Achieving climate-neutral steel by 2050

How the steel sector can shift from coal-based to clean production

Agora Industry

POLICY BRIEF

1 **Emissions from steel production – responsible for roughly eight percent of global greenhouse gas emissions – plateaued in 2021, signaling a potential turning point and a strategic opportunity to accelerate the transition towards green steelmaking.** While this slowdown is due mainly to lower output rather than cleaner production routes, the sector now faces a pivotal moment: with 70 percent of blast furnaces due for reinvestment in the next decade, capital can be redirected towards near-zero technologies, turning the current moment into a springboard for green industrial growth.

2 **Hydrogen-based direct reduced iron (H_2-DRI) has become the leading technology for decarbonising primary steel.** Announced capacity totals 89 million tonnes (Mt), with several projects under construction. While the proof of concept for H_2-DRI is clear, technology development must be accelerated substantially to reach climate-neutral steel by mid-century. While low-carbon, scrap-based steelmaking could meet roughly half of 2050 demand, the rest must shift to H_2-DRI – adding up to 1,000 Mt of near-zero ironmaking capacity.

3 **Achieving this large-scale H_2-DRI capacity increase – up to 50 Mt a year by the late 2030s – will require international collaboration and domestic policy action across the value chain.** While the role of broad multilateral cooperation evolves, progress can be built through pragmatic partnerships and alignment among governments, international bodies, steelmakers and buyers – through establishing clean value chains or clear standards for green iron and steel. Domestically, supportive policy frameworks can accelerate investment, reduce risk and stimulate demand to create a viable business case for climate-neutral steel.

4 **Once static among heavy emitters, the iron and steel sectors now have producers emerging as global leaders in transforming industry.** Countries with established steel industries can build resilient, next-generation steelmaking by defining clear pathways to climate neutrality. Emerging producers have the opportunity to develop competitive, clean steelmaking industries from the outset – driving a global shift towards green heavy industry. As a major anchor for green hydrogen demand, the steel sector's transformation can also create multiplier effects that unlock investments across other industries.

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Policy Brief
Achieving climate-neutral steel by 2050. How the steel sector can shift from coal-based to clean production

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Content

List of abbreviations

Term	Explanation
AEL	Alkaline iron electrolysis
BECCS	Bioenergy carbon capture and storage
BF	Blast furnace
BOF	Basic oxygen furnace
Capex	Capital expenditures
CCS	Carbon capture and storage
CO	Carbon monoxide
CO_2	Carbon dioxide
CS	Crude steel
DACCS	Direct air carbon capture and storage
DR	Direct reduction
DRI	Direct reduced iron
EAF	Electric arc furnace
EOR	Enhanced oil recovery
EU ETS	European Union emissions trading system
Fe	Iron
GHG	Greenhouse gases
GJ	Gigajoule
GWP	Global warming potential
H_2	Hydrogen
HBI	Hot briquetted iron
LNG	Liquefied natural gas
MOE	Molten oxide electrolysis
Mtpa	Megatonnes per annum
NG	Natural gas
NZE-scrap-EAF	Near-zero emissions scrap electric arc furnace
Opex	Operating expenditures
OSBF	Open slag bath furnace
PGH	Process gas heater
SAF	Submerged arc furnace
SMELT	Smelter
t CO_2eq	Tonne of carbon dioxide equivalent
TRL	Technology readiness level
USD	US dollar

A note on terminology

Climate-neutral, near-zero and **net-zero** steel are used relatively interchangeably throughout the text – although 'near-zero' is used to describe the technologies (e.g., hydrogen-based DRI) and 'net-zero' to describe the final 2050 emissions scenario. We are basing this on an International Energy Agency understanding that:

"'Near-zero' emissions is specifically reserved for technologies that are already compatible with an energy system at net-zero emissions. Distinctive recognition of such performance already today is critical, particularly given the higher risks and costs that come with development and early deployment of innovative technologies. Incentivising these technologies now can help kick-start market uptake, paving the way to eventual widespread diffusion." (IEA, 2024)

We make a distinction with **'lower-emission'** technologies like fossil gas-based DRI and blast furnace-blast oxygen furnace (BF-BOF) with carbon capture and storage (CCS) that can lower emissions compared to unmitigated BF-BOF routes but are not compatible with an energy system at net-zero emissions.

Executive summary

Steel is the backbone of the modern economy – and for the climate transition. Accounting for roughly nine percent of global carbon dioxide (CO_2) emissions, the sector cannot remain an afterthought: a decisive, near-term shift in how iron and steel are made is essential for climate neutrality by 2050. This policy brief distils new Agora analysis and stakeholder input to create a practical, value-chain policy roadmap for an orderly and credible path to decarbonised steel whilst boosting competitiveness.[1] As emissions from steelmaking are reduced, pressures around costs, trade and energy can also catalyse investment and jobs, strengthen supply chain resilience and open growing markets for green steel, supporting sustainable, fair growth towards climate neutrality.

The story on emissions in the steel sector since 2019 is both encouraging and cautionary; the emissions curve is bending down earlier than expected, but not nearly fast enough. Global steel emissions appear to have peaked in the early 2020s and come down by about 1% since 2021. However, this is not because of increases in decarbonised production facilities, but instead due to a reduction in global production. Production has followed a drop in demand for steel in the Chinese construction sector lower industrial demand in Europe and Japan. This trend seems to be continuing into 2025, where we see steel demand slightly below the same period of 2024.

Globally, the sector still relies predominantly on coal-based blast furnace-basic oxygen furnace (BF-BOF) (70 percent), with a smaller share from scrap-based electric arc furnace (EAF) (22 percent) and direct reduced iron (DRI)-EAF (8 percent). That production route distrubution has remained almost unchanged since 2021, meaning that as soon as the demand for steel starts increasing, production and emissions will follow. For a durable reduction pathway, stronger policy is needed to incentivise decarbonised production facilities that can replace the integrated blast furnace route and durably bend the emissions curve decisively downwards.

Looking to 2050, the destination is clear even if the exact route varies by region. Scrap-based steel can likely deliver around 40 to 50 percent of global output by mid-century. That would mean production of around 1,000 million tonnes (Mt) per year in a world demanding similar amounts of steel to today (2,000 Mt per year). This would require collection, sorting and quality standards (for example copper) to improve, and circular design accelerates. The remainder must be clean with primary steel.

Among primary routes, hydrogen-based DRI-EAF is the only commercially mature option with a credible line of sight to deep decarbonisation at scale this side of 2050. Primary electrolytic "electro-steel" routes are promising but unlikely to supply more than a modest wedge by 2050 from today's technology readiness level. By contrast, BF-BOF plus carbon capture and storage (CCS) faces unresolved capture-rate, cost and infrastructure challenges; where near-zero product standards tighten, it is unlikely to carry a major share. Fossil gas DRI (NG-DRI) can help as a halfway-step (especially where methane leakage is tightly controlled) but needs to be paired with a clear pathway to switch-over to clean hydrogen.

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[1] This paper builds on analysis published by Agora Industry in 2023 with the 15 Insights into Global Steel Transformation (Agora, 2023). The analysis is based on Agora Industry Global Steel Transformation Tracker, GEM and SEI. This includes all projects that are near-zero emissions compatible. NG-DRI → H_2-DRI 2030 covers projects that will start operation of their DRI plants with fossil gas but have publicly communicated the intention to use either 100 percent low-carbon hydrogen or a significant share of low-carbon hydrogen by 2030. COG-H_2-DRI refers to coke oven gas hydrogen DRI and refers to projects in China that are using H_2-rich coke oven gases from the blast furnace. NG-DRIH_2 → DRI projects refer to projects that mention the possibility to use low-carbon hydrogen in the future without a concrete objective to do so by 2030.

If hydrogen-DRI is the workhorse of steel decarbonisation, it is important to understand the scale. Our analysis indicates the world must lift DRI capacity additions to approximately 50 Mt per year after 2030 (on a rolling basis), with three- to four-year project build times implying a continuous pipeline entering construction from the mid-2030s onward. That is a formidable but not unprecedented build-rate, comparable to historical blast-furnace surges in the early-2000s in China that delivered around 100 Mt new BF-BOF capacity per year. The binding constraints are known: low-cost renewables and grids, bankable hydrogen supply (or green iron/HBI trade as "embodied hydrogen") and DR-grade ore secured through new mines, beneficiation and logistics.

This is where market design and policy determine outcomes. The current scarcity of final investment decisions (FIDs) in hydrogen and DRI reflects missing offtake and risk-sharing frameworks rather than technology availability. Steel can be the anchor offtaker that turns a large share of today's green hydrogen project pipeline into reality – if governments and buyers deploy the right tools: (carbon) contracts for difference to bridge operating cost gaps, green public procurement to create a price-discoverable premium, product-level standards and monitoring, reporting and verification (MRV) to define "near-zero", and scrap quality/circularity standards to lift the secondary share without blunt export bans. For many import-dependent regions, HBI trade, produced where ore and renewables are abundant and shipped to EAFs—can accelerate the transition while domestic hydrogen infrastructure matures. This will require international trade and investment partnerships, de-risking for many of the projects in high capital cost regions and financing instruments to get started.

Finally, industrial policy matters as much as process engineering. Overcapacity remains a systemic risk that erodes margins and deters clean investment; a cooperative agenda on capacity discipline, standards mutual recognition and plurilateral carbon-leakage solutions is overdue. The prize for getting this right is large: a resilient, shock-proof steel base that underpins clean electricity, clean mobility and clean manufacturing – and that competes on cost, CO_2 emission reductions and reliability.

