

Net-Zero Steel: Overcoming the inertia of a fragmented transition

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SYSTEMIQ

Observations on the challenges of sector transition and insights from the first fully open-source global steel model: Steel-IQ

Executive Summary of this whitepaper is available [here](#)

Steel is the material backbone of the global economy, underpinning everything from urban infrastructure to energy, mobility, and defence. It is a strategic asset: governments across the political spectrum aim to retain or expand steel capacity as a foundation of industrial sovereignty, supply-chain security and employment. Steel is also responsible for 7-9% of global greenhouse gas emissions, more than any other material.

500 Mt

of blast furnace capacity
remains operational in 2050

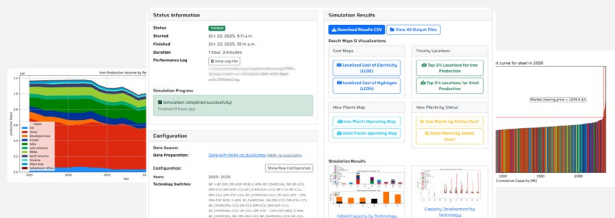
under the business-as-usual scenario

There is a viable path to decarbonising the iron and steel industry by mid-century. But how fast can it decarbonise while navigating regional demand shifts, fragmented policy and weak green demand signals, rising trade frictions, and intensifying economic security and competitiveness imperatives? The answer matters not only for climate, but for every government and investor trying to determine which producers will remain competitive as the sector navigates the transition.

To interrogate this question, we developed Steel-IQ – a global techno-economic model of the iron and steel sector, built with philanthropic funding and released as

open source. Unlike proprietary “black box” forecasts, Steel-IQ offers a transparent view of how technology costs, resource constraints, policy interventions and regional demand dynamics interact over time.

Our analysis confirms that steel sector’s deep decarbonisation is achievable but exposes four key forms of deep-seated inertia: long investment cycles, political resistance to decoupling of iron- and steelmaking processes, hard physical constraints on raw materials, and a bottleneck in engineering and OEM capacity. This whitepaper explores what Steel-IQ reveals about these constraints, and what must change to accelerate the transition.



Steel-IQ sets a new benchmark in open analytics for heavy industry, enabling stakeholders to design, test, and evaluate pathways to a low-carbon, competitive global steel industry.

Explore more at www.systemiq.earth/steel-iq

What constrains the transition?

Long investment cycles create lock-in

Future steel demand growth is unevenly distributed, creating a disconnect between where steel is made today and where it will be needed tomorrow. Steel-IQ makes regional demand trajectories explicit through its demand module.

In China, demand has started to decline structurally as construction slows down, population falls and the economy rebalances towards services and high-tech manufacturing. This leaves a large surplus of relatively young blast furnace-basic oxygen furnace (BF-BOF) capacity: average blast furnace ages are around 12–15 years, compared with roughly 40 years in Europe, making early retirement economically painful and politically sensitive. How this surplus capacity is managed – whether

