

HYDROGEN IN IRON MAKING:

Is Hydrogen Injection in a Blast Furnace the Best Way to Cut Emissions?

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Hydrogen (H_2) injection into blast furnaces (BF) is often seen as a bridge technology for steel decarbonisation. However, it is hydrogen-inefficient, technically constrained, and cannot achieve deep emissions cuts. Even in best-case scenarios, reductions plateau well below net-zero, leaving large volumes of carbon dioxide (CO_2) that will become a growing economic liability as carbon prices rise.

By comparison, hydrogen-based direct reduction (H_2 -DRI) paired with renewable electricity is far more efficient—requiring 40–60% less hydrogen per tonne of steel and capable of near-zero emissions. On a cost-per-tonne of CO_2 avoided basis, H_2 -DRI is already the more compelling pathway for long-term competitiveness.

Understanding the relative efficiency and long-term viability of different decarbonisation pathways remains central to charting the future of steel. Questions around the cost of avoided emissions, the strategic allocation of capital between transitional and transformative technologies, and the role of policy in steering investments highlight the complexity of the choices ahead.

BLAST FURNACE INJECTION OF HYDROGEN IN THE STEEL INDUSTRY

The use of hydrogen as a reducing agent for iron ore, in place of coke, is gaining attention as a decarbonisation measure in the steel sector, since it generates water rather than CO_2 during the ore reduction process. Steelmakers across the world are already trialling hydrogen co-firing in BFs, the most emission-intensive part of primary steel making, with the aim to reduce the carbon intensity of steel production and utilise existing iron and steel making infrastructure.

In India, Tata Steel carried out a multi-day hydrogen injection trial at its Jamshedpur works in April 2023, reporting a potential ~10% coke-rate reduction, equivalent to a 7–10% cut in CO_2 per tonne of crude steel.¹

In Japan, Nippon Steel announced in December 2024 that its 12m³ Super COURSE50 (the company's own brand of BF adaptation) test furnace had demonstrated up to a 43% reduction in CO_2 emissions, and equipment is now being installed to enable hydrogen-rich gas injection at the Kimitsu No. 2 BF from 2026.²

In China, Baowu Steel commissioned the world's first 400 m³ HyCROF (hydrogen-enriched carbonic oxide recycling oxygenate furnace) in 2022, achieving a breakthrough

1 https://www.reuters.com/business/sustainable-business/indias-tata-steel-begins-hydrogen-gas-injection-trial-blast-furnace-2023-04-24/?utm_source=chatgpt.com

2 https://www.nipponsteel.com/en/news/2024i220_100.html

in top-gas recycling under pure oxygen conditions; reported outcomes included a 30–40% increase in production capacity and more than a 30% reduction in the solid fuel rate.³ Earlier, in 2021, Shanxi Jinnan Iron and Steel succeeded in large-scale continuous hydrogen injection into a BF, cutting the average fuel rate by 36 kg/t and CO₂ emissions by around 5.6%.⁴

European steelmakers are also pushing ahead. Thyssenkrupp Steel in Germany became the first company worldwide to inject hydrogen into an operating BF in 2019, demonstrating that up to 20% of CO₂ emissions could be avoided by partially substituting coke with hydrogen.^{5 6} Dillinger and Saarlund, German steelmakers, are advancing coke-oven-gas injection and plan to move towards pure hydrogen injection in two furnaces, aiming for a 40% reduction in CO₂ by 2035.⁷ ArcelorMittal's Asturias plant in Spain began hydrogen injection in 2021 using hydrogen extracted from natural gas and coke-oven gas, and similar projects are under consideration at Bremen and Dunkirk.^{8 9}

TECHNICAL CHALLENGES

BFs are optimised for coke, so adapting them to handle hydrogen injection requires major modifications. Given the significant investment involved in retrofitting BFs for hydrogen co-firing, it raises the question: is hydrogen co-firing a practical step toward a lower-carbon future, or an expensive diversion of capital that delivers only partial decarbonisation? Several technical challenges related to hydrogen injection in BFs are outlined below:

1. The first issue is scale. Small-scale test furnaces are hundreds of times smaller than their commercial counterparts, raising concerns about whether the same performance can be reliably achieved at full industrial scale.¹⁰ In China, where hydrogen injection has been implemented in a 1,860 m³ BF, the reduction in emissions has been limited to just 5.6%, highlighting the challenges of scaling up the technology.¹¹
2. A second challenge concerns a potential increase in energy consumption. Much of the waste heat and gases generated during the steel making process, including that from coke oven gas, is already recovered and reused in the form of steam or electricity. As such, diverting coke oven gas, which has a typical hydrogen content of 55%, for use in a BF may result in a need to procure additional electricity or fuel. Although some projects also aim to compensate for this by recovering currently unused waste heat, it remains uncertain whether this will be sufficient to fully offset the shortfall.¹² Furthermore, since the reduction of iron ore with hydrogen is an endothermic reaction, hydrogen injection is expected to increase overall energy requirements.¹³

