Technology Review for Carbon Neutrality

Perspective

# How could steel industry decarbonisation benefit the global south?

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**ABSTRACT**

Industrialised countries face legally binding decarbonisation commitments, but carbon pricing and capital subsidies have not overcome structural cost disadvantages for steel decarbonisation. Developing countries need decades of primary steel production for development, but cannot afford the green premium and cannot take the conventional carbon-intensive path. Hydrogen-based direct reduced iron technology changes what is possible: green iron production can now locate where costs are lowest. Some developing country locations offer substantial cost advantages. This article proposes a production chain configuration where industrialised country subsidies flow through contract structures to enable developing country production. EU steelmakers gain lower-cost inputs and enhanced competitiveness. EU public funders achieve decarbonisation at lower cost while building a competitive green steel industry. Developing country producers gain bankable offtake enabling investment otherwise inaccessible, with export partnerships providing the foundation for domestic green steel sectors. The configuration works within existing policy frameworks, requiring adjustment rather than new mechanisms. Implementation can proceed through first-mover partnerships rather than awaiting comprehensive international coordination.

**KEYWORDS**

Steel decarbonisation; green iron; hydrogen direct reduced iron; global south development; industrial policy; green trade

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## 1. Primary steel and development

Steel provides the physical basis for infrastructure, machinery, and transportation systems enabling economic production and basic services: water systems, electricity grids, sanitation, healthcare facilities, and transport networks. For most economies, the foreign exchange to sustain infrastructure development cannot be generated without the broader industrialisation ecology of which a steel industry typically makes up core nodes.

Industrialised countries have accumulated in-use steel stocks (IUSS) of 11–16 tonnes per capita over decades or centuries of steel production[1]. At these levels, IUSS reaches saturation and consumption drops[1,2]. Steel production and consumption shift from accumulation to replacement, and industrialised countries increasingly meet demand through secondary steel: recycling scrap steel in electric arc furnaces (EAFs), which can be decarbonised using renewable energy. The USA already produces 70% of steel through EAF recycling, the EU 43%, though some advanced economies remain lower (Japan 26%, China 10%) [3].

Developing countries will need many decades of sustained primary steel production to build IUSS to adequate levels: a material reality that challenges Sustainable Development Goal (SDG) timelines and is often overlooked in development economics. The notion that developing countries can bypass industrialisation contradicts historical evidence. There is no historical precedent of a country developing without industrialising, and there is no industrialisation without substantial basic material accumulation in infrastructure[4]. China's transformation illustrates this trajectory: from 1976 to 2024, crude steel production grew fifty-fold to 1,005 Mt/y while IUSS increased from less than 1 t/cap to 8.8 t/cap[3,5]. This accumulated steel infrastructure enabled lifting 800 million people from poverty[6]. At 8.8 t/cap, China has not yet reached saturation, with annual production around 700 kg/cap[3].

India exemplifies countries at earlier stages. At 125 Mt/y production, approximately 90 kg/cap and 2 t/cap IUSS, India resembles China's situation decades ago[3]. Building to 8 t/cap will require many decades of sustained primary steel production from iron ore. Low-IUSS countries have minimal scrap available regardless of recycling efficiency: many decades of primary steel production must accumulate before significant proportions of demand can be met through recycling[2].

Africa faces acute steel poverty. Of 1.5 billion people, 600 million lack electricity and 400 million lack basic water: direct consequences of insufficient steel-dependent infrastructure. Most countries have IUSS levels below 1 t/cap[3]. Of 53 African countries, four account for most production: South Africa (5 Mt/y), Egypt (11 Mt/y)[3], Morocco (2 Mt/y)[7] and Algeria (2 Mt/y)[8]. African crude steel production totalled 28 Mt in 2024, about 19 kg/cap. Supply and accumulation levels will have to increase radically and be sustained for decades before basic needs can be met for significant proportions of populations.

## 2. Scope and approach

Steel production is responsible for 7%–9% of global emissions[9]. Industrialised countries face legally binding decarbonisation commitments. Developing countries, needing decades of primary steel production, cannot pursue the conventional carbon-intensive path. There is no carbon budget for another generation of coal-based steel sectors.

But the most promising technology enabling full decarbonisation also creates new options. Hydrogen-based direct reduced iron enables geographic separation of ironmaking from steelmaking. Some developing country locations have conditions for lowest-cost green iron production. In important instances, there is potential for the pursuit of decarbonisation and development to be mutually reinforcing.