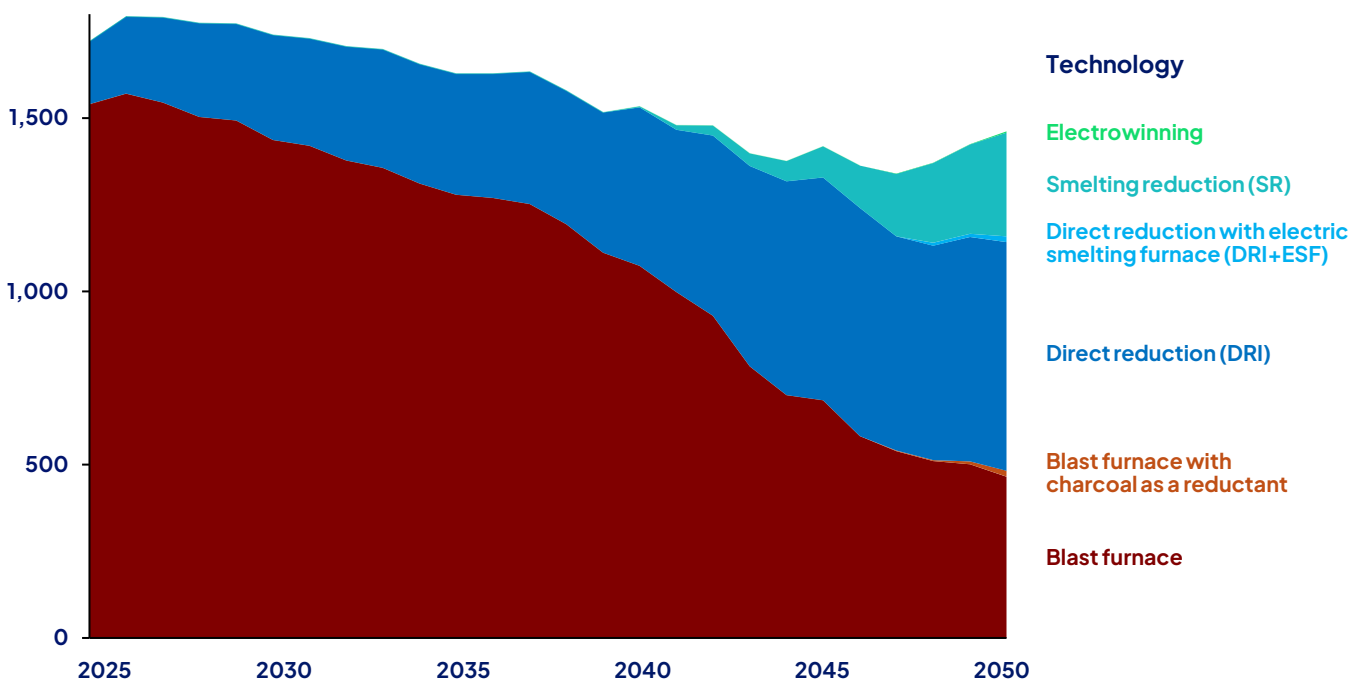
through accelerated phase-out, or renewed export surges – will shape global markets; recent dynamics echo the 2015–2016 period, when excess Chinese capacity drove a ~100 Mt export wave that depressed steel and iron ore prices worldwide.

By contrast, India and Southeast Asia are the engines of future demand growth. In these regions, high cost-sensitivity and access to low-cost thermal coal favour new blast furnace investments, unless policy or economics shift decisively.

This creates a risk of long-term carbon lock-in. Under the business-as-usual scenario, Steel-IQ shows that almost 500 Mt of blast furnace capacity remains operational in 2050, reflecting the absence of strong economic signals for early retirement of newly built assets. Without targeted policy or dramatic shifts in relative costs, these regions will continue embedding high-carbon assets that operate well into the second half of the century.

EXHIBIT 1 Under the business-as-usual scenario, almost 500 Mt of blast-furnace capacity remain operational by 2050

Iron production capacity by technology Mtpa



Decoupling ironmaking from steelmaking is economically rational but politically resisted.

The transition may produce one structural shift with strong economic logic but significant political, trade and execution risks: the decoupling of ironmaking from steelmaking, and the emergence of green iron as a globally traded intermediate product. When the primary input shifts from coking coal to clean energy, co-location of the two

steps is no longer obviously optimal. Regions with abundant, inherently cheap renewable resources, including the Gulf states and Australia, have a structural cost advantage in ironmaking that high-energy-cost regions such as Europe, Japan and South Korea do not.

For those regions, concentrating domestic investment in steelmaking and high-value downstream processing, while importing green iron from lower-cost producers, may be

more economically rational than attempting to retain the full value chain. That is not a costless choice: potential job losses are politically sensitive, and the risks of depending on new supplier geographies and partners are real. The trade-off between cost competitiveness and strategic autonomy will be drawn differently in every market.

Steel-IQ can test how this decoupling might evolve under different energy price, policy and trade assumptions, making the terms of that trade-off explicit for governments and producers before investment decisions are locked in.