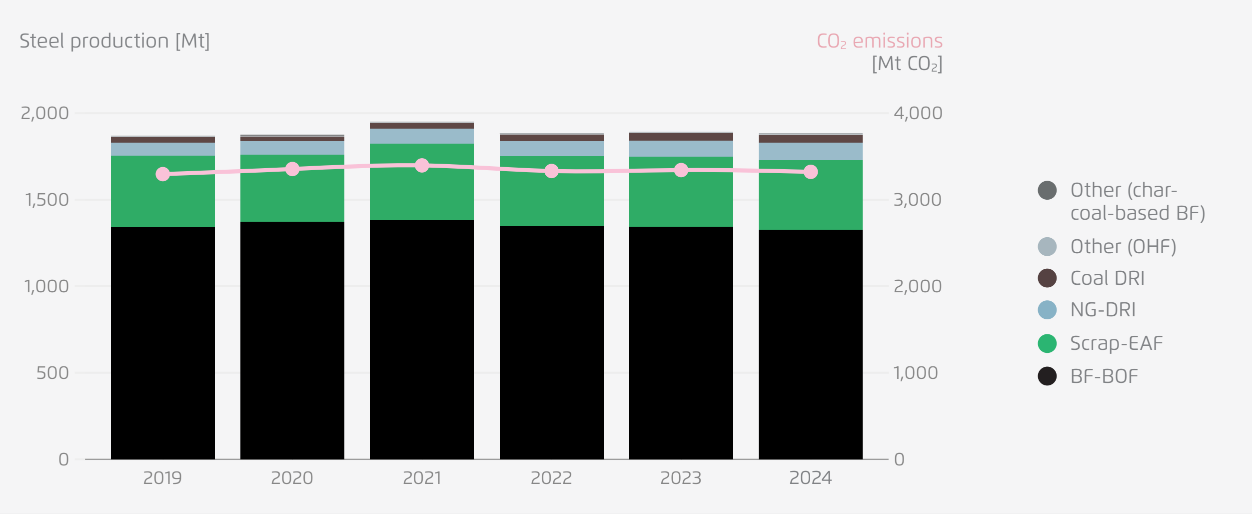
The task is difficult but doable. If governments and industry move in concert – scaling scrap circularity, deploying hydrogen-DRI at speed, building the enabling energy and materials infrastructure and establishing credible demand – steel can decarbonise on timelines consistent with climate safety while strengthening industrial competitiveness and resilience.

Chapter 1: Emissions have peaked in the global steel sector

Steel emissions peaked in 2021 and since plateaued. However, this is due to a sluggish economy rather than a shift towards near-zero steel making.[2] Steelmaking route shares have been strikingly stable since 2019: the global system remains dominated by coal-based BF-BOF, with a smaller wedge of DRI-EAF and scrap-EAF. In fact, despite many 1.5 °C scenarios anticipating a rapid surge in secondary steel, scrap-EAF output has barely risen since 2020, underscoring how little of today's emission dip is due to structural change.

Global crude steel production by production route and steel sector CO_2 emissions, 2019–2024

→ Fig. 1



Agora Industry (2025) based on the World Steel Association (2024). From 2019 to 2024, BF-BOF route contributes ~90% of total CO_2 emissions annually.

Looking forward, based on assumptions about demand growth for steel and the current investment pipeline, coal-based steel production is already undergoing major regional shifts.[3] Our 2030 outlook brackets a plausible landing point around 5 percent below 2020 emissions under current momentum. The decomposition highlights three levers that matter more than any others:

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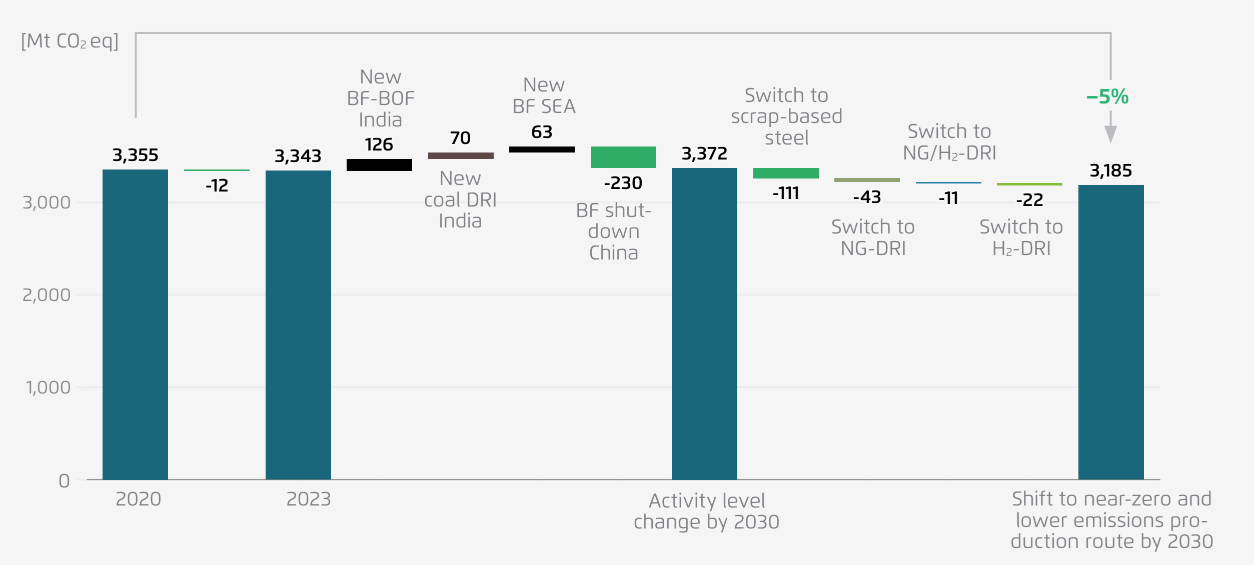
[2] Our bottom-up assessment focuses on scope 1 emissions at the plant gate, using route-specific intensities from the literature. It does not reallocate power sector emissions; consequently, absolute values are not directly comparable with top-down inventories (e.g., IEA), but the relative ranking and levers are robust and action-relevant.

[3] Demand assumptions were based on the **Facility-level global net-zero pathways under varying trade and geopolitical scenarios: final technical and policy report for the net-zero steel project**, Net Zero Industry, 2024. It sets steel demand to 2050 using a top-down econometric model (GDP/capita, population, infrastructure needs) and shows the growth path by region in **Figures 13 to 15** (historical and forecast demand; scrap availability).

1. In China, around 100 Mt of coal-based capacity is expected to close as older blast furnaces retire, but this decline will be partly offset by growth elsewhere, with India adding roughly 60 Mt of new BF-BOF capacity, an additional 30 Mt of coal-based DRI and another 30 Mt of BF-BOF capacity across Southeast Asia. Overall, the global map of coal-based steelmaking is moving south and west, even as China scales back.
2. A wave of conversions from integrated blast furnaces to scrap-based EAFs is underway, reducing total BF-BOF steelmaking capacity by about 50 Mt. These switches mark a growing trend towards secondary steel production, which significantly cuts carbon emissions compared to the coal route by reusing existing material streams.
3. At the same time, producers are replacing blast furnaces with near-zero and lower-emissions iron routes. About 20 Mt of capacity is shifting from BF-BOF to hydrogen-ready or natural-gas-based DRI paired with EAFs, with the gas-based plants designed to convert to full hydrogen operation later in their lifetimes. An additional 30 Mt is expected to move to fossil gas-based DRI (NG-DRI) without a defined hydrogen conversion timeline, signaling a transitional step towards deeper decarbonisation.

2030 Outlook: projected CO_2 emissions development of the steel sector → Fig. 2



Agora Industry (2025) based on perceived trends in key regions regarding coal-based steel production as well as in-depth analysis of the near-zero steel announcement pipeline.

These investments into near-zero steelmaking facilities determine whether the sector hugs an APS (around 1.7 °C) or slides back toward STEPS (around 2.5 °C), which would raise emissions by 8 percent by 2030. Today's evidence suggests APS remains within reach, but the NZE requirement on the order of an approximately 23 percent drop by 2030 demands a markedly faster pivot in both route mix and project delivery.

Crucially, the projections also warn against complacency. Steel cycles quickly: if demand rebounds without parallel route shifts, emissions could climb again. The question for policy is therefore not whether peak has occurred, but what locks in the decline. Three priorities emerge:

- → Unlock secondary steel at scale by raising scrap collection, sorting and quality standards (such as on copper limits and traceability), so the secondary share grows in reality and not just in scenarios.
- → Accelerate primary route conversion by bringing forward DRI-EAF capacity and ensuring credible pathways from NG-DRI to green hydrogen, avoiding a halfway transition.
- → Anchor investment with demand signals (near-zero definitions, product-level standards and green public procurement) so today's announcement pipeline translates into FID-backed projects rather than deferred plans.

Bottom line: the sector is past its peak, but for the wrong reason. To turn this cyclical dip into a structural decline, policy must swing the route mix decisively toward scrap-EAF and hydrogen-ready DRI-EAF before the next upswing in demand. Today's near-zero steel announcements to build out more EAFs and hydrogen-based DRI would already allow for some decrease. In the short term, these projects need policy to turn from announcements to FID. Looking ahead, a policy mix is needed to build a further ~900 Mt of clean primary steel production by 2050 to set us on a path to net-zero steel by mid-century.

