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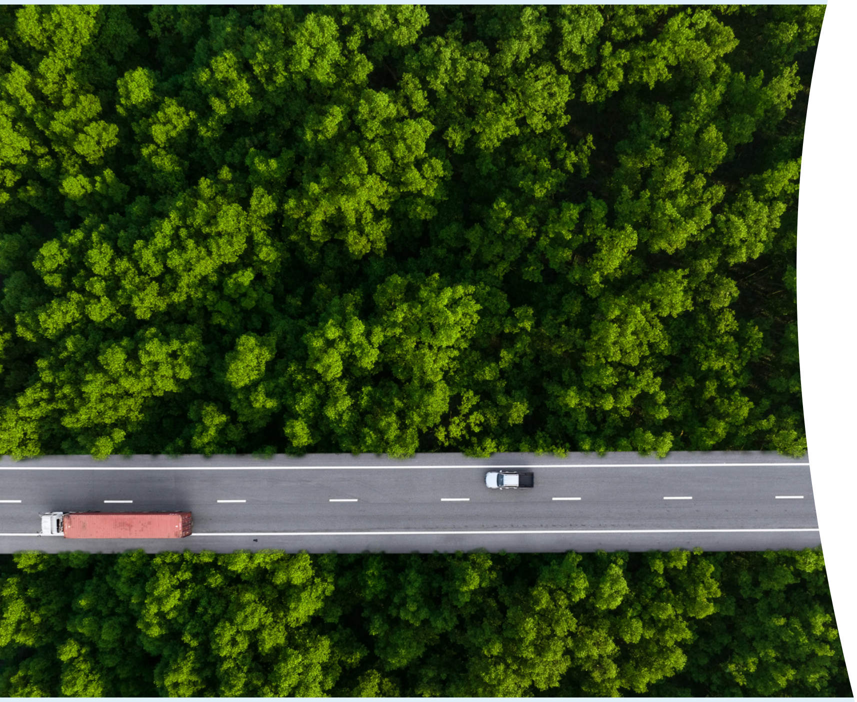
ACCELERATING EAST ASIAN CORPORATE CLIMATE ACTION

EXPLAINER–

CARBON CAPTURE IN THE STEEL SECTOR;

BF-BOF ABATEMENT

April 2024



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INTRODUCTION

Carbon capture is a technology largely developed for applications in the oil and gas industry, first commercially tried over 50 years ago. However, in recent years it has attracted significant attention in other industries with high carbon footprints (e.g. power generation, steel production, cement making, etc.) in hope that it will capture carbon dioxide (CO_2) and prevent the need to transition away from historically high-polluting technologies.

In this Explainer we look at carbon capture in the steel sector, but it should be noted that there are only two currently commercially operational carbon capture projects in the sector, as recorded in the IEA's CCUS Projects Database, taking up 1% of the total capacity currently in operation.[1] Moreover, of carbon capture and storage (CCS) projects announced globally, only 0.5% of capacity is planned for the steel sector in the next 20 years, despite steel being responsible for 7–9% of global emissions. Currently, only 1 CCS project is planned on a blast furnace-basic oxygen furnace (BF-BOF) plant compared to 76 hydrogen (H2) or H2-ready - direct reduced iron (DRI) projects by 2030.[2]

Despite this, certain steel companies have pointed toward a future reliance on the technology to reach net zero by 2050. Additionally, steel decarbonisation pathways for companies consistently account for the technology having a material role to play in the sector's decarbonisation. Relatedly, limited data on new fossil free primary processes such as H2-DRI help explain why they are less represented in decarbonisation pathways compared to CCS.[3] Consequently, the overall costs of mitigation and the demand for CCS are likely overestimated.

We discuss the various headwinds that carbon capture technologies face specific to integrated BF-BOF plants, the most widespread carbon-intensive technological pathway for steel production. Each step of the CCS process; carbon capture, transportation and storage is relatively independent. Each can occur in different places and have their own processing methods and technical bottlenecks. However, for the steel sector, there are specific challenges that integrated steel plants face in developing carbon capture technologies that could effectively decarbonise only a part of their operations. We compare the technical readiness of BF-BOF + carbon capture with other decarbonisation options for the industry attracting serious investment globally.

