorivervalleyinstitute.org/green-steel-in-the-ohio-river-valley-the-timing-is-right-for-the-rebirth-of-a-clean-green-steel-industry/

Energy Transitions Commission (2021). *Steeling Demand: Mobilising buyers to bring net-zero steel to market before 2030,* ETC.
https://www.energy-transitions.org/publications/steeling-demand/

Fan, Z., and S.J. Friedmann (2021). *Low-carbon production of iron and steel: Technology options, economic assessment, and policy,* Joule, 5.
https://www.cell.com/joule/pdf/S2542-4351(21)00095-7.pdf

Forster, P., D. Rosen, R. Lamboll and J. Rogelj (2022, November 11). *What is the tiny remaining 1.5C carbon budget means for climate policy*, Carbon Brief.
https://www.carbonbrief.org/guest-post-what-the-tiny-remaining-1-5c-carbon-budget-means-for-climate-policy/

Global Energy Monitor (2023). *Global Steel Plant Tracker.*
https://globalenergymonitor.org/projects/global-steel-plant-tracker/ (Accessed April 2023, Most recent update)

Hasanbeigi, A. (2022). *Steel Climate Impact - An International Benchmarking of Energy and CO_2 Intensities*, Global Efficiency Intelligence, Florida, United States.
https://static1.squarespace.com/static/5877e86f9de4bb8bce72105c/t/624ebc5e1f5e2f3078c53a07/1649327229553/Steel+climate+impact-benchmarking+report+7April2022.pdf

Hristova, B. (2022, October 13). ArcelorMittal Dofasco to demolish coke plant starting next year en route to halting coal use by 2028, *Canadian Broadcasting Company.*
https://www.cbc.ca/news/canada/hamilton/arcelormittal-dofasco-green-steel-1.6615570

HSBC (2023). *Our energy policy to support net zero transition.*
https://www.hsbc.com/news-and-media/hsbc-news/our-energy-policy-to-support-net-zero-transition (Accessed June 5th 2023)

Intergovernmental Panel on Climate Change (2023). *AR6 Synthesis Report (SYR).*
https://www.ipcc.ch/report/sixth-assessment-report-cycle/

International Energy Agency (2020, October). *Iron and Steel Technology Roadmap; Towards more sustainable steelmaking.*
https://www.iea.org/reports/iron-and-steel-technology-roadmap

International Energy Agency (2021, October). *Net Zero by 2050 A Roadmap for the Global Energy Sector.*
https://www.iea.org/reports/net-zero-by-2050

International Energy Agency (2022a, September). *ETP Clean Energy Technology Guide*.
https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide (Most recent update September 2022)

International Energy Agency (2022b, December). *Coal 2022.*
https://www.iea.org/reports/coal-2022

International Iron Metallics Association (Accessed 25th May 2023). *Hot Briquetted Iron (HBI).*
https://www.metallics.org/hbi.html

Lakhani, N. (2023, April 19). Nearly 120 million people in US exposed to unhealthy levels of soot and smog – report. *The Guardian.*
https://www.theguardian.com/us-news/2023/apr/19/us-air-pollution-unhealthy-levels-smog-soot-california (Accessed May 24, 2023)

Mission Possible Partnership (2021). *Net-Zero Steel; Sector Transition Strategy.*
https://missionpossiblepartnership.org/wp-content/uploads/2021/10/MPP-Steel-Transition-Strategy-2021.pdf

Myers, K. (2023, May 16). Green steel could help rebuild America's Rust Belt. *Canary Media.*
https://www.canarymedia.com/articles/clean-energy-manufacturing/green-steel-could-help-rebuild-americas-rust-belt

Nicholas, S. and S. Basirat (2023). *ArcelorMittal: Green steel for Europe, blast furnaces for India*, IEEFA.
https://ieefa.org/resources/arcelormittal-green-steel-europe-blast-furnaces-india

Nishida, Y., T. Aikawa, Y. Okubo, A. Hirose and T. Ohno (2022). *The path to green steel; pursuing zero-carbon steelmaking in Japan,* Renewable Energy Institute.
https://www.renewable-ei.org/en/activities/reports/20221118.php

Pete, J. S. (2023, May 31). Cleveland-Cliffs to reline blast furnace in 2025, *Northwest Indiana Times.*
https://www.nwitimes.com/news/local/business/cleveland-cliffs-to-reline-blast-furnace-in-2025/article_25131a98-ffdf-11ed-8393-7f5bd7ca2248.html?utm_campaign=snd-autopilot&utm_medium=social&utm_source=twitter_nwi (Accessed June 5, 2023)

Rivera, A., S. Movalia, H. Pitt and K. Larsen (2022). *Global Greenhouse Gas Emissions: 1990-2020 and Preliminary 2021 Estimates*, Rhodium Group.
https://rhg.com/wp-content/uploads/2022/12/Global-Greenhouse-Gas-Emissions-1990-2020-and-Preliminary-2021-Estimates.pdf

Sohn, H. Y. (2019) *Energy Consumption and CO_2 Emissions in Ironmaking and Development of a Novel Flash Technology,* Metals 10, no. 1: 54.
https://doi.org/10.3390/met10010054

Swalec, C. (2022). *Pedal to the Metal 2022*; It's not too late to abate emissions from the global iron and steel sector, Global Energy Monitor.
https://globalenergymonitor.org/wp-content/uploads/2022/06/GEM_SteelPlants2022.pdf

Wang, P., M. Ryberg, Y. Yang, K. Feng, S. Kara, M. Hauschild and WQ. Chen (2021). *Efficiency stagnation in global steel production urges joint supply- and demand-side mitigation efforts,* Nat Commun 12, 2066.
https://doi.org/10.1038/s41467-021-22245-6

World Steel Association (2022a). *Sustainability Indicators; 2022 Report.*
https://worldsteel.org/wp-content/uploads/Sustainability-Indicators-2022-report.pdf

World Steel Association (2022b). *World Steel in Figures 2022.*
https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2022/

Yu, S., J. Lehne, N. Blahut and M. Charles (2021). *1.5C Steel: decarbonising the steel sector in Paris-compatible pathways,* E3G.
https://www.e3g.org/publications/1-5c-steel-decarbonising-the-steel-sector-in-paris-compatible-pathways/