Chapter 2: Next-generation steelmaking

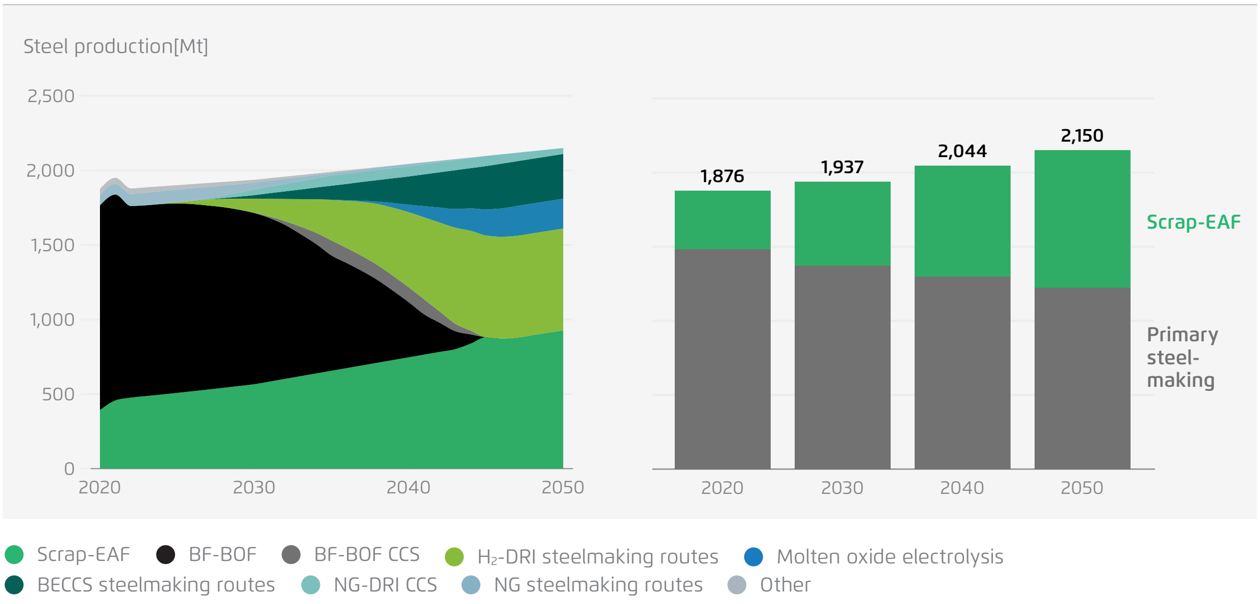
The role of scrap in decarbonising steel

Scrap-based steel should be a central pillar of the steel industry's decarbonisation strategy, but recent market data shows the shift has been slower than many studies anticipated for the early 2020s. Globally, the EAF share edged up only marginally, from about 28.6 percent in 2023 to roughly 29.1 percent in 2024, while industry statistics indicate that actual scrap melting fell year-on-year in 2024. In Europe, the EAF share hovered around the mid-40s (around 44 to 45 percent) rather than breaking decisively higher, underscoring that policy intent has not yet translated into a structural surge in secondary steel output.

In the coming decades, the potential remains substantial. Multiple assessments converge on a world in which scrap supplies can meet roughly 45 to 50 percent of steel demand by mid-century, consistent with our earlier estimate of around 43 percent and around 950 Mt of scrap-based steel in 2050 under an approximately 2.15 gigatonne (Gt) demand case. Independent modelling brackets total 2050 steel demand between around 1.9 and 2.5 Gt, (The Net-Zero Industry Project, n.d.) implying that even on optimistic scrap trajectories the system still requires on the order of around 1 Gt of primary steel in 2050. In other words, rising scrap availability, driven by the gradual turnover of long-lived stocks in buildings and infrastructure, will carry a larger share over time, but not enough to eliminate the need for near-zero primary routes.

Steel sector pathways to climate neutrality: technology mix and global steel production by route, 2020–2050

→ Fig. 3



Agora Industry and Wuppertal Institute (2023): 15 insights on the global steel transformation

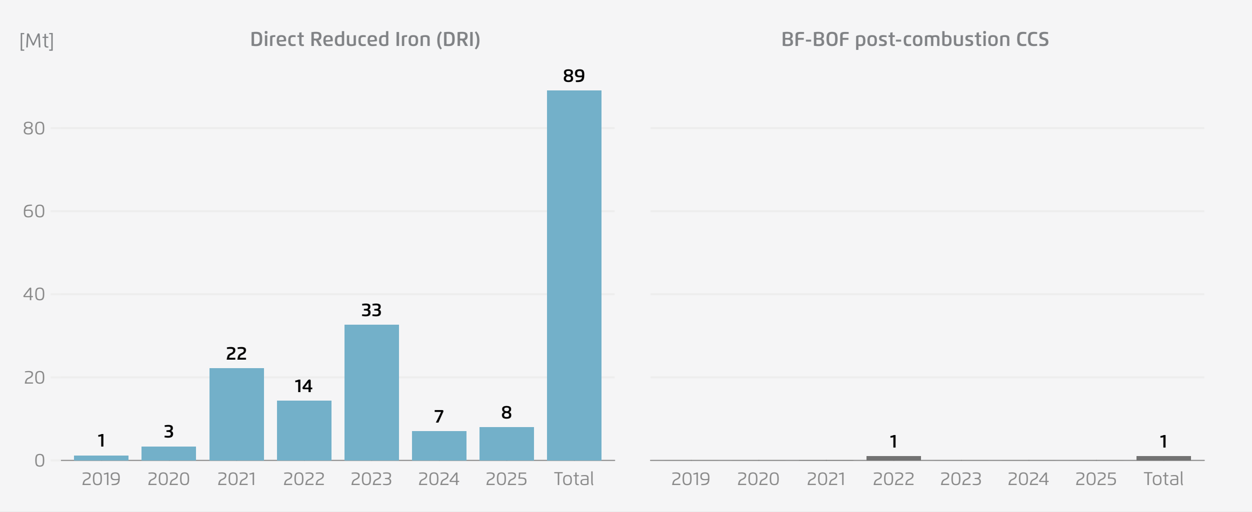
The role of post-combustion CCS on an integrated blast furnace route

For years, the prospect of redesigning and retrofitting blast furnaces with CCS was hailed as the solution for reducing carbon emissions in the sector. Despite focused efforts via several major research projects, including in the EU and Japan, the evidence that CCS is a viable option for deep decarbonisation of primary steel is relatively thin. CCS on blast furnaces faces a number of technological, economic and regulatory risks.

One key challenge is that blast furnace-based steelmaking sites have multiple sources of carbon emissions, which means that adding carbon capture to multiple streams can hit techno-economic limits: even with an optimistic assumption of 90 percent capture on the main stacks, for site-wide capture on BF-BOF it is unlikely that more than 70 percent of emissions can be captured, leaving around 0.6 tonnes of CO_2 per tonne of steel. At a typical 5 Mt per year plant, that still means around 3 Mt of CO_2 each year. Much of the remainder sits in dilute streams, such as sinter off-gas, where capture becomes increasingly costly and technically challenging.

Meanwhile, investment decisions on the ground into real industrial projects show that CCS on the BF is currently a non-starter. By 2030, the global pipeline for hydrogen DRI totals around 89 Mt (with around 20 Mt planning 100 percent renewable hydrogen from day one), while commercial-scale BF-BOF-CCS amounts to just 1 Mt. Real projects on CCS remain tiny: Tata Jamshedpur captures only around 5 tonnes per day for on-site reuse, and ArcelorMittal's Dunkirk DMX pilot aims at 0.4 kilotonnes per year on the way to a prospective 1 Mt per year.

2030 pipeline of near-zero steel announcements → Fig. 4

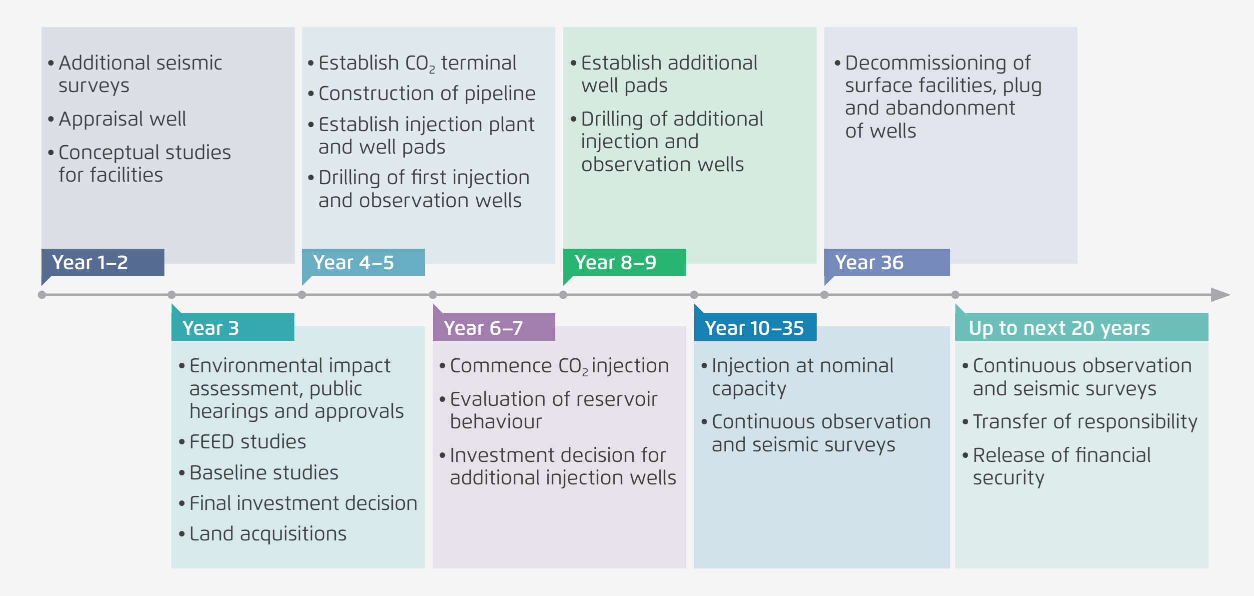


Agora Industry (2023)

Furthermore, CCS on a blast furnace does nothing to address emissions from upstream coal mining. Methane emissions from coking coal mining account for some 300 Mt CO_2eq (based on a 100 year global warming potential) to 900 Mt CO_2eq (based on a 20 year climate impact). This comes at a time when methane emissions are increasingly being scrutinized by regulators and scope 3 emissions are part of the scope of various green steel standards. This means that coal-based steel with CCS faces a real offtake risk on green markets.

The practical hurdles for CCS at such a large scale are formidable. Building storage takes time: eight to ten years from studies to injection at nominal rates, before counting permits and network build-out. Geological risks often only arise once the injection is underway, leading to potential unexpected cost increases or a reduction in capacities. Most steel sites are unlikely to be in close proximity of suitable storage sites, and there is currently no large-scale CO_2 transport infrastructure to speak of. Developing one-off infrastructure raises costs and risk, and major question marks on costs, regulation and risk-allocation remain. Meanwhile, experience across Europe show that costs associated with the transport and storage components of the CCS value chain are often underestimated in studies; early data emerging from projects moving from planning to implementation frequently reveal significantly higher costs than initially projected.