This article explores what such configurations would require: bankability, net benefits to all participants, political feasibility. Rather than model all possible configurations to identify an optimum, we design and explore what one such configuration would require to meet these requirements and trace its implications. Some requirements can be met with more certainty than others: for example comparative costs can be estimated fairly accurately, but political feasibility far less so. The intention of the article is to illustrate what might be possible. All major technology transitions and transformations are associated with high levels of uncertainty and risk. So is inaction. Decarbonisation transition has the additional requirement of a limited time frame; waiting for certainty carries its own risks. So does missing the window: developing countries risk lock-in to another generation of exclusion from industrialisation unless configurations that serve both are acted on.

Section 3 describes the technology that makes geographic separation possible and the evidence for sweetspot cost advantages. Section 4 examines the challenges facing green iron production in both industrialised countries and developing countries. Section 5 proposes a configuration that addresses these challenges through collaboration across country and bloc boundaries and specifies the policy adjustments it requires. Section 6 offers recommendations for different actors. Section 7 concludes.

## 3. Green iron sweetspots

Hydrogen-based direct reduced iron ($H_2$-DRI) has emerged as a most likely technology for primary steel decarbonisation[10,11]. $H_2$-DRI enables geographic separation of ironmaking from steelmaking: a fundamental shift from blast furnace (BF) ironmaking technology that requires co-location with the basic oxygen furnace (BOF) steelmaking step.

Unlike BF where coking coal is used to produce molten iron that cannot be economically transported for transfer to the BOF, $H_2$-DRI uses hydrogen as the reductant to produce solid iron transportable as hot briquetted iron (HBI) to EAF steelmaking. Thus, production of green iron at sweetspots, using green hydrogen, emerges as a crucial option for reducing decarbonisation costs and rates[12–16]. There has been rapid progress in commercialising $H_2$-DRI technology over the past five years. Currently, 60% of global steel is produced via the BF route, 30% via the scrap steel-EAF route, while 10% of global steel production takes the DRI-EAF route[3].

An explicit proposal for geographic separation in the steel industry appeared first in peer-reviewed literature in 2020[17]. Initial analyses examined individual country opportunities: South Africa[18] and North Africa exports to European locations[19]. Subsequent studies expanded to global and international scales[12,13]. Recent granular regional techno-economic analyses provide credible quantified evidence. Detailed studies[14,15] examine potential HBI production and import costs across multiple sweetspot regions and importing countries. These analyses demonstrate substantial potential cost advantages: sweetspots can deliver HBI for steelmaking in Germany at 26% lower costs than local production of DRI in German locations using hydrogen pipeline infrastructure[14]. When incorporated into overall steelmaking economics, using imported green HBI leads to cost reductions of approximately 15%–20% for overall steelmaking at German locations[14]. Similar cost advantages exist for steelmakers in Republic of Korea and Japan sourcing HBI from Brazil, Australia, Saudi Arabia, and Egypt. Opportunities might also be possible for Chinese EAF steelmakers although cost analyses are not available.

Some steelmakers, including major producers in the EU, Japan, Republic of Korea, and China, face imminent decarbonisation choices with multi-decadal consequences: source green iron domestically, import iron ore plus hydrogen, or import HBI. Hydrogen imports create severe vulnerabilities through either ammonia conversion, storage, transport and re-conversion or long-distance hydrogen pipelines. HBI imports eliminate these risks: solid material ships via standard vessels, stockpiles cost-effectively at ambient conditions, and sources from multiple continents. Moreover, HBI requires importing only 65% of the mass of equivalent iron ore since oxygen comprising 35% of iron ore has been refined out at source.

The question is not imports versus self-sufficiency. Import dependence for iron units is the baseline condition for European primary steelmaking: the EU already imports virtually all iron ore required for primary steel. The relevant choices include the rate of transition to secondary steel (also complicated by a mixture of technology, economics, macroeconomy, and politics), and for remaining primary steel, the import configuration: iron ore plus hydrogen, or green HBI directly. The question is proportions of local production and imports, and under what terms.

## 4. Challenges for green iron production

Green iron costs 30%–50% more to produce than conventional iron in early commercial deployment[10]. This premium must be covered for commercial investments in green iron and steel production to proceed. Investments need to begin now and the 2025–2030 window is critical: investment decisions for multi-billion-dollar plants with 30–50-year lifespans will lock in geographic patterns, cost structures, supply chain configurations, and emissions profiles for decades.

Industrialised countries have responded with substantial policy support. The EU's package includes carbon pricing, legal net-zero targets, carbon contracts for difference (CCfDs), carbon border adjustment mechanisms, and approximately €10 billion in capital grants to green DRI projects so far[20], while the USA's Inflation Reduction Act (IRA) provides significant tax credits for low-carbon hydrogen production[21], though the policy environment has become uncertain[22].