3 <https://worldsteel.org/case-studies/environment/china-baowu-development-and-application-of-low-carbon-metallurgical-technology-based-on-hydrogen/>

4 <https://www.sciengine.com/IS/doi/10.13228/j.boyuan.issn0449-749x.20220075>

5 <https://www.thyssenkrupp-steel.com/en/newsroom/press-releases/thyssenkrupp-steel-concludes-first-test-phase-successfully.html>

6 https://www.valveworldexpo.com/en/Media_News/News/Business_News_Archive/Retrofitting_Instead_of_New_Construction_EU_Funds_Hydrogen_Technology_for_Blast_Furnaces

7 <https://en.saarstahl.com/news/press-releases/it-s-all-systems-go-for-the-green-transformation-the-german-minister-of-economics-saarland-s-minister-president-and-saarland-s-minister-of-economics-examine-the-green-steel-strategy-for-dillinger-and-saarstahl/?id=7584>

8 <https://corporate.arcelormittal.com/media/news-articles/arcelormittal-asturias-starts-coke-oven-gas-injection-for-blast-furnace-b>

9 <https://corporate.arcelormittal.com/media/news-articles/arcelormittal-europe-to-produce-green-steel-starting-in-2020>

10 <https://www.ramboll.com/en-us/insights/decarbonise-for-net-zero/exploring-hydrogen-s-potential-to-decarbonise-steel-from-blast-furnaces>

11 <https://www.sciengine.com/IS/doi/10.13228/j.boyuan.issn0449-749x.20220075>

12 <https://www.greins.jp/course50/en/technology/technology03/>

13 <https://onlinelibrary.wiley.com/doi/full/10.1002/srin.201900108>

3. A further, well known limitation arises from the design of the BF itself, which is optimised for reduction reactions using coke. Coke not only acts as a reductant but also provides mechanical stability within the furnace, facilitating the smooth flow of materials and gases.¹⁴ Hydrogen lacks these stabilising properties, and its partial injection can alter the heat and mass transfer dynamics, potentially resulting in issues such as unstable gas flow and thermal imbalance.
4. A fourth challenge is the BF's refractory lining, which is not designed for high hydrogen use. Unlike DRI shaft furnaces—built to handle up to 60% hydrogen with advanced, oxidation-resistant materials—BFs rely on carbon- and alumina-based bricks suited for coke-based reduction. Injecting hydrogen creates more oxidizing and thermally volatile conditions, which can degrade these linings prematurely. To operate safely at high hydrogen levels, a costly and complex furnace relining with more robust materials would likely be required, likely undermining the perceived economic benefit of using existing infrastructure to produce low(er) carbon steel.¹⁵

EFFICIENCY OF GHG ABATEMENT USING HYDROGEN

A review of several studies indicates that, under simulated BF operating conditions, around 2.1–2.8 kg of H₂ per tonne of crude steel (tcs) is required via the conventional BF–BOF route to achieve a 1% reduction in CO₂ emissions.^{16 17} Calculations based purely on chemical reactions, however, suggest a somewhat lower figure of roughly 1.7–2.4 kg H₂/tcs.^{18 19} For the H₂–DRI process, the equivalent requirement—based on substituting BF-produced pig iron with H₂–DRI—is approximately 0.7 kg H₂/tcs. This means that, under BF operating simulations, the requirement is around 40% or less of that for hydrogen injection into BFs. Using hydrogen in a BF for iron ore reduction is generally less efficient than using it in a DR shaft furnace due to several factors related to process control, reaction kinetics, and material properties. Crucially, BFs are optimised for a reducing gas mixture dominated by carbon monoxide, while DR shafts excel at using hydrogen.^{20 21 22} Furthermore, owing to the faster reduction kinetics of hydrogen compared with carbon monoxide (CO), complete metallisation can in principle be achieved more rapidly in a shaft furnace, further enhancing its overall efficiency. In BF, a considerable share of the injected hydrogen leaves with the top gas without fully reacting.²³

Looking at overall hydrogen demand, the H₂–DRI process requires roughly 62 kg H₂/tcs to fully reduce iron ore into sponge iron. By comparison, under simulated BF operating conditions, injecting enough hydrogen to achieve a 21.4–26.1% reduction in CO₂ emissions requires about 29–34 kg H₂/tcs. These results highlight two key problems, first, that hydrogen use in the BF is only about half as efficient as in a DR shaft, and secondly, that there is an upper limit, albeit not yet certain, to hydrogen use as a reductant in a BF, thus drastically limiting any green credentials. To summarise, this process is less efficient and achieves lower emissions reductions compared to other more established technologies.