Feedstock availability Part 1

The high-grade ore ceiling

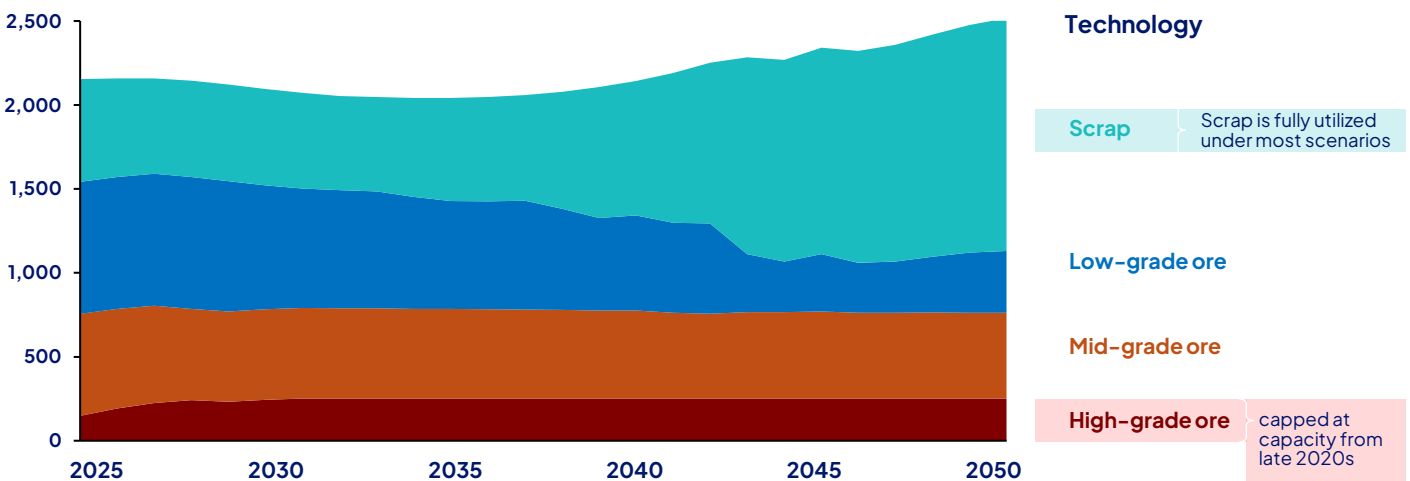
Direct Reduced Iron (DRI) is central to most steel decarbonisation roadmaps because it can be combined with hydrogen and then low-carbon electricity in Electric Arc Furnaces (EAFs) to avoid coal use. However, conventional shaft DRI processes which dominate installed capacity today typically require high-grade iron ore pellets

(above 67% Fe with low silica, alumina and other impurities) to operate efficiently.

In Steel-IQ simulations, global DRI capacity struggles to exceed 500 Mt even under favourable policy assumptions, reflecting these physical constraints on high-grade ore supply.

EXHIBIT 2 High-grade iron ore and scrap are fully utilized under most scenarios

Iron units by source Mtpa



This means the industry should look beyond shaft DRI alone to deliver deep decarbonisation at scale. Ore-flexible ironmaking technologies – notably Electric Smelting Furnaces (ESF) and fluidised-bed DRI processes that can process lower-grade ores – must complement DRI to unlock further emissions reductions. Without technological breakthroughs in beneficiation or large-scale deployment of ore-flexible processes, the high-grade ore ceiling will cap the contribution of the DRI pathway, forcing continued reliance on either blast furnaces or scrap-intensive routes with their own quality constraints. Any strategy that assumes DRI can fully replace blast furnaces at scale without ore-flexible technologies is likely underestimating physical constraints.



