



Decarbonizing Iron and Steel

EU Policy Brief
by Future Cleantech Architects

Executive Summary

The European steel sector is approaching a critical reinvestment and refurbishment window between now and 2035. Much of the European Union's (EU) blast furnace fleet is aging, with an average age of around **50 years**. Blast furnaces typically require major reinvestments roughly every 15–20 years, meaning that decisions taken in this period will determine whether assets lock in high-emissions production for decades or shift toward low-carbon pathways.

This brief recommends key policy decisions by the EU to decarbonize ironmaking, which is both the **highest emitting** and lowest value-added step in the steel value chain. Decarbonizing iron production while retaining high-value steelmaking, finishing, and recycling activities in the EU is therefore central to preserving strategic industrial know-how and value chains while reducing emissions.

The steel industry is responsible for approximately **5% of greenhouse gas emissions in the EU and 7% globally** due to its heavy reliance on coal. Around **70–80%** of process emissions are generated by the first step in the steelmaking process: the conversion from iron ore to iron. Traditional steelmaking via the blast furnace/basic oxygen furnace (BF-BOF) route dominates globally, including in the EU. Emission intensities vary considerably across plants due to differences in process design, energy and material efficiency, and system boundaries (e.g. treatment of upstream inputs such as coke or pellets). Globally, BF-BOF emissions average around **2.2 tonnes of carbon dioxide per tonne (tCO₂/t) of crude steel**, whereas EU production is estimated at approximately **1.8 tCO₂/t of crude steel**.

In 2024, the EU produced **129.6 million tonnes (Mt)** of steel, accounting for around 7% of global supply and making it the world's third-largest producer after China (~55%) and India (8%). Of this total, 57.8 Mt (~45%) was from recycled, or secondary, steel, above the global average of roughly 30%.¹ The remaining **71.8 Mt** was primary steel, produced by reducing around 98 Mt of iron ore.² Since the EU's domestic iron ore production, mainly based in Sweden, is insufficient to meet EU demand, the sector relies heavily on imports, primarily from countries such as Australia, Brazil, Canada, and Ukraine. This means that while the EU has large installed steelmaking capacity, it remains structurally dependent on imported upstream inputs, particularly iron ore and coking coal.

The global steel sector suffers from significant and increasing overcapacity, as well as depressing factory utilization rates and profit margins. Yet the need to decarbonize is becoming more urgent. One reason is that the industry is highly polluting, and its decarbonization will improve both climate and public health by reducing emissions of air pollutants which are **linked to degraded local air quality** in communities surrounding steel production sites. Additionally, failing to decarbonize will become more costly as free allowances under the EU Emissions Trading System are phased out between 2026 and 2034 following the introduction of the Carbon Border Adjustment Mechanism. Without abatement, EU steelmakers' carbon cost exposure will increase signifi-

cantly. In a structurally low-margin global steel market, decarbonization pathways will only scale if they are paired with clean, affordable energy and demand-side measures such as standards, lead markets, and green public procurement.

Several decarbonization pathways exist, but they differ significantly in cost, scalability, infrastructure requirements, and suitability for deployment in Europe. Decarbonization of the steel sector should include increasing electrification of low- and high-temperature heat, as well as maximizing steel recycling. The main improvement, however, must come from moving the primary ironmaking process away from coal, and ultimately from all polluting production pathways on a global scale.

This transition must be supported by policy measures and financial incentives for innovators and industry. Hydrogen-based direct reduced iron (DRI) combined with an electric arc furnace (EAF) using electricity is currently the most mature alternative primary steelmaking pathway expected to scale in time to support the EU's 2050 targets. These facilities could potentially produce 50% of the EU's 2024 primary iron demand.³

A key challenge is the availability of clean, affordable hydrogen, which requires abundant low-carbon electricity, the build-out of extensive and expensive hydrogen infrastructure, and industrial conversion of end-use equipment. The renewable hydrogen DRI-EAF production route consumes particularly large quantities of clean electricity. Switching 100% of the EU's 2024 primary steel production (i.e. 71.8 Mt) to this route would take about 97% of all solar electricity produced in the EU in 2024.⁴

In addition, transporting hydrogen by ship is **inefficient and costly**. Therefore, one option is to produce iron abroad with clean hydrogen and export it to Europe as hot briquetted iron (HBI). This is relatively simple and could even be cheaper in absolute terms than shipping iron ore ingots. This could also support diversified and resilient supply chains for low-carbon iron inputs, as HBI is well suited for long-distance bulk shipping and avoids the need to transport hydrogen to European steelmaking regions.