¹⁴ <https://www.techniques-ingenieur.fr/en/resources/article/ti554/metallurgical-coke-m7341/v1>

¹⁵ <https://www.ispatguru.com/refractory-lining-of-blast-furnace/>

¹⁶ <https://www.sciencedirect.com/science/article/pii/S0959652617306169>

¹⁷ https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4473005

¹⁸ <https://link.springer.com/article/10.1007/s12613-022-2474-8>

¹⁹ <https://www.sciencedirect.com/science/article/pii/S0196890421010980>

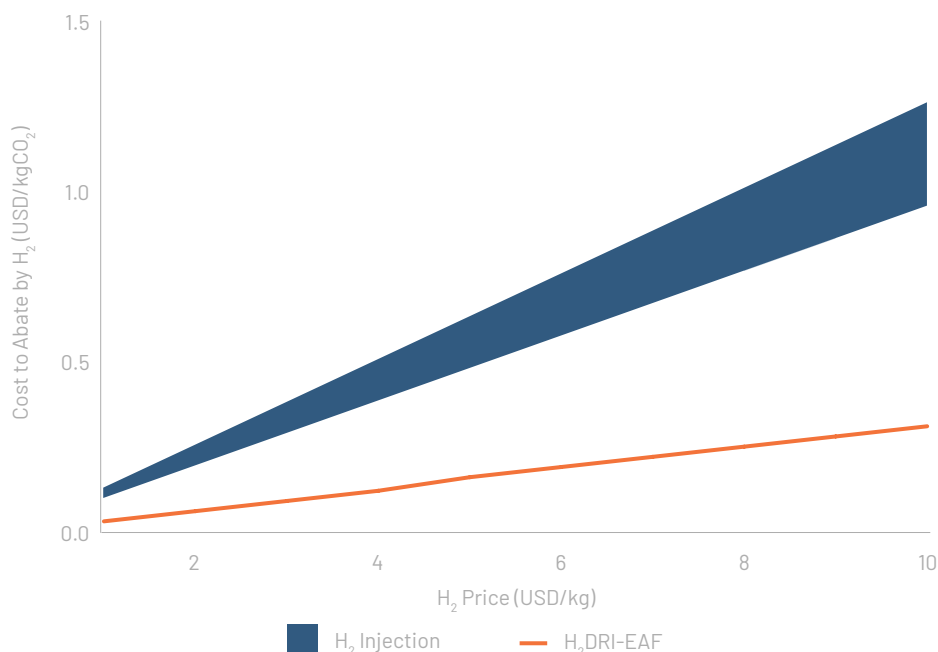
²⁰ <https://www.midrex.com/tech-article/dealing-with-an-uncertain-future-direct-reduction-in-the-hydrogen-economy/>

²¹ https://www.jstage.jst.go.jp/article/isijinternational/64/14/64_ISIJINT-2024-145/_html/-char/en

²² <https://link.springer.com/article/10.1007/s11663-023-02822-4>

²³ <https://www.sciencedirect.com/science/article/pii/B9780323853736000119>

Figure 1. Efficiency of Hydrogen Related CO₂ Abatement in a BF and DRI Shaft as a Function of Hydrogen Costs



Source: TA analysis^{18 19 24}

At higher injection rates, BF's require large volumes of hydrogen, yet the abatement efficiency remains relatively low. This means that more hydrogen must be used to avoid each tonne of CO₂, driving up costs and reducing overall effectiveness. Importantly, hydrogen injection into BF's cannot achieve near-zero emissions, leaving significant residual CO₂ that will become an increasing liability as carbon pricing and regulatory frameworks tighten in the future.

Hydrogen injection into BF's faces significant technical challenges and is expected to take significantly longer to reach commercial viability compared to H₂-DRI, which is already nearing commercialisation. Compared to H₂-DRI, hydrogen injection into BF's not only delivers lower emissions reduction potential, its actual upper limit is still uncertain. While falling hydrogen prices are expected to enhance the cost competitiveness of H₂-DRI, the future cost for hydrogen injection into BF's remains uncertain, at risk of being shaped by carbon pricing and, more broadly, by additional costs associated with managing residual CO₂ emissions.

²⁴ This comparison considers only the cost of H₂ used to abate 1 kg of CO₂ and does not include capital expenditure differences between the BF and DRI units.

DATA AND DISCLAIMER

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