Feedstock availability Part 2

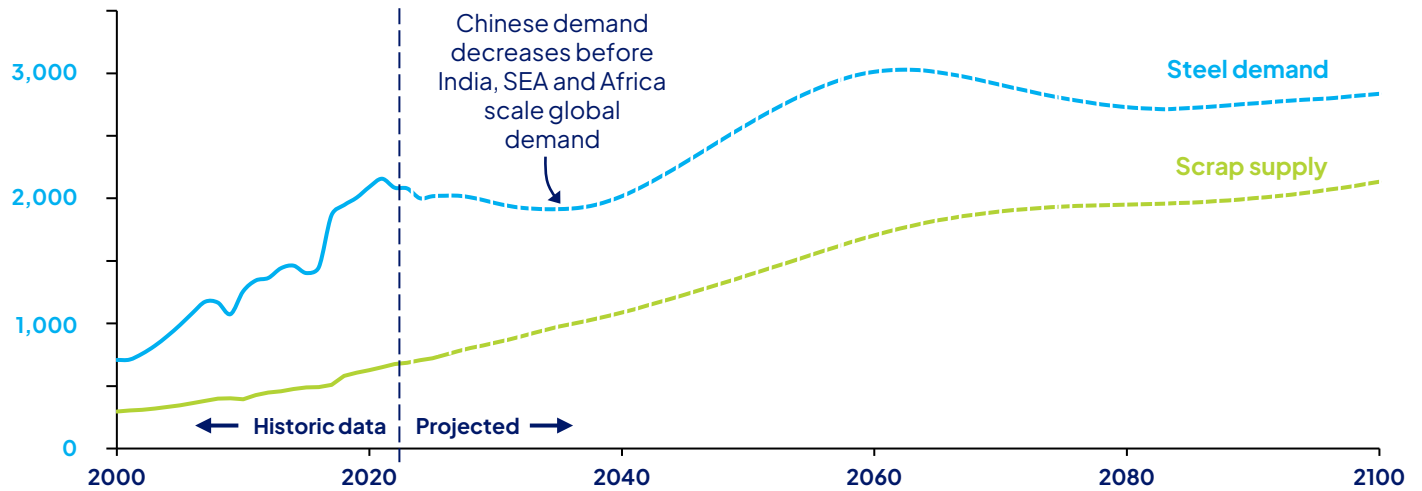
Scrap quantity and quality

Scrap-based EAF production is the lowest-emissions steelmaking route at scale and plays a growing role across all scenarios. Steel-IQ projects that global scrap

availability rises from around **0.6 billion tonnes** today to roughly **1.4 billion tonnes** by 2050, driven primarily by China's massive in-use stock of steel products reaching end-of-life as the construction boom of the 2000s–2010s retires. That means that scrap will become a feedstock for a bigger share of global steel production and demand, as the following exhibit shows.

EXHIBIT 3 Global scrap availability will more than double to 1.4 billion tonnes by 2050, largely driven by retiring Chinese infrastructure

Global steel demand and scrap availability Mt



However, volume is only half of the story; quality is the binding constraint for scrap-based production of flat and other high-specification steels. Tramp elements such as copper and tin accumulate in the scrap pool and are difficult and costly to remove with conventional steelmaking, which can lead to surface defects and poor performance in demanding applications. In practice, this pushes producers towards advanced scrap sorting, tighter supply-chain control and blending with ore-based metalics such as DRI or pig iron. This means '100% scrap' narratives for flat steel products need to be grounded in

realistic assumptions about sorting, dilution with virgin iron, and the timing of scrap pool evolution. If China develops sophisticated scrap sorting and processing at scale, as its history of policy support and industrial scaling would suggest, it could pivot from the world's largest source of surplus carbon-intensive steel to a leading low-emissions steel producer. China's scrap transition is arguably the single largest wildcard in global steel decarbonisation, and its outcome would reshape competitive dynamics for producers in Europe, the Middle East and the rest of Asia.

Engineering and OEM capacity bottleneck

Perhaps the most overlooked constraint in the transition is the physical capacity to deliver it. Even if finance and policy are aligned, the sector still needs enough engineering and OEM bandwidth to design, build and retrofit plants at unprecedented speed. Steel-IQ's deep decarbonisation pathways imply constructing or majorly retrofitting on the order of 100 Mt of ironmaking capacity per year for around two decades – a sustained deployment rate only briefly matched by China's build-out in the 2000s.