Timeline to develop and operate onshore CO_2 storage → Fig. 5



Agora Industry (2024), based on Danish Energy Agency (2021)

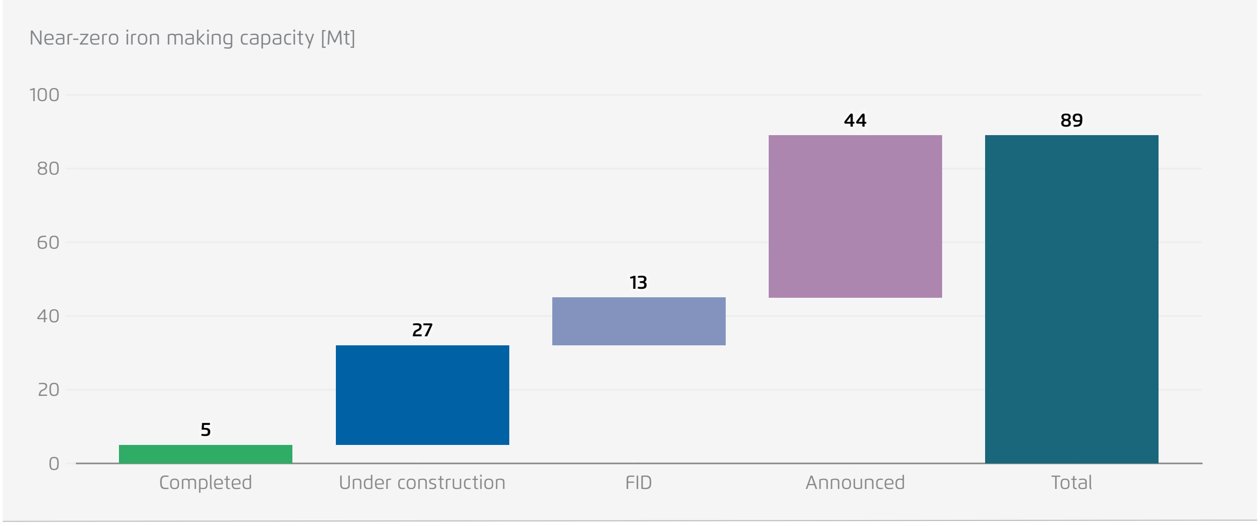
When firms must choose, they move away from CCS on blast furnaces (see figure 4). The economics reinforce this: by 2030, BF-BOF-CCS and NG-DRI could sit in a similar cost range, but DRI is hydrogen-ready and can reach near-zero as green H_2 scales. On the other hand, BF-BOF-CCS locks in the residual emissions of approximately 0.51 tonnes CO_2 per tonne (in the best case when upstream coal mine methane emissions are ignored) and offtake risk under emerging green steel labels.

The role of DRI with renewables-based hydrogen as a feedstock

Hydrogen-based DRI is not a distant promise; it is already the centre of gravity for real investment decisions. Our latest update of the global near-zero project pipeline totals about 89 Mt of announced DRI capacity by 2030, reflecting companies' revealed preferences when forced to choose a decarbonisation route. Earlier tracker snapshots showed 84 to 94 Mt rising quickly, while BF-BOF with post-combustion CCS barely registered, at roughly 1 Mt by 2030. This divergence is visible in Agora's pipeline charts and underlines where capital is actually flowing.

Breakdown of near-zero steel announcements, 2030

→ Fig. 6

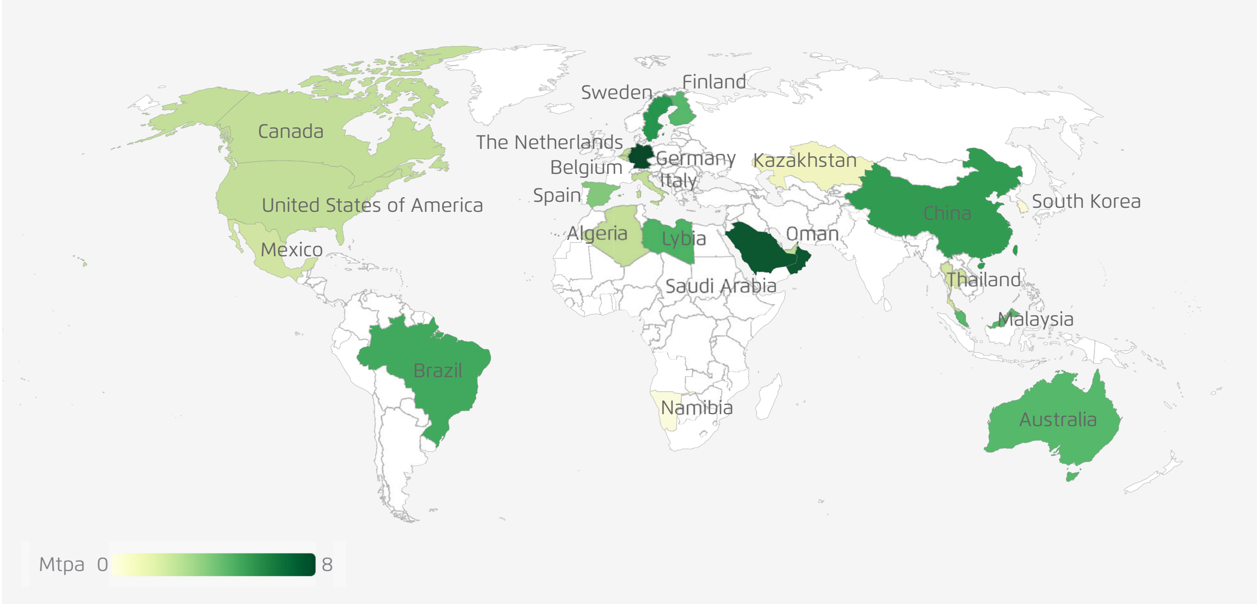


Agora Industry (2025). FID = Final Investment Decision

One reason is maturity. DRI has been deployed for decades on fossil gas, and the hydrogen-ready evolution is already on an industrial scale. HBIS commissioned a 0.6 Mt hydrogen-ready DRI-EAF line in China in 2023. The first commercial plants designed to run on 100 percent renewable hydrogen are scheduled in Spain, Sweden and Germany in the mid-2020s. These examples show hydrogen DRI-EAF is market-ready this decade, not a 2040s bet.

2030 near-zero steel announcement pipeline by country

→ Fig. 7



Agora Industry (2025). Part of the DRI plants were considered near-zero as the project descriptions describe moving to renewable hydrogen after an initial phase running on fossil gas which would lower the carbon intensity of the products significantly.

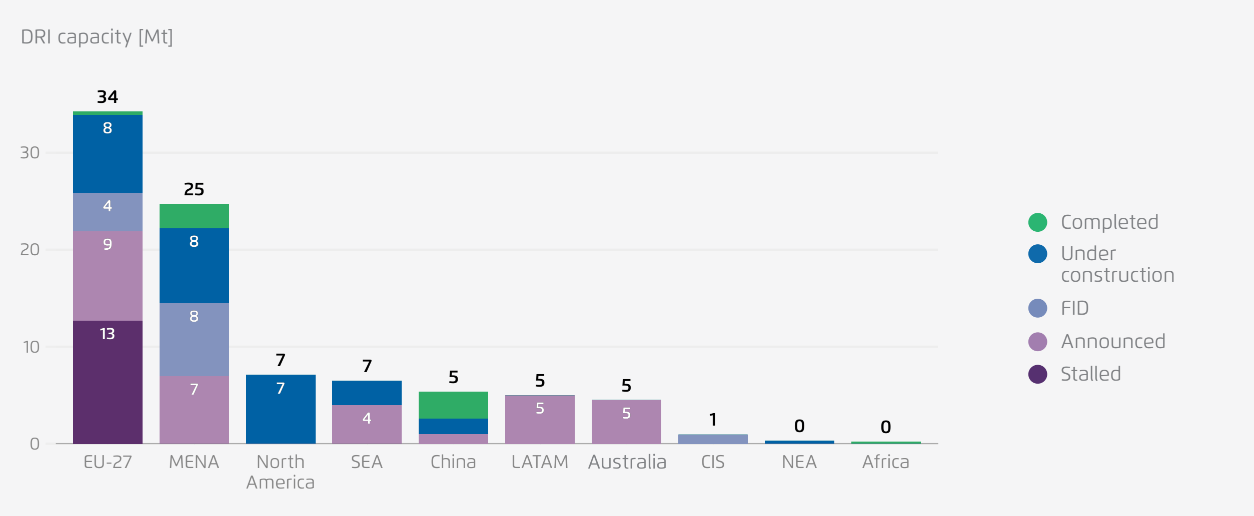
The emissions case is even stronger. In Agora's comparative analysis, hydrogen DRI-EAF achieves up to a 100 percent reduction versus BF-BOF when run on renewable hydrogen and power, with process sheets showing residual fossil emissions of around 0.01 tonnes CO_2 per tonne of crude steel. By contrast, retrofitting BF-BOF with post-combustion CCS typically tops out around 73 percent capture for the whole site due to multiple dilute sources, leaving a high residual that standards will struggle to accept as "near-zero". DRI, uniquely, can start on fossil gas and ratchet to 100 percent hydrogen, tightening emissions over time.

Finally, hydrogen DRI unlocks a practical industrial model. Because DRI can be briquetted (HBI) and shipped, countries rich in renewable energy and iron ore can export green iron, while importers run EAFs or smelter-BOFs, lowering system costs and avoiding the losses and infrastructure of shipping hydrogen itself. Agora's scenarios show this trade can be a win-win and that prioritising steel for a modest share of low-carbon hydrogen supply is feasible; the larger near-term bottleneck is scaling DRI engineering and construction capacity, not the technology itself. This is why, when decisions are due, companies keep choosing hydrogen-based DRI.