Although requisites for carbon capture to have any utility in climate change mitigation, this Explainer does not cover technological, emission, energy or economic challenges for the transportation and storage for CO_2. Unproblematic, reliable transportation and indefinite storage of CO_2 are currently optimistic and unproven assumptions and each warrants its own stand-alone Explainer.

It is worth underlining that while there are numerous academic studies theorising costs, efficiency and implementation of CCS, there has been no large-scale carbon capture storage project completed on a BF-BOF plant, resulting in limited tangible information regarding the parameters of interest and evaluating the technology within the frame of climate mitigation. In particular, this analysis leans on the most comprehensive study of integrating carbon capture into a BF-BOF plant to date, which is the Iron and Steel CCS Study by IEAGHG, a research programme of the IEA.[4] In this context, we only address carbon capture at BF-BOF steel plants and do not explore the variety of challenges transportation and storage of CO_2 face.

TECHNOLOGICAL COMPLEXITY OF PLACEMENT, SCALE AND GAS CAPTURE

For the purpose of this Explainer, our analysis will primarily focus on post-combustion technologies as the most mature of all carbon capture technology groups. As post-combustion capture utilising chemical absorbents has found commercial application in various industries, it is the most technically ready option for the steel industry even though it remains in a research and development rather than pilot phase. Capture technologies currently considered elsewhere in the steel sector including looping cycles, oxy-combustion and pre-combustion technologies are out of scope of this Explainer.[5]

Post-combustion or not, it is the complexity of the BF-BOF process that makes CCS implementation challenging. Integrated steel plants typically emit significant amounts of pollutants from key points such as the power plant, sinter plant and coke hot oven stoves. However, variations in the configuration of steel plants based on location pose challenges in developing modular carbon capture systems tailored for the industry. These challenges contribute to the persistent technical barriers of carbon capture due to the complexity of design and the extensive customisation required, thereby limiting its widespread deployment.[6] The number of flue stacks, the chimneys from which gases are exhausted into the air, on a steel mill spanning enormous areas of land suggests the scale of implementation would be extremely significant with dozens of units required to capture all flue gases, interconnected across the entire steel mill. In effect, the most significant retrofitting project in a steel plant's lifetime.

Aside from process and scale, the carbon capture plant design, selection of absorbent and thermal energy requirements must be different for varying compositions of flue gases as there are no one-size-fits-all technologies.[7] Although the concentration of CO_2 is higher in the flue gases of a steel plant, as compared to flue gases from a coal- or natural gas-based power plant, the presence of multiple gases such as nitrogen (N_2), carbon monoxide (CO), methane (CH_4), hydrogen (H_2), etc. and varying concentrations from different source points presents a significant challenge in the effectiveness of deploying carbon capture in the steel sector.[8]

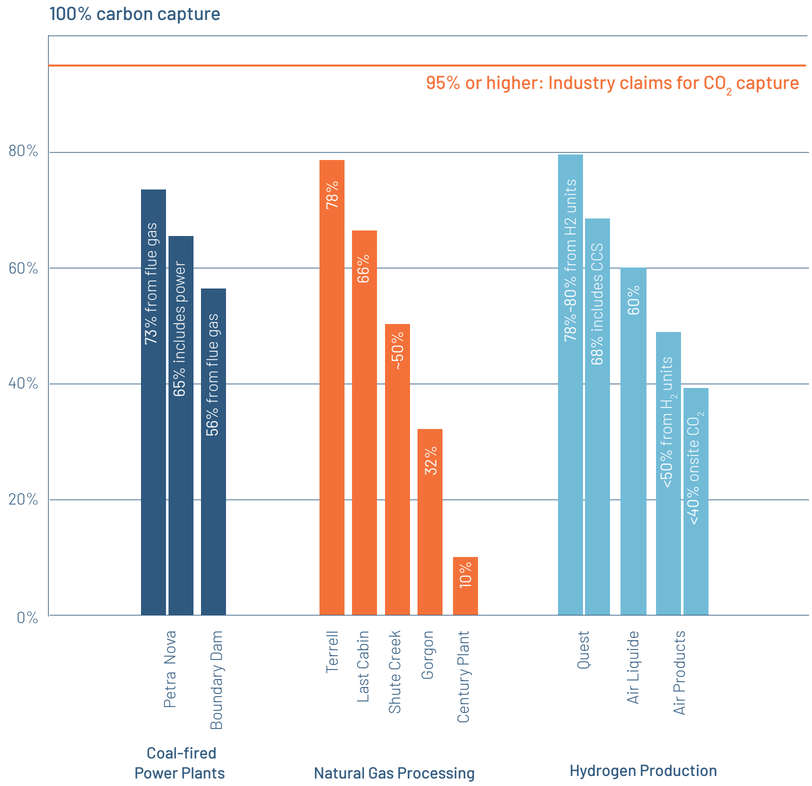
Table 1. Different CO2 and other gas concentrations in various flue gases in the BF-BOF process[9]