Recent waves of DRI and EAF announcements have already strained engineering firms and equipment suppliers, lengthening lead times. As the transition accelerates, engineering and manufacturing capacity could become a binding constraint, creating a de facto queue for projects regardless of available funding. For both incumbents and policymakers, realistic deployment timelines and early engagement with OEMs are therefore as important as capital availability. In practice, being early in the OEM queue may matter as much as having capital committed.

Policy response and its limitations

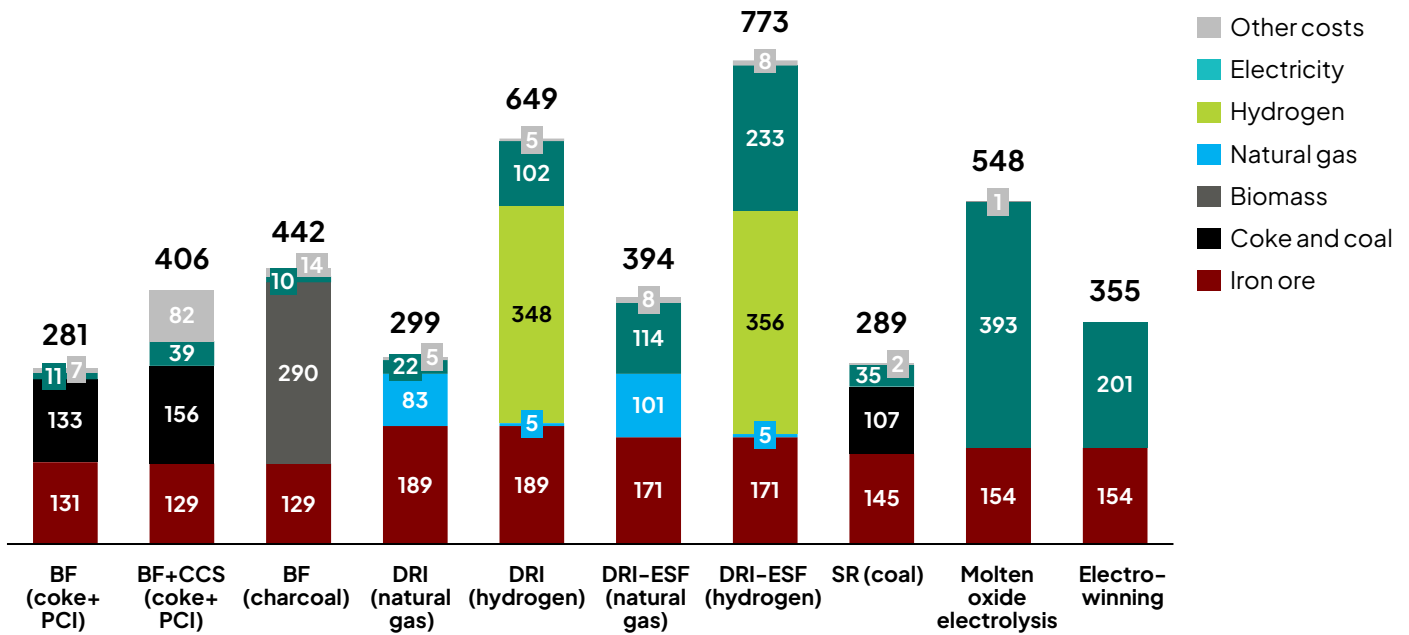
The cost gap: why CAPEX subsidies alone are not enough

Capital expenditure support can make marginal low-carbon projects investable and bring forward final

investment decisions, but it does not on its own close the operating cost gap with depreciated blast furnaces. Most low-emissions routes remain substantially more expensive to run than existing BF-BOF plants or gas- and coal-based DRI-EAF modules under typical fuel price and carbon cost assumptions.