Not all of the 89 Mt of announced projects have made it to FID. The EU and MENA regions are clearly winning the race towards creating large pipelines of decarbonised iron production. The EU has 8 Mt of capacity under construction, a further 4 Mt that has reached FID and another 9.2 Mt that is awaiting investment decisions. In MENA, 2.5 Mt have already been completed, 7.7 Mt are under construction, 7.5 Mt have reached FID and a further 7 Mt are in the pipeline waiting for FID. For the EU, the main driver of this build-out has been the EU's ambitious climate policy. For MENA, the main driver has historically been access to cheap fossil gas, but increasingly it is also the potential for globally competitive low-carbon hydrogen costs that will make it a hub for near-zero iron and steel production (see figure 8).

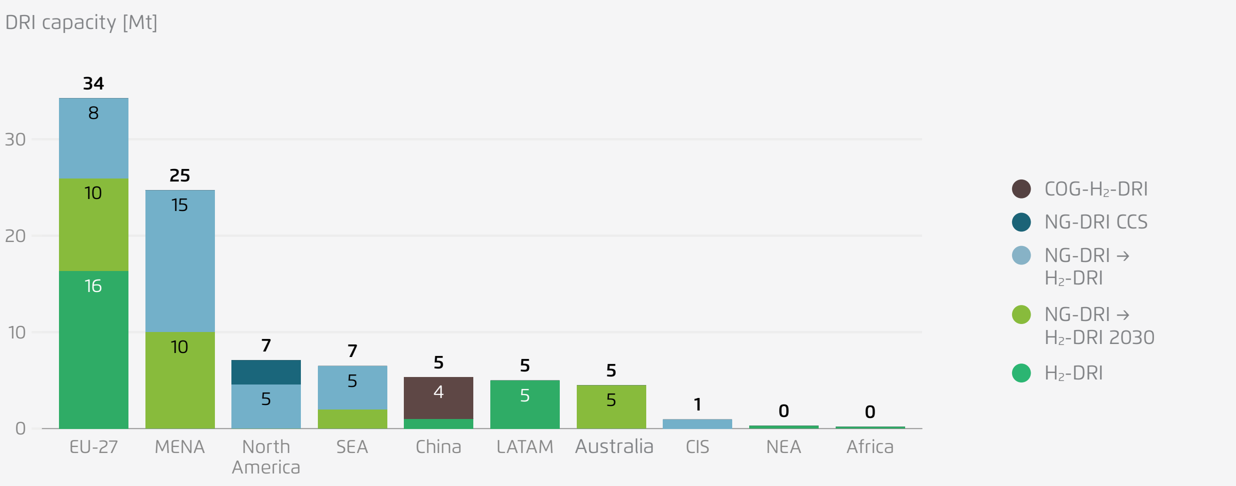
However, when we look at the proposed feedstock for these projects, we see that a minority of these projects are going straight to renewables-based hydrogen. In MENA, examples like Meranti's 2.5 Mt project in Duqm port in Oman will run on fossil gas until the carbon price makes renewables-based hydrogen economically competitive. Their target is to transition to 85 percent hydrogen by 2050. On the other hand in Europe, many projects are aiming to go straight to renewables-based hydrogen, like the first 100% H_2 project in Sweden that will come

2030 DRI project pipeline: by project status → Fig. 8



Agora Industry (2025) based on Agora Industry (2023) and GEM (2024). The data Includes all projects that are near-zero emissions compatible. SEA = Southeast Asia; NEA = Northeast Asia without China; CIS = Commonwealth of Independent States; FID = Final Investment Decision

2030 DRI project pipeline: by fuel type → Fig. 9



Agora Industry (2025) based on Agora Industry (2023) and GEM (2024). The data includes all projects that are near-zero emissions compatible. SEA = Southeast Asia; NEA = Northeast Asia without China; CIS = Commonwealth of Independent States; NG-DRI → H_2-DRI 2030 covers projects that will start operation of their DRI plants with natural gas, but have publicly communicated the intention to use either 100% low-carbon H_2 or a significant share of low-carbon H_2 by 2030. COG-H_2-DRI refers to coke oven gas H_2-DRI and refers to projects in China that are using H_2-rich coke oven gases from the blast furnace. NG-DRI → H_2-DRI projects refer to projects that mention the possibility to use low-carbon H_2 in the future without a concrete objective to do so by 2030.

online in 2026 using fossil gas only as a carbonising agent in the DRI rather than a fuel or reducing agent. In Latin America, where the economics of green hydrogen make clear sense, the announced project in Brazil will also start directly with green hydrogen (see figure 9).

Fossil gas-based DRI can deliver around 50 percent reductions when compared to an integrated blast furnace route. However this is still around 1 tonne of CO_2 per tonne of steel. When upstream methane emissions are fully considered, the reduction may be even less. CCS on fossil gas-based DRI will only tackle plant-level emissions, leaving midstream and upstream emissions untouched. As well as this, the same uncertainties outlined above for CCS and transport remain on techno-economics of high (more than 90 percent) CO_2 capture rates. Additionally, CO_2 transport and storage will require extensive infrastructure and face uncertain cost structures. We should not stop at a halfway transition, meaning that large scale deployment of green hydrogen is necessary to fully decarbonise the steel sector (see figure 10).

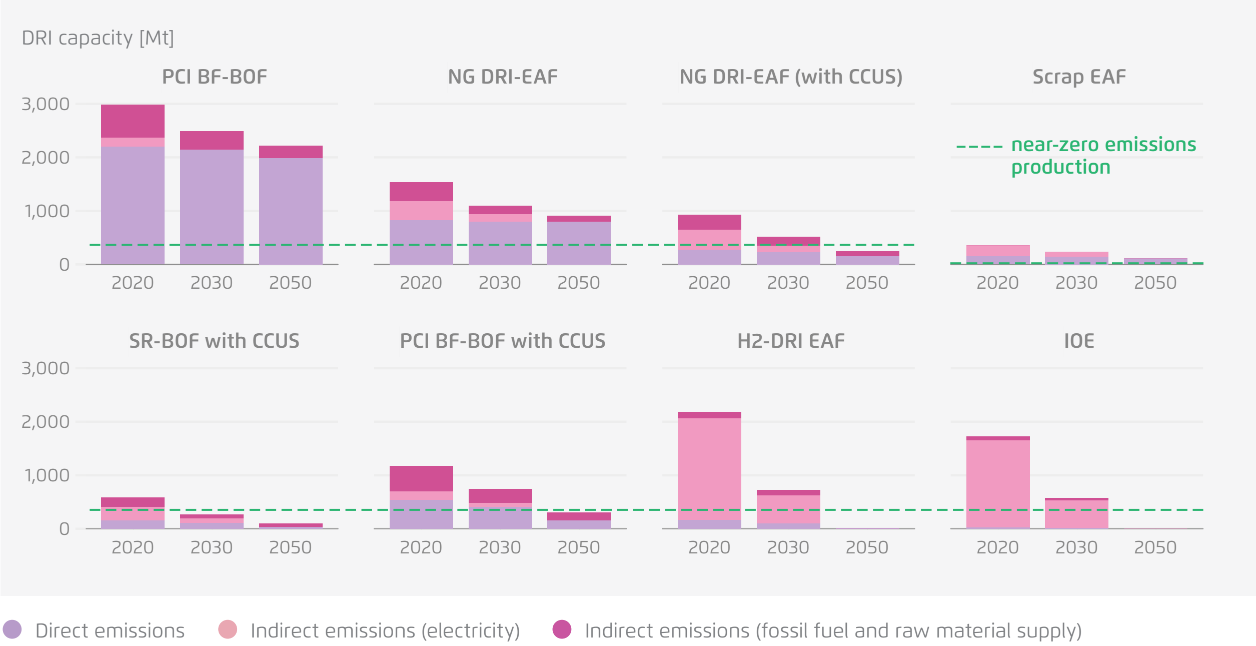
The key distinction between project announcements and FIDs lies in commitment: while announcements signal intent, only FIDs represent real financial backing and progress toward construction. Experience from the hydrogen sector shows that many projects have struggled to reach FID as hydrogen costs proved higher than expected. With the right policy framework and a strong carbon price signal, progress from announcements to FIDs could accelerate, supporting faster deployment of near-zero steelmaking capacity.

Based on current investment decisions, around 45 Mt of net-zero-compatible DRI capacity is expected to come online by 2030. If all projects likely to reach FID by mid-2027 proceed, this figure could rise to around 62 Mt, though still well below the approximately 100 Mt required for a 1.5 °C-aligned pathway. Only 6 Mt of this capacity will use hydrogen from the outset, with another 12 Mt planning to integrate significant shares of low-carbon hydrogen, and 3 to 4 Mt in China already using hydrogen derived from coke-oven gases. This implies a low-carbon hydrogen demand of roughly 1.1 Mt by 2030. Given typical construction times of three-and-a-half to four years, projects without FID by mid-2027 will not start up before 2030, underscoring the urgency of advancing investment decisions now (see figure 11).

To conclude then, as of today, hydrogen-based DRI will be the main technology pathway for climate-neutral primary steel production. However, hydrogen uptake is at risk without clear policy signals to allow iron and steelmakers to fully transition to hydrogen-based steelmaking.