	Hot Strip Mill	Hot Blast Stove	Power Plant	Coke Oven Stack
CO_2 (Vol%)	1.9	13.9	14	22
CO (mg/m^3)	22	38	<3	0.18%
O_2 (Vol%)	0.17	0.092	0.076	0.035
NOX (mg/m^3)	152	87	168	300
SOX mg/m^3	171	229	300	200
VOC mg/m^3	0.14	0.039	0.43	-
PM10 mg/m^3	6.7	NR	3.3	NR

CCS IS NOT A FULL SCALE DECARBONISATION OPTION AND IT IS FREQUENTLY UNDERPERFORMING

As a consequence, it is no surprise that emission reductions from the use of carbon capture technology vary depending on application, with carbon capture technologies installed on source points with high concentrations of CO_2 generally having higher rates of capture. However, in general, carbon capture projects have consistently undershot expected capture rates beset by technical and economic challenges as highlighted in IEEFA's analysis in Figure 1. This is a key driver to our bearish sentiment towards the abatement potentials of carbon capture technology in the steel sector.

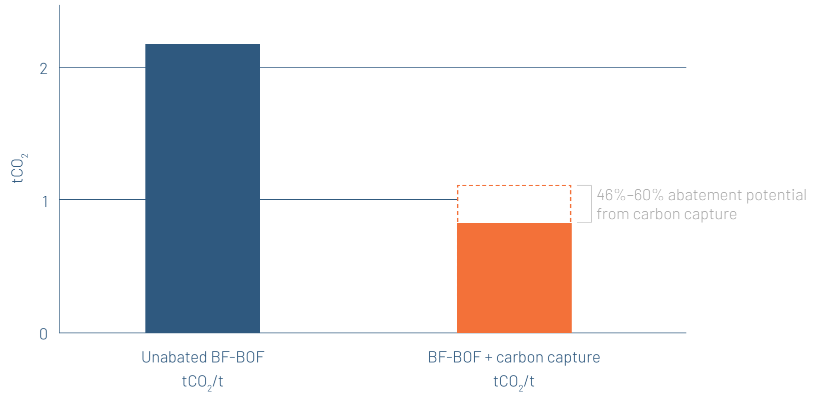
Figure 1. Capture rates from global carbon capture projects



Source: IEEFA, adapted from https://ieefa.org/ccs

The majority of emissions from BF-BOF steel plants stems from the captive power plant or cogeneration plant (a localised source of energy for a steel plant), which usually utilises coal, as well as other fuel sources such as BF off-gas. These steel mill power plants have similar and relatively low flue CO_2 concentration similar to a thermal coal power plant. This makes it susceptible to failure given carbon capture projects have rarely been successful on thermal coal power plants.[10] Given the technical complexity of abating CO_2 emissions using carbon capture on integrated steel mills, we do not believe that the steel sector would deviate from the poor results of the global operational carbon capture projects.

Figure 2. Likely emission reduction range from carbon capture in an integrated BF-BOF plant[11]



In addition, other analysts have already set a low bar for decarbonisation potential. Studies suggest that utilising post-combustion carbon capture technologies could theoretically achieve emission reduction of 46–60% from a typical BF-BOF carbon intensity of 2.1tCO_2/t.[12 13 14] Even here there is widespread uncertainty. Carbon capture emission reductions remain largely theoretical concerning their application in BF-BOF steel plants where large-scale adoption is yet to occur.