EU states represent the most advanced policy implementers, with steel companies announcing over 30 commercial-scale $H_2$-DRI plants for construction by 2030[20]. Despite committed subsidies, few projects have reached final investment decision, and implementation is moving very slowly, especially given the rate of construction investment required to meet legally binding net-zero commitments by 2040–2045 in major steel-producing EU member states including Germany and Sweden[20]. The reason becomes clear in practice: even with capital grants covering upfront investment, companies realise that ongoing operational costs, particularly of hydrogen supply, remain structurally uncompetitive in many EU locations. Securing credible hydrogen operational subsidies to cover investment pay-back time is problematic.

ArcelorMittal's experience illustrates this. Despite securing €1.65 billion in subsidies from EU governments (€850 m France, €460 m Spain, €280 m Belgium, €55 m Germany), the company's European CEO indicated they cannot achieve economic viability with local hydrogen production[23]. The company acknowledged that importing green DRI would be economically superior for their steelmaking operations. Capital grants address initial investment but cannot overcome fundamental geographic cost disadvantages in ongoing production. Moreover, as Europe's IUSS saturates and steel supply shifts increasingly to recycling-based secondary production, domestically-located primary green iron capacity risks becoming stranded assets.

Industrialised countries are shifting structurally from primary steelmaking to secondary steelmaking based on scrap recycling. Iron-making's role in these economies is already diminishing. The choice is not domestic versus foreign iron-making; it is managed transition aligned with structural change, or subsidised resistance that defers and concentrates adjustment costs.

Current German CCfDs require green iron production to occur domestically[24]. This restriction blocks allowing CCfDs to support green steel production while sourcing green iron from locations where production costs are structurally lower. Political concerns about employment effects if ironmaking occurs offshore have emerged in high-level policy debates, reinforcing domestic production mandates. However, comprehensive empirical analysis of employment impacts across the full value chain has not yet been conducted.

In developing country sweetspots, limited fiscal space precludes funding the green premium. Domestic green steel markets are too small and fragmented for bankable offtake. Customer segments such as construction have less appetite for paying green premiums. Higher perceived risk increases capital costs. Investment based only on domestic government support and local markets is problematic.

## 5. Production chain configuration: an illustrative example

Given this situation, we propose a production chain configuration that meets the requirements: bankability, net benefits to participating actors and those funding from public funds, and political feasibility. We show how it works and what policy adjustments are necessary.

The challenges can be addressed and opportunities realised through a strategic partnership that distributes costs and benefits across the value chain, delivering substantial net benefits for all partners, including taxpayers funding subsidies and the broader economies in industrialised countries and developing country sweetspots. Political feasibility concerns have been raised regarding perceived "losses" — we address this below.

### Mechanism

The mechanism we have designed operates as follows. CCfDs are offered by auction to green steelmakers, revealing least-cost green steel investment solutions. An EU EAF steelmaker (or consortium) with CCfD backing contracts with a sweetspot producer for long-term green HBI supply through Green Iron Offtake Agreements (GIOTAs). The steelmaker provides what fragmented developing country markets cannot: a single large-volume contract, 20-year commitment, take-or-pay provisions, euro-denominated payment, and investment-grade credit rating. The sweetspot project becomes bankable without requiring developing country subsidies or domestic demand aggregation.

The sweetspot iron maker then offers long-term contracts to renewable energy and hydrogen suppliers, which could be islanded to ensure clean attribution. Trollip et al. (2022)[18] and Agora Industry (2025)[15] modelled islanded hydrogen supplies, yielding the comparative cost results cited earlier. Bankability cascades down the value chain: CCfD to steelmaker to iron maker to hydrogen and energy suppliers.

CBAM and CCfDs function as complementary instruments. CBAM applies costs to embedded carbon in imports: green HBI with zero or minimal embedded emissions faces no CBAM liability, while fossil-based alternatives bear full carbon costs. CCfDs separately cover the green production premium for domestic steelmaking.

Current German CCfD regulation[24] restricts support to domestic green iron production. This is a particular implementation choice, not fundamental to the broader policy architecture, which could conceivably cover imported green HBI. The essential policy framework is in place; implementation requires adjusting interpretation rather than creating new mechanisms. The challenge is political. CCfDs already allow imported hydrogen as an intermediate feedstock; the same logic applies to HBI. So far subsidies have favoured incumbent BF/BOF integrated steelworks. Existing EAF steelmakers, with different interests, can lead the decarbonised primary steel transition.