Global average direct and indirect emissions intensities of crude steel production via key pathways in Net Zero Emissions (NZE) by 2050 scenario

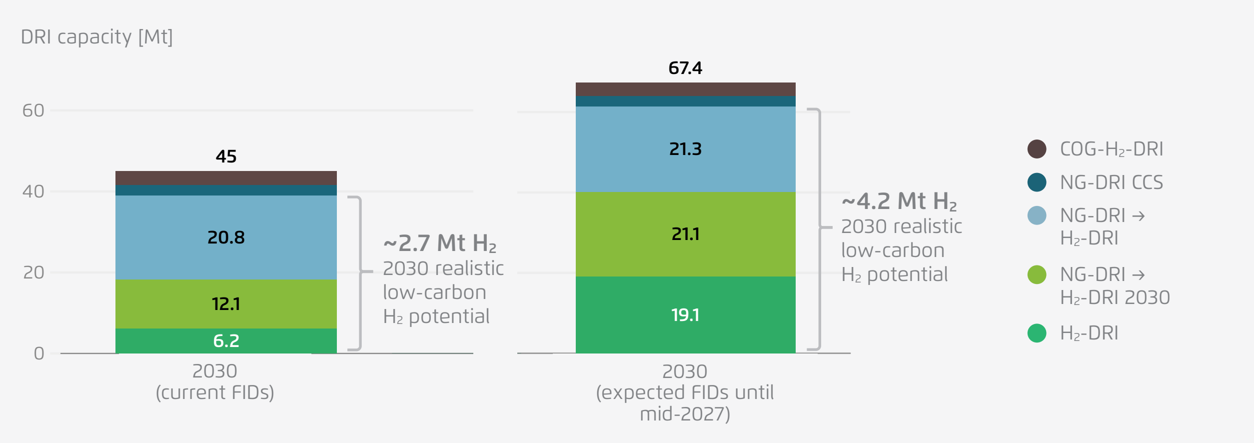
→ Fig. 10



IEA (2023). PCI BF-BOF = blast furnace-basic oxygen furnace with pulverised coal injection; DRI-EAF = natural gas-based direct reduced iron-electric arc furnace; Scrap EAF = scrap-based electric arc furnace; SR-BOF = innovative smelting reduction-basic oxygen furnace; CCUS = carbon capture utilisation and storage; H_2 = hydrogen-based; NG = natural gas-based; IOE = iron ore electrolysis. BFI energy intensities used for all processes until 2030; post-process routes use zero scrap, except for the Scrap EAF route, which uses 100% scrap. The near-zero emissions production thresholds are imposed on a direct + indirect emissions basis

Near-zero emissions capable DRI projects that are likely to reach FID by 2027: by intended fuel use

→ Fig. 11

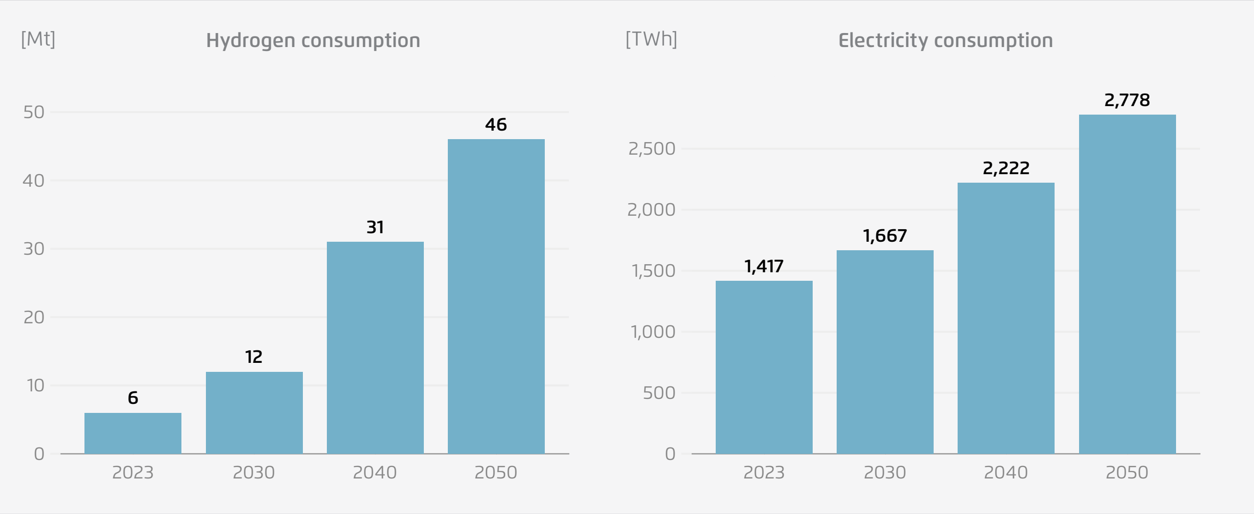


Agora Industry (2025) based on Agora Industry (2023) and GEM (2024). The low-carbon hydrogen potential has been derived from announced DRI project capacities, assuming a specific hydrogen consumption of 0.069 tonnes of H_2 per tonne of DRI.

Chapter 3: Unlocking hydrogen and building out renewables

Rapid clean steel deployment depends on parallel investment in renewable electricity, expanded grids and establishing a hydrogen value chain: production, transport and storage. Because these supporting networks have long lead times, governments and industry must plan early and coordinate delivery across permitting, financing and interconnection. Fossil gas-based DRI can provide a fast start, but it needs a clear, time-bound pathway to renewable power and clean hydrogen; without that, projects risk stalling at a halfway decarbonisation of roughly 50 percent instead of reaching near-zero. For some countries, such as India or in Europe, this also means remaining reliant on fossil gas imports and volatile prices.

Global steel sector H_2 and electricity demand in the IEA's NZE 2050 scenario, 2023–2050 → Fig. 12



IEA (2025a)

Because of higher-than-expected production costs and missing offtake from key hydrogen users such as steel producers, a wealth of low-carbon hydrogen announcements has not yet translated into widespread FIDs. There are 26 Mt of announced low-carbon hydrogen[4] projects in the pipeline; however, only ~1 Mt have reached completion and another 3 Mt have reached FID (IEA, 2025b). An additional 22 Mt is currently stuck at the feasibility stage of project completion (IEA, 2025b).

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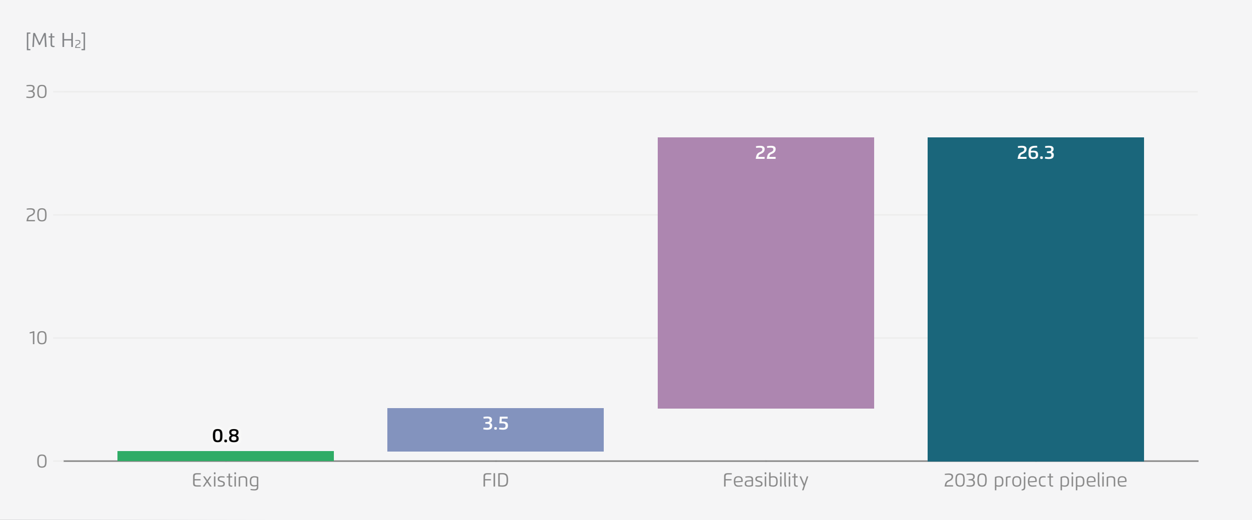
[4] Low-carbon hydrogen is sometimes also referred to as "low-emissions hydrogen" (IEA 2025: Global Hydrogen Review 2025, p. 273). Exact definitions regarding admissible greenhouse gas emission intensity vary between regions. In the EU, for example, low-carbon hydrogen implies hydrogen production with a reduction of at least 70% in greenhouse gas emissions compared to conventional fossil fuels, with a threshold of 3.38 kg CO_2eq per kg of hydrogen. In the future, such thresholds will need to be further tightened with a view to reach climate neutrality. For example, the IEA Net-zero by 2050 scenario shows an emissions intensity of below 1 kg CO2eq per kg of hydrogen by 2050. (Agora Energiewende and Agora Industry 2024: Low-carbon hydrogen in the EU.)

Global renewable hydrogen production costs are higher than most studies projected two years ago, undermining bankability and delaying FIDs. Finally, today's policy frameworks do not yet enable projects to be built at scale; clearer long-term incentives, robust offtake mechanisms, and coordinated infrastructure support are needed to translate announcements into steel-relevant hydrogen supply.

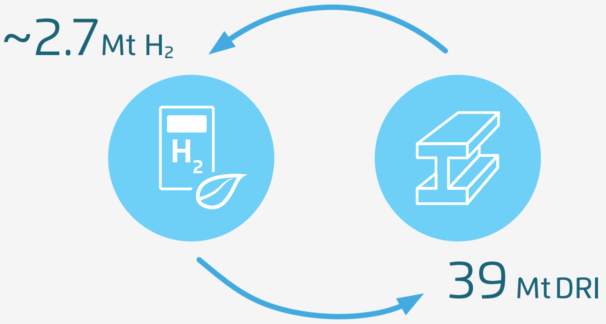
2030 low-carbon H_2 project pipeline → Fig. 13



IEA (2025b). FID = Final Investment Decision

The steel industry could help to unlock 2.7 Mt of low-carbon hydrogen FIDs, if all steel companies that are planning to operate DRI plants with low-carbon hydrogen face the right market conditions and policy incentives to use 100 percent clean hydrogen by 2030. The steel sector alone could thus help to unlock the increase of low-carbon hydrogen production from currently 3.5 Mt to up to 7 Mt by 2030. Policy incentives are needed to make this a reality. This includes both large-scale subsidies for hydrogen use in steel, coupled with lead market instruments to pass on some of the green premium to consumers to incentivise using hydrogen directly in integrated DRI plants or importing embodied hydrogen in the form of HBI.

By 2030: steel demand for H_2 could trigger offtake agreements for ~2.7 Mt H_2 → Fig. 14



The low-carbon hydrogen potential has been derived from announced DRI project capacities, assuming a specific hydrogen consumption of 0.069 tonnes of H_2 per tonne of DRI.

Currently, most announced export-oriented green hydrogen projects plan to transport hydrogen mainly as ammonia, the preferred carrier (IEA, 2025). Complementing this with green iron trade could unlock more FIDs for low-carbon hydrogen. Shipping hydrogen adds substantial conversion, transport and reconversion costs, making inter-regional trade expensive unless hydrogen is moved as embodied hydrogen – such as in HBI – that avoids these penalties. If hydrogen is exported embodied in HBI instead, shipping costs fall and handling is simpler, so interregional green iron trade could unlock more FIDs. Therefore, if policymakers and buyers prioritise HBI-based trade corridors, they can convert today's announcements into bankable export projects.

Climate-neutral steel requires reliable access to affordable renewable electricity, low carbon hydrogen and supporting infrastructure. By prioritising steel as a key hydrogen-offtake sector, the right policy incentives can help to unlock more FIDs for low-carbon hydrogen projects.

Chapter 4: Policy recommendations

Over the course of this project, Agora Industry conducted stakeholder engagement with policymakers, steelmakers and manufacturers across the entire value chain to assess what helpful policies already exist and what more is needed to push forward steel decarbonisation to reach climate-neutral steel production by 2050.

The resulting policy mix is designed to close gaps **along the entire iron and steel value chain** – from upstream energy and hydrogen, through midstream ironmaking to downstream markets – so that investment in near-zero steel becomes bankable.

What currently exists

Globally, the policy landscape for decarbonisation is very mixed, leading to uneven levels of support for industries depending on their location.

In the EU, steel companies have been under the most pressure to make investments in their steel fleets and produce decarbonised steel by the next decade, given they are facing the end of free allocation in the EU emissions trading system (ETS) by the mid-2030s. Countries like Spain, Germany, France, Italy, Sweden and Belgium have tried to offer benefits (in the form of subsidies, contracts for difference and de-risking operation costs) to steel companies to transition. Germany was the most generous, offering its steel companies a total of EUR 7.3 billion for new DRI facilities across the country and pledging to implement carbon contracts for difference to help with operational costs for using hydrogen.

On the EU level, trade restrictions have taken precedent in the last years with the “Safeguard” measure, that was extended until June 2026, designed to protect the EU steel industry from cheaper imports resulting from global overcapacity. On the other side of the EU ETS, the carbon border adjustment mechanism (CBAM) is moving from reporting to payment in the next few years. The EU Innovation Fund continues to back first movers like Stegra’s Boden plant that received EUR 250 million to help de-risk the project for private sector finance. Additionally, steps are being taken in the Ecodesign for Sustainable Products Regulation (ESPR) to introduce digital product passports and formalise labels on green steel by adopting a standard in the upcoming Industry Accelerator Act. These pieces of legislation lay a path towards product-level rules that can be used for lead market policies like green public procurement and embodied carbon requirements.

In India, the Ministry of Steel announced the 2024 Green Steel Taxonomy and certification scheme that set plant-level emission thresholds and star ratings, steering finance, procurement and offtake towards near-zero products.

China’s net-zero steel pathway leans on efficiency upgrades, greater scrap recycling and a gradual shift toward EAF/DRI, with hydrogen and CCUS highlighted as longer-term options under the 2060 carbon neutrality goal; however, progress is uneven. China’s 15 percent EAF share target for 2025 has stalled near 10 percent amid high power costs, scrap bottlenecks and BF-BOF overcapacity (Agora Energy China and Agora Energiewende, 2025). Recent policy moves focus on capacity/output control rather than a comprehensive decarbonisation package (for example the steel capacity-replacement scheme was suspended for revision in August 2024 and output control guidance tightened), leaving a fragmented policy landscape that still prioritises managing overcapacity while incrementally advancing near-zero routes (Transition Asia, 2024).

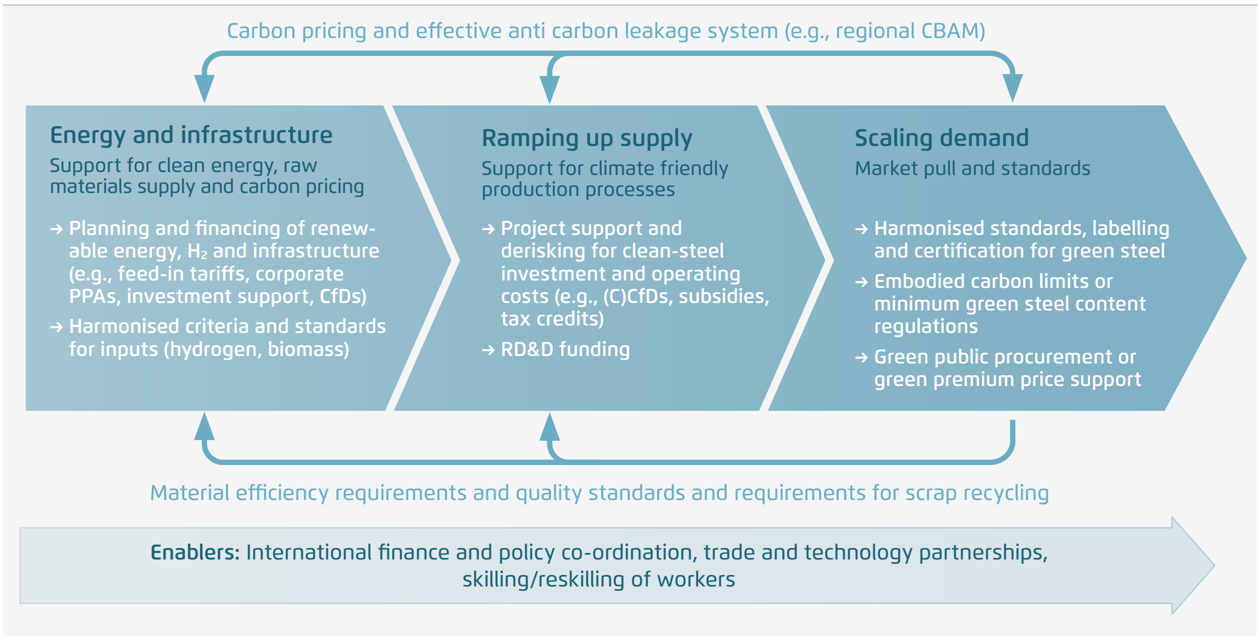
Japan and South Korea have also started to move forward with at least analysing what kinds of technologies should be adopted to decarbonise their steel sectors in line with the countries' Nationally Determined Contributions and 2050 targets. Japan couples sizeable finance with standard-setting under its GX strategy: it has designated JPY 2 trillion to the Green Innovation Fund, the GX Promotion Act, BF-side pilots (such as hydrogen injection/CCS at Kimitsu) and around JPY 251 billion to expand EAF capacity, plus work on "verified reduction" metrics. South Korea prioritises hydrogen market creation via the clean hydrogen portfolio standard (CHPS) contracts for difference-style scheme, a ≤4 kg CO_2e/kgH_2 certification, and longstanding green public procurement, although steel-specific rules remain light.

Globally, carbon pricing is gaining traction in order to kick-start transition investment. China is expanding its national ETS beyond power and moving towards absolute caps, while Japan's GX-ETS becomes mandatory from 2026 alongside a carbon levy. The UK is also widening its ETS (and exploring linkage with the EU). Across Latin America, Brazil has legislated a national ETS as Mexico transitions from pilot to operation and Chile refines its carbon tax. These are important developments as carbon pricing underpins a successful industry transition policy mix.

Across steelmaking companies, the signal is consistent. First, tighter trade defenses and a credible CBAM to counter overcapacity and carbon-cost undercutting. Second, first-mover finance and risk-sharing: contracts for difference or equivalent operating support, access to state-aid windows and guarantees for hydrogen, power and offtake risks. Third, infrastructure and input-cost relief: faster grid build-out, hydrogen networks and affordable renewable power. Fourth, clear, interoperable standards and demand creation: recognised definitions of near-zero steel embedded in procurement and private contracts so that early volumes clear at viable prices. A minority emphasise modular, de-risked project delivery, but most prioritise trade measures plus bankable demand.

Entire value chain policy mix

A climate-neutral steel sector requires a comprehensive policy framework across the entire value chain → Fig. 15



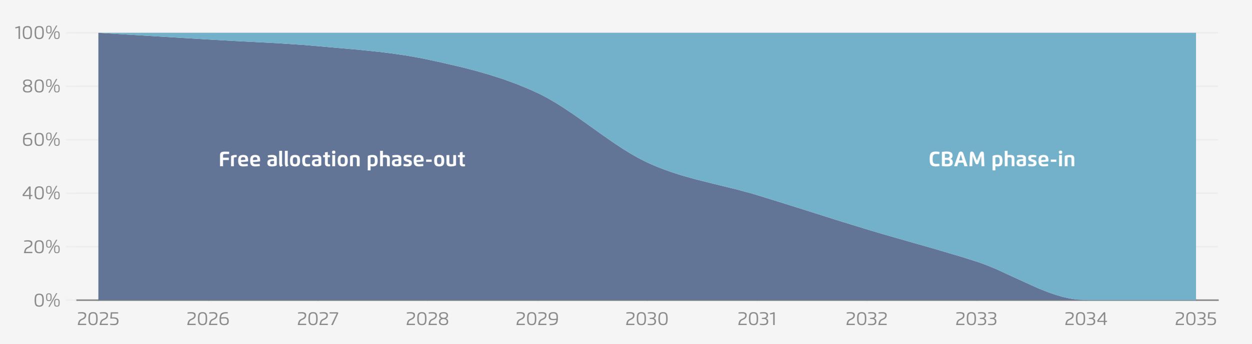
Agora Industry (2025). (C)CfD = (carbon) contract for difference

Energy and infrastructure: Support for clean energy and raw materials supply

Renewables infrastructure for supply and availability of cheap, renewables based electricity is the basis of enabling a roll-out of green steel production. Contracts for Difference (CfDs) can be used for renewables to bridge the price gap with fossil electricity and power purchase agreements (PPAs) can facilitate long term stable offtake agreements for utility companies to make investments in increasing renewables capacity. Standards for defining green hydrogen as well as sustainable biomass are also needed at the raw materials supply end of the value chain to ensure a level playing field for green industrial products. Countries should ring-fence scarce renewable hydrogen for no-regret uses (notably ore reduction in hydrogen-based DRI) via European Hydrogen Bank/H_2Global-style tenders and carbon contracts for difference (Agora Industry, ICCT and RAP, 2025).