In integrated steel mills, although most of the CO_2 is formed in the BF, it is also formed with many other flammable gases. To maximise efficiency, these are directed to the steel mill's power plant for combustion, hence most of a BF-BOF steel plant's CO_2 emissions stem from the power plant flue, not the BF flue. To effectively reduce emissions, carbon capture efforts should prioritise the highest emitting sources within the plant such as the power plant, hot blast stoves and sinter plant. However, due to the fragmented nature of emissions source points, capturing all emissions using a single technology is unfeasible. Integrated steel plants feature numerous major emissions sources, often numbering between 10–20, excluding fugitive emissions. This diversity implies that in order to effectively reduce emissions and align with net zero goals, the integration of a corresponding variety of carbon capture technologies operating at high capture rates is needed.

CARBON CAPTURE TECHNOLOGY DOES NOT ADDRESS OTHER GHG EMISSIONS FROM UPSTREAM COAL MINING

The combustion of coal is the primary contributor to the significant emission footprint of the steel sector, but these emissions are not solely attributable to its use in the BF-BOF process. Upstream emissions have to be factored into carbon intensity figures as demanded by industry standards such as Responsible Steel.[15 16]

Methane emissions associated with coking coal are particularly high due to deeper mining processes. The volume of methane released from coal mining operations rivals national greenhouse gas emissions, with estimates suggesting that global metallurgical coal methane emissions exceed those of countries like Germany or Canada.[17] Accounting for fugitive methane emissions from coal mining could substantially elevate the emissions linked with BF-BOF-based steel production routes.

According to the IEA's Global Methane Emission Tracker, emission intensities from metallurgical coal extraction vary among different countries.[18] Coking coal emission intensities range from 5.4 kgCH_4 per tonne for Australian coal to 22.4 kgCH_4 per tonne for Russian metallurgical coal. Considering a 100-year global warming potential (GWP) of 28tCO_2/t for methane and an average usage of approximately 700 kg of metallurgical coal per tonne of steel, additional fugitive emissions in tCO_2e from BF-BOF-based steelmaking processes range from 0.1 to 0.44tCO_2e/tLS, equating to an additional 5%-21% CO_2e per tonne of steel.[19] Furthermore, the emissions from methane emitted from abandoned mines are not included in these intensity calculations, yet they could significantly contribute to overall emissions.[20]

It is also important to note that the increased energy demand for carbon capture and CO_2 compression could potentially lead to higher fugitive methane emissions, unless renewable electricity is utilised as the fuel source for the carbon capture units.[21]

RENEWABLE ENERGY WOULD ALSO HAVE TO POWER CCS

Additional electrical energy required for CO_2 compression is typically met by supplementary energy sources, once again often sourced from a steel mill's captive coal power plant, leading to significantly higher primary energy consumption compared to a steel plant without carbon capture.

CCS is a non-trivial process which in itself requires complex engineering and has to be operated by significant energy supplies. In total, energy requirements are theorised to range from 1.0–5.6GJ/tCO_2. Considering it takes approximately 21GJ of energy per tonne of steel, abating all emissions from the production process would account for a 10%–54% increase in energy requirements.[22] [23] As capturing all emissions is unlikely to occur, a more applicable figure would be an implied energy requirement increase of 5%–27% for a CO_2 emission reduction of 46% to 60% respectively, as this is the likely range of capture. It is likely that energy requirements would be at the higher end of the range, with carbon capture on coal power plants, which have similar flue gases to captive coal power plants at steel plants, which have a typical energy requirement of 3.89GJ/tCO_2.[24]

Due to the high additional energy requirements caused by carbon capture infrastructure, it typically requires power from an additional energy source, such as natural gas noted in IEAGHG case studies, though it is more likely sourced from a steel mill's existing power source, commonly a coal power plant or grid electricity. This results in an increased energy intensity per unit of steel. As coal power plants typically incur a 20%–30% electricity output penalty when carbon capture is integrated on the power plant, the steel power plant would need to be previously operating at low utilisation levels or source the additional power externally.[25] To mitigate further indirect emission increases, having sufficient access to and scale of captive- or grid-based renewable electricity would be a requirement for CCS technology. Given the limited abatement potential of carbon capture on steel plants, there are also better applications of renewable electricity to provide more efficient and deeper emission reductions.