### Political feasibility

Political feasibility concerns have been raised, often framed around "job losses", "security of supply", and "sovereignty". These framings require scrutiny. Primary iron-making in industrialised countries is diminishing as the structural shift to secondary steel proceeds. BF/BOFs will close. Claims of "losses" are more accurately assessed against this trajectory, not against a status quo that is in fundamental flux. This configuration involves decisions about where to build new capacity — new investments, new jobs using a new production technology and new feedstocks — not closure of existing facilities and "losses". Some green iron investment will locate in the EU where conditions favour it; some will likely be imported from sweetspots. A further argument for domestic production is to demonstrate the technology in a familiar institutional environment before international rollout; this does not contradict our proposal. Preparatory steps for sweetspot partnerships can proceed in parallel with domestic demonstration.

Ironmaking accounts for roughly 10% of steel sector jobs; 90% are in steelmaking and downstream activities, which this configuration retains and strengthens in industrialised countries[25]. Where domestic green iron production makes strategic and economic sense, there are good reasons for it; the current

CCFD regulation simply does not provide for imported green HBI.

Security of supply and self-sufficiency claims similarly warrant examination. The EU already imports virtually all iron ore for primary steel production and this dependence is unavoidable. The question is which mix of imports (how much iron ore vs. how much HBI), not whether to import. As noted above, HBI offers superior supply security to hydrogen imports.

Political feasibility is not a fixed parameter but a dynamic condition, shaped through action. Important aspects of feasibility are created through demonstration and coalition formation, if conditions are favourable enough. The relevant question in our example is not whether it is feasible but under what conditions it might become so. Political feasibility claims warrant scrutiny on all sides. In North–South policy discourse, industrialised country political constraints are often treated as binding conditions that others must work around, while developing country political constraints are treated as problems to be solved[26]. Deep decarbonisation requires flexibility among all partners. Our proposed first-mover initiative reveals specific costs, benefits, and implementation pathways and what might be required to build political feasibility.

This approach is well-grounded in historical precedent. Transformations of capital-intensive industries have rarely proceeded through comprehensive pre-planned frameworks. In the steel industry, major transformations came from private innovators: Bessemer blast furnace (1856), Siemens open hearth (1865), Durrer basic oxygen furnace (1948). EAF mini-mills emerged through companies like Nucor demonstrating viability in the 1960s–70s, eventually capturing over 70% of US steel production against incumbent resistance which is "normal", well understood and expected[27]. Coalitions of first movers are recorded as effective bottom-up policy makers[28–30]. The challenge is to get the ball rolling fast enough to meet Paris Agreement obligations, not solve for the entire system.

**The benefits vary in their level of proof**

*Directly demonstrable:* The steelmaker gains lower-cost input; the sweetspot producer gains bankable offtake enabling investment otherwise inaccessible.

*Plausible through economic reasoning:* Lower input costs enhance competitiveness for green steel producers, with benefits flowing to steel-consuming industries and the broader economy. Decarbonisation is achieved at lower public cost. Total system costs are reduced. Renewable energy capacity built for green iron export becomes available for broader industrial development.

*System-level, harder to prove and perhaps not possible to prove definitively:* EU steelmakers gain lower-cost green iron inputs; a more competitive EU green steel industry becomes sustainable without ongoing subsidy. The developing country industrialises on a decarbonised pathway through its own resource endowments — not aid, not concessional finance, but commercial partnership on competitive terms. Global decarbonisation proceeds at lower total cost. Lower cost enables faster deployment, meaning greater cumulative emissions avoided.

We do not have, and likely never will have, a complete macroeconomic model that proves net benefits to everyone's satisfaction. What we can demonstrate is that the partnership enables outcomes unavailable to either party acting alone. Many of these benefits are substantial and plausible. A reasonable case exists for prioritising overall economic benefits over protecting a small concentrated industry. Where losses are concentrated, just transition mechanisms can compensate, as with the coal industry.

Guinea illustrates the least developed country (LDC) pathway. Iron ore resources and renewable energy potential exist, but minimal industrial infrastructure. Export revenue funds infrastructure development while building industrial capacity. Small initial EAF mini-mills use the green iron to establish local primary steel production and with export revenues become a catalyst for broader industrialisation. Other sweetspots—Brazil, Australia, Saudi Arabia, Egypt—offer similar resource advantages with more developed existing infrastructure.

Subsidies have been announced and public funds committed. The technical and economic foundations exist. What remains is arrangements where willing actors, focusing on their own value propositions and the credibilities of their direct counterparties, can bootstrap the transition.

## 6. Recommendations

The primary recommendation works within existing policy architecture: do not wait for new comprehensive international frameworks before implementation begins. The necessary policies are already in place; they require adjustment rather than new development. The Paris Agreement's nation-state architecture represents a hard-won diplomatic achievement. While not designed with global production chains primarily in mind, it can be made to work as described in this article.