Companies need to depend on being able to close the cost gap with green steel production within the amortisation period. To start with, a carbon price is an effective baseline policy to provide a clear market signal for enabling green industrial investments. In Europe, the end of free allocation under the EU ETS that was finalised in 2023 was key for companies to move towards transition investments. Carbon pricing also generates revenues that can be reinvested in climate solutions. An emissions trading system provides a clear timeline to climate neutrality, enabling clear investment decisions.

EU ETS free allocation phase-out and CBAM phase-in → Fig. 16



The percentage values in this figure refers specifically to emissions from industrial production of products currently covered by the Carbon Border Adjustment Mechanism (CBAM), therefore it does not represent all emissions under the ETS, nor all industrial emissions under the ETS. For industrial products that remain outside CBAM, some free allocation may still be granted beyond 2035.

Ramping up supply: support for climate-friendly production processes

Policy makers must support steelmakers to scale hydrogen-fed DRI to replace blast furnace capacity by mid-century through project-level risk-sharing using carbon contracts for difference, state subsidies where possible to improve the business case for project investments and enable concessional finance for projects.

For countries with limited renewable potential, green-iron (HBI) import corridors can be used to reduce the costs of HBI production and, more widely, steel production. This will need coordination along the value chain to create incentives to create a fluid HBI market. From an EU standpoint, using existing mechanisms like extending the H_2Global double auctions to include long term HBI offtake. The EU could also classify green HBI as a strategic material under EU industrial policy and embed green iron supply into clean trade partnerships and free trade agreements (such as with Australia, Brazil, South Africa, Canada or the MENA region). This would create reliable, bankable feedstock while domestic hydrogen scales (Agora Industry, 2025).

Increasing the use of scrap to nearly 50 percent of global production, or around 1,000 Mt per year, is vital to achieving net-zero emissions in the steel sector by 2050. To reach this target, scrap should be treated as a strategic resource to help clear bottlenecks in collection, grading and cross-border trade. Governments should jointly track supply, align standards and traceability, and remove distortive restrictions so scrap flows to where it cuts emissions fastest. To do this, policy can be used to strengthen design-for-reuse and high-quality sorting, channel investments in recycling infrastructure and EAF upgrades and mobilise blended finance to scale systems globally.

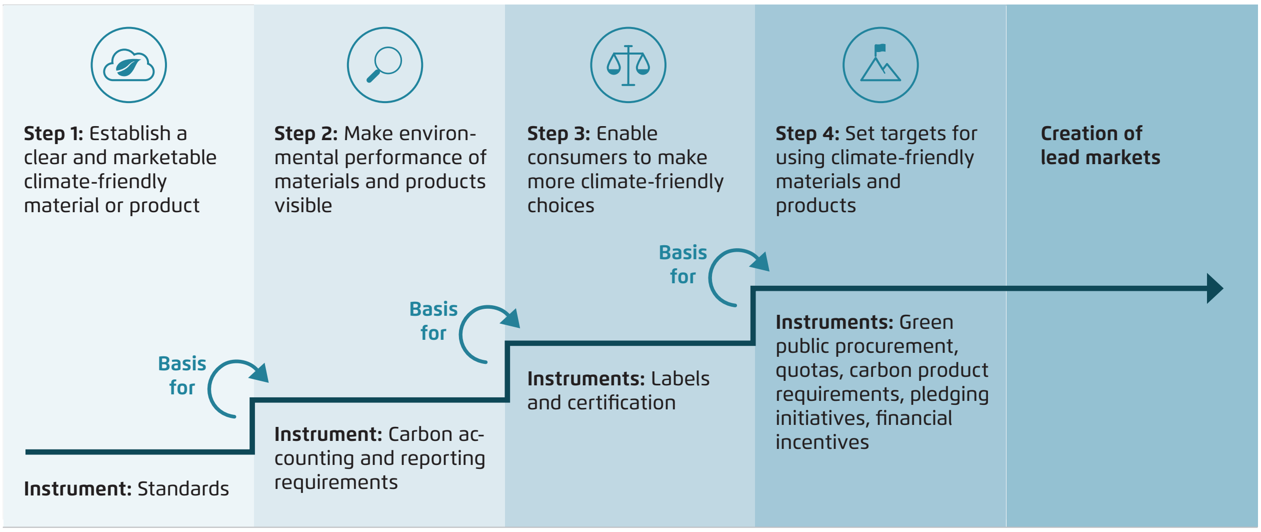
Scaling demand: market pull and standards

Across regions, the demand side is too thin. Lead market policy can create demand-pull via product standards and procurement for certified near-zero steel. Market pulls are needed to close the cost gap for green industrial investments and move frameworks for green products to operational rules. The first step would be to harmonise standards across regions that can be used as the basis for green steel labels for consumers to feel confidence in these green products. Standards are needed for green steel and green HBI to enable HBI trade. Since green steel standards often encompass upstream inputs and intermediate products like HBI, mutual recognition between potential exporting and importing countries is crucial to kick-start HBI trade.

Green public procurement can be used to create lighthouse projects for green industrial goods and provide transition incentives for companies to invest in midstream green production methods. Additionally, binding content requirements or embodied carbon limits in key end-use sectors (construction, automotive, machinery) can guarantee early demand and allow for the pass-through of the green premium, eventually replacing the need for contracts for difference. These policies would need to be underpinned with verification – Environmental Product Declarations, digital product passports, robust accounting – and implementation would need to be coordinated across jurisdictions so buyers can confidently specify near-zero steel (see figure 17).

Taken together, this policy mix – credible carbon signals and clean-energy support upstream, risk-sharing for DRI/HBI midstream and hard demand instruments downstream – addresses the core issue: to close the cost gap between green steel production routes and coal-based steel using credible offtakers to de-risk investment at scale.

Suite of policy instruments for lead market creation → Fig. 17



Agora Industry (2024): Creating markets for climate-friendly basic materials

References

Agora Energy China and Agora Energiewende (2025): *China's energy transition and climate status report.* URL: https://www.agora-energiewende.org/publications/china-energy-transition-and-climate-status-report

Agora Energiewende and Agora Industry (2021): *12 insights on hydrogen.* URL: https://www.agora-energiewende.org/publications/12-insights-on-hydrogen

Agora Industry and Wuppertal Institute (2023): *15 insights on the global steel transformation.* URL: https://www.agora-industry.org/publications/15-insights-on-the-global-steel-transformation

Agora Industry (2023): *Global Steel Transformation Tracker.* Model version 2.1, Berlin, 25.10.23. URL: https://www.agora-industry.org/data-tools/global-steel-transformation-tracker

Agora Industry (2024): *Creating markets for climate-friendly basic materials. Potentials and policy options.* URL: https://www.agora-industry.org/publications/creating-markets-for-climate-friendly-basic-materials

Agora Industry, Agora Energiewende and Instituto E+ Transição Energética (2024): *12 insights on hydrogen – Brazil edition.* URL: https://www.agora-industry.org/publications/12-insights-on-hydrogen-brazil-edition

Agora Industry (2025): *The role of green iron trade in accelerating competitive steel transformation.* URL: https://www.agora-industry.org/publications/the-role-of-green-iron-trade-in-accelerating-steel-transformation

Agora Industry, ICCT and RAP (2025): *Prioritising hydrogen for the most effective uses. An overview.* URL: https://www.agora-industry.org/publications/prioritising-hydrogen-for-the-most-effective-uses

Danish Energy Agency and Energinet (2021): *Technology Data – Carbon Capture, Transport and Storage.* URL: https://ens.dk/en/analyses-and-statistics/technology-data-carbon-capture-transport-and-storage

GEM (2024): *Global Energy Monitor.* Retrieved from globalsteel planttracker: https://globalenergymonitor.org/projects/globalsteel planttracker

IEA (2023): *Tracking Clean Energy Progress 2023.* URL: https://www.iea.org/reports/tracking-clean-energy-progress-2023

IEA (2024): *Definitions for Near-Zero and Low-Emissions Steel and Cement, and Underlying Emissions Measurement Methodologies.* URL: https://www.iea.org/reports/definitions-for-near-zero-and-low-emissions-steel-and-cement-and-underlying-emissions-measurement-methodologies

IEA (2025a): *Demand and Supply Measures for the Steel and Cement Transition.* URL: https://www.iea.org/reports/demand-and-supply-measures-for-the-steel-and-cement-transition

IEA (2025b): *Global Energy Review 2025.* URL: https://www.iea.org/reports/global-energy-review-2025

The World Steel Association (2024): *Annual production steel data – crude steel* (global, by region/country). URL: https://worldsteel.org/data/annual-production-steel-data/?ind=P1_crude_steel_total_pub/CHN/IND

The Net-Zero Industry Project (n.d): *Net-Zero Steel Pathways and Countries' Results.* Retrieved November 3, 2025, from https://netzeroindustry.org/net-zero-steel-pathways-and-countries-results/

Transition Asia (2024): *Decoding China's steel capacity replacement policies: A decade-long journey, pausing to forge ahead.* URL: https://transitionasia.org/decoding-chinas-steel-capacity-replacement-policies-a-decade-long-journey-pausing-to-forge-ahead/

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About Agora Industry
Agora Industry develops scientifically sound and politically feasible strategies for successful pathways to a climate-neutral industry – in Germany, Europe and internationally. The organisation which is part of the Agora Think Tanks works independently of economic and partisan interests. Its only commitment is to climate action.

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