TECHNICAL READINESS IS POOR COMPARED TO OTHER DECARBONISATION AND ABATEMENT METHODS

Carbon capture technology currently lags behind other methods of emission reduction in terms of development and implementation. The costs associated with both CAPEX and OPEX are either still in the research and development or pilot phase, or are altogether unknown. Furthermore, the potential for emissions abatement through carbon capture is low compared to more established technologies, such as those mentioned in Table 2. Both upstream and downstream challenges pose significant obstacles to the credibility of carbon capture, namely due to coal mining and transportation and storage challenges, the latter are particularly pronounced, varying greatly depending on geographic and geological factors.

Historically, carbon capture has faced operational issues and demonstrated poor performance when applied to other sectors. In contrast, the Scrap+EAF process is highly mature and has made considerable progress in producing complex steel varieties like electrical steel for automotive applications. Similarly, direct reduced iron (DRI) technology is well-established, often utilising hydrogen levels of 60%–70%, albeit derived from fossil sources. However, increasing hydrogen concentration beyond 70%–80% remains in a pilot phase.

Table 2. Summary of BF-BOF+Carbon Capture compared to other low carbon steel production methods

	BF-BOF + Carbon Capture	H2-DRI-EAF	Scrap-EAF
Capex	Uncertain	Proven	Proven
Abatement efficacy	46%-60%	+90%	+95%
Upstream Challenges	Coal mining emissions	Hydrogen Production	Scrap availability
Production Challenges	Carbon capture poor track record, energy requirements, Amine degradation	Hydrogen concentrations above 70%-80% remain challenging	None
Downstream Challenges	Transportation and Storage of carbon dioxide	None	None
Status	R&D	Pilot	Production

Before 2030, steelmakers should make necessary investments to scale and mature near zero emission steel production focusing on scrap steel, H_2-DRI processes with both DR and BF grade ores. Developing carbon capture technologies will not deliver abatement required by shifting customer demands and leaves steel companies exposed to carbon pricing mechanisms and carbon borders such as CBAM.

CONCLUSION

Carbon capture technology faces significant hurdles due to the diverse emissions sources on steel plants, various capture applications, and the large-scale infrastructure needed at integrated steel mills.

Relying solely on emission reductions from carbon capture is unlikely to achieve the necessary decarbonisation for steel production to reduce GHG emissions and move the sector toward net zero emissions, and particularly not in the time frame required. This is because of technical limitations that hinder the deployment of carbon capture infrastructure across all emissions source points, a history of carbon capture projects failing to deliver promised capture rates and the significant release of fugitive methane emissions from continued reliance on coking coal.

Furthermore, the energy requirements for additional carbon capture infrastructure imply an increased demand for energy, and how this energy is sourced directly impacts the effectiveness of emission reduction through carbon capture technology. Most of the world's steel plants currently operate captive coal power plants which are co-fired with off-gases to generate the necessary electricity for operations. If additional energy for carbon capture were to come from coal-based power, emissions would rise simultaneously. While theoretically, emissions from increased coal power generation could be captured, doing so would require even more energy and certainly produce more fugitive coal mine methane emissions.

Overall, carbon capture alone is not suitable for fully decarbonising the steel sector and does not align with a net zero emissions goal. With industry eyes on the commercial scale Baotou CCS project in China, due for imminent completion. Instead, steel companies should continue their focus on emerging technologies like H_2-DRI which show more promise for decarbonising the sector.

For these reasons we believe that carbon capture in the steel industry will remain largely relegated to R&D and pilot projects for the foreseeable future, continuing the technology's 50 years of development without moving the needle towards its "promised potential". The steel sector has long talked about the potential of carbon capture to lower emissions; however, this potential has never come to fruition, and more importantly, the technology will not deliver near zero emission steel without incorporating other more expensive options such as direct air carbon capture (DACC). With East Asia lagging behind in decarbonisation, the steel sector should pivot away from carbon capture and toward technologies such as H_2-DRI-EAF and Scrap-EAF steel, with renewable electricity ideally providing the necessary energy for all of these processes.

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