**For industrialised country governments:** Modify existing subsidy mechanisms (CCfDs, Climate Contributions[31]) to allow offshore green iron production to qualify for support currently restricted to domestic production. This requires solid credible independent economic analysis, particularly comprehensive assessment of net employment effects across the full value chain, examining whether lower input costs for steelmaking and downstream industries offset ironmaking job effects, and effective engagement with affected constituencies. Such analysis would likely demonstrate delivery of decarbonisation at lower public cost while enhancing steel sector competitiveness.

**For steelmakers in industrialised countries:** Issue competitive tenders for long-term GIOTAs to source lowest-cost HBI from sweetspot suppliers. Consumption-based CCfDs focus the transition on competitive EAF steelmaking and downstream activities where jobs and value are concentrated.

**For governments in sweetspot regions:** Create enabling conditions for $H_2$-DRI investments: streamlined project approval, infrastructure coordination, supportive regulatory frameworks. Revenue from green iron exports funds broader infrastructure and industrial development.

**For development finance institutions:** De-risk investments in sweetspot $H_2$-DRI projects. Long-term GIOTAs with creditworthy off-takers substantially reduce risk and make projects bankable[32].

**For industry actors across the value chain:** Proceed based on own value assessment and commercial interests. Each actor evaluates direct counterparties' credibility through binding commercial arrangements. Multiple partnership configurations can develop in parallel.

**China's situation warrants separate consideration:** Chinese steelmakers have invested heavily in EAF capacity (~150 Mt), but utilisation remains around 60% due to scrap constraints[33,34]. China's in-use steel stock has not yet reached saturation levels that would generate sufficient scrap for a full shift to secondary production. China is also pursuing $H_2$-DRI domestically: HBIS has commissioned a 600,000 t/y hydrogen-enriched DRI plant and already exports green steel to Europe, while Baowu plans a 1 Mt $H_2$-DRI facility[35]. China leads globally in electrolyser capacity and renewable energy deployment[35]. Whether Chinese domestic $H_2$-DRI could compete with sweetspot imports on cost remains uncertain. Domestic DRI-based steel can sometimes be less expensive than imported HBI due to China's substantial renewable potential, though geographic mismatch between renewable-rich western regions and coastal steelmaking centres adds complexity[36].

Notably, Chinese state-owned enterprises are major partners in developing sweetspot resources. For example, the Simandou project in Guinea involves Rio Tinto partnered with Chalco Iron Ore Holdings (a consortium led by Chinalco with Baowu participation), while the adjacent Winning Consortium Simandou (WCS) mining concession has Baowu as a 49% partner[37]. This suggests Chinese strategic interest in securing high-grade iron ore from sweetspots, potentially for future green HBI production either for export to China or for third-country markets. The dynamics merit further analysis but do not contradict our central argument. Depending on comparative costs, Chinese investment in sweetspot iron ore supports the thesis that these locations could play a significant role in steel decarbonisation, whether serving Chinese domestic demand or competing in global green steel markets.

## 7. Conclusion

Steel decarbonisation is required. But carbon pricing has not delivered sufficient incentive. Capital subsidies have not overcome ongoing cost disadvantages. The situation has changed. Direct reduced iron technology enables geographic separation of ironmaking from steelmaking, and in many cases green iron imports from sweetspots are substantially lower cost than local production at major steelmaking locations in industrialised countries. New options are available.

The configuration proposed here realises one such option for combinations where it makes industrial, economic, and strategic sense. For some EU steelmakers, sourcing green iron from sweetspot locations would result in lower input costs and enhanced competitiveness. For EU public funders, it achieves decarbonisation at lower cost while building a competitive green steel industry. For developing country producers, it provides bankable offtake enabling investment otherwise inaccessible; the CCfD-backed contract structures solve the challenge of limited fiscal space and fragmented markets.

Once export-oriented green iron facilities are operating, they could become the foundation for a domestic decarbonised steel sector that leapfrogs the conventional carbon-intensive route. The export partnership provides the anchor investment; the anchor investment provides the foundation; the foundation enables a development trajectory otherwise foreclosed.

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## Author contribution statement

The sole author was responsible for the conception, design, analysis, and interpretation of the work; drafted and revised the manuscript; approved the final version; and is accountable for all aspects of the work.

## Data availability

Not applicable.

## Use of AI statement

During the preparation of this work, the author used Claude.ai solely for language editing. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

## Declaration of competing interest

The author has no competing interests to declare that are relevant to the content of this article.

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