EXHIBIT 4 There is a substantial operating cost gap between new green technologies and blast furnaces

Estimated variable costs of ironmaking in 2030, average for OECD countries \$/t



Steel-IQ analysis identifies a specific failure that public capital programmes must be designed to avoid: relying on CAPEX subsidies alone risks creating stranded or underutilised green assets. Recent experience in Europe, where several high-profile projects have been delayed or paused despite significant capital support, underlines this risk. Without complementary operating mechanisms –

such as durable and predictable carbon pricing, or green procurement that guarantees demand – green capacity can be built but remain uneconomic to run. The result is “white elephants”: assets that deliver neither expected emissions reductions nor acceptable returns for investors or public sponsors.

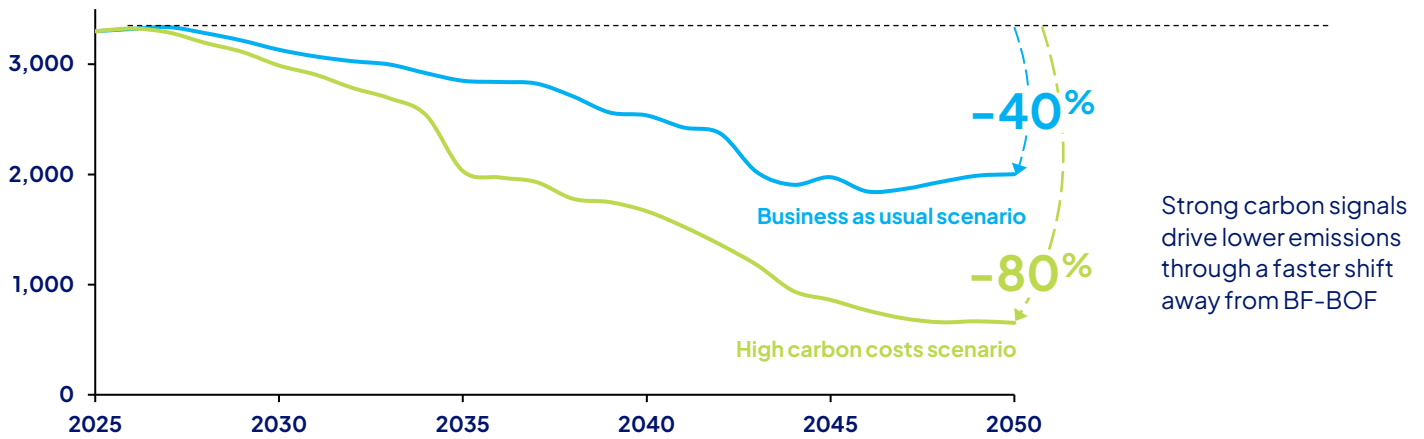
Carbon pricing as the decisive variable

Steel-IQ confirms that carbon pricing is an important lever for shifting the competitiveness of low-emissions routes, especially when combined with trade measures and targeted subsidies. Carbon costs, including explicit carbon taxes and border adjustments, significantly improve the relative economics of hydrogen-based DRI and ore-flexible low-carbon routes. Steel-IQ’s cost modelling makes it possible to identify the carbon price

levels at which the operating cost gap between green routes and depreciated blast furnaces close under different fuel price and technology assumptions. That gives policymakers and investors a more concrete anchor rather than a directional signal. That level varies significantly by region and fuel mix, which is why fragmented pricing regimes produce uneven transition incentives rather than systemic change.

EXHIBIT 5 Strong carbon signals drive lower emissions through a faster shift away from BF-BOF

Estimated direct GHG emissions Mtpa



While mechanisms such as the EU's Carbon Border Adjustment Mechanism (CBAM) are now active, fragmented global pricing regimes create arbitrage opportunities rather than driving sector-wide decarbonisation. In the absence of aligned international frameworks, trade flows may simply re-route: producers will seek to divert low-carbon steel to markets with carbon

costs, such as the EU, while directing higher-carbon output to unregulated jurisdictions. This "carbon shuffling" redistributes emissions geographically without reducing them globally, undermining climate objectives and distorting competitive dynamics and investment signals across regions. Steel-IQ's trade and policy modules are designed to capture these effects explicitly.