With a few local exceptions, clean energy in the EU is limited and expensive, especially in the main steelmaking regions, leading to high projected levelized costs of hydrogen (LCOH), which in many cases remain higher than fossil-based alternatives such as coal. As a contingency, several of the new DRI projects intend to use unabated natural gas until affordable hydrogen becomes available. In contrast, geographic regions with favorable conditions, such as high solar irradiance, strong and consistent wind, or abundant hydropower, have a competitive advantage in projected LCOH. In regions where such conditions are less favorable, access to a clean and reliable electricity grid can nevertheless enable competitive low-carbon hydrogen production.

¹ Global electric arc furnace share of crude steel production as a proxy for global recycled steel share.

² Iron ore demand (~98 Mt in 2024) is calculated using ~1.37 t iron ore per tonne of primary (BF-BOF) liquid steel. This assumes 1.45 t iron ore per tonne of hot metal, ~16.7% BOF scrap share, and ~88% metallic yield, ensuring internal mass balance consistency and avoiding scrap double counting.

³ Assuming **68 Mt** hot metal apparent consumption in 2024, **34 million tonnes per annum (Mtpa) DRI** capacity announced, including 12 Mtpa with final investment decision.

⁴ Assumptions: **304 TWh solar PV production in the EU (2024)**; total metallic charge requirement of 1.2 t/t of crude steel; 20% scrap share in the metallic charge; hydrogen consumption of 50 kg hydrogen per tonne of DRI. This corresponds to ~60 kg hydrogen per tonne of steel in a fully DRI-based charge (0% scrap), and ~48 kg hydrogen per tonne of steel under the 20% scrap assumption applied here. Further assumptions: 55 kWh/kg hydrogen for electrolysis; 489 kWh/t steel for EAF steelmaking; 177 kWh/t DRI for DRI auxiliaries; and 828 kWh/t DRI for DRI process heat.

Another innovative low-carbon solution is direct electrification in the form of molten oxide electrolysis or electrowinning. These production routes do not consume hydrogen and instead use electricity to directly convert iron ore into metallic iron through electrochemical reactions. While total electricity demand is broadly comparable to hydrogen-based DRI pathways, these processes can achieve near-zero direct CO₂ emissions and avoid the need for hydrogen supply infrastructure, while also offering modular production pathways. Direct electrification technologies fundamentally redesign steelmaking chemistry rather than incrementally improving carbon-based processes. They can simplify plant design, reduce the number of processing steps, and potentially

work with a wider range of ore qualities, which could improve resource efficiency and resilience in supply chains.

Direct electrification should be viewed as a promising post-2035 technology pathway. Deployment at scale will require successful pilot projects and anticipatory grid planning this decade. While it is not expected to deliver large-scale emissions reductions in the near term, due to current technological maturity, it has strong long-term potential, particularly in regions with abundant low-cost clean power. Sustained public and private research, development, and demonstration support will be critical to accelerate commercial readiness.

Recommendations

To achieve deep decarbonization in the steel sector, this report sets out the following policy recommendations:



1. Set a clear coal phase-out trajectory for ironmaking



2. Secure affordable and clean electricity



3. Strategically redesign the green steel global value chain



4. Create lead markets and trusted global standards for green steel



5. Circumvent hydrogen: Invest in innovative primary steel production pathways



6. Make Europe a leader in scrap quality upgrading

Definitions Related to the Steps for Steelmaking



Primary steel (ore-based)

Primary steel is produced from iron ore as the main input. This includes:

- ▶ Blast furnace/basic oxygen furnace (BF-BOF) production
- ▶ Direct reduced iron (DRI) with electric arc furnace (EAF) when iron ore is the primary feedstock.



Secondary steel (scrap-based)

Secondary steel is produced primarily from recycled scrap using EAFs, without requiring iron ore reduction.



Recycled steel use

The share of steel production that uses scrap as an input material, including both scrap-based secondary steel production and scrap used alongside primary iron inputs in primary steelmaking routes



Scrap availability and quality

The total volume of scrap physically available on the market. This depends on product lifetimes, collection rates, sorting quality, and trade flows. Scrap availability does not automatically translate into scrap use. Because steel products often remain in use for decades (e.g. buildings, infrastructure, machinery), scrap supply grows slowly even when demand for low-carbon steel increases rapidly.

Steel scrap is a critical feedstock for low-carbon steelmaking, particularly in EAF production. However, not all scrap is equal. The quality and composition of scrap strongly influence the types of steel that can be produced and whether additional refining or dilution with primary iron is required.



Pre-consumer scrap

(also called prompt or manufacturing scrap) is generated during industrial production processes such as stamping, cutting, or machining. It