Strategic Priorities: Navigating the next decade

For iron and steelmakers: flexibility over one-way bets

For incumbents, an effective decarbonisation strategy increasingly hinges on securing the right inputs and maintaining flexibility under uncertainty. Feedstock availability is a binding constraint: DRI-based routes require access to high-grade iron ore or advances in beneficiation and ESF or similar technologies, while greater reliance on scrap demands improved sourcing, sorting and quality management, particularly for flat and high-specification products. At the same time, markets are likely to fragment as carbon costs and trade measures diverge across regions, making carbon performance a condition of market access rather than a simple compliance issue.

In this context, strategy must pivot from vague "optionality" to concrete operational flexibility. High-flex EAFs capable of switching between scrap- and ore-based metallic charges, diversified portfolios of ore and scrap supply, and active piloting of ore-flexible low-carbon ironmaking (such as ESF or fluidised-bed DRI) all increase

resilience to shifting input prices and policy. Continuing to invest heavily in conventional blast furnaces with the expectation of "retrofitting later" risks creating stranded assets if carbon prices, trade rules or customer requirements tighten faster than anticipated. Given emerging OEM bottlenecks, early planning and realistic deployment timelines for retrofits and new builds emerge as critical sources of competitive advantage. Securing a position in the engineering pipeline coupled with technological and resource diversification has option value that is independent of any single scenario prevailing. It is one of the few near-term moves that improves competitive positioning whether the transition accelerates or stalls

For investors and financiers: Due diligence beyond the plant economics

For capital providers, the transition fundamentally reshapes risk and return profiles across geographies and technologies. Exposure to low-cost clean energy, carbon regulations, feedstock constraints and trade measures increasingly determines long-term competitiveness at the asset level. Financing decisions that ignore the evolution of scrap markets and the reality of CBAM-type border measures risk locking capital into assets that are technically sound but economically fragile.

Due diligence therefore needs to move beyond technology readiness levels and single-plant economics. It should explicitly assess feedstock security (ore and scrap), regional policy trajectories (including carbon prices and border adjustments), flexibility to adapt to changing input costs and market access conditions, and the likelihood of delays linked to OEM and infrastructure bottlenecks.

For policymakers: Integrated policy packages over isolated targets

No single policy instrument can deliver the transition in isolation. Capital subsidies and R&D support can accelerate deployment, but without durable operating-period signals – such as robust carbon pricing,

carbon CfDs or equivalent mechanisms – they risk wasting public funds on underutilised assets. The objective should be integrated policy packages that pair upfront support with long-term visibility on carbon costs, enable low-carbon infrastructure (power, hydrogen, transmission, ports) and manage trade impacts to avoid simple leakage.

Because ore grades, scrap flows, carbon pricing differentials and engineering and OEM capacity limits interact in complex ways, policy cannot rely on high-level targets alone. Transparent, open-source modelling frameworks such as Steel-IQ can help align expectations, quantify trade-offs and stress-test policy packages against physical and economic realities before large public commitments are made.

Conclusion

The time for reliance on long-term targets has passed.

Steel plants built or retrofitted in the late 2020s will still be operating in the 2040s, which means the investment decisions of the next five to ten years will largely determine the sector's emissions and competitive profile through mid-century. The path to decarbonised steel sector is conceptually clear but obstructed in practice by interconnected constraints on materials, economics, policy and execution capacity, and those constraints are real regardless of which political priority dominates in any given market or decade. The window to build around them, through feedstock security, flexible capacity and early OEM engagement, is narrowing. The next ten years will be decisive.

Steel-IQ is Systemiq's open-source techno-economic model of the global iron and steel sector. Version 2.0 (released May 2026) is significantly faster and more user-friendly, while maintaining the richness, flexibility and transparency valued by users across industry, policy, finance and civil society.

Learn more and download the model at www.systemiq.earth/steel-iq or reach out to the team at steel-iq@systemiq.earth to discuss these insights and how Steel-IQ may be applied to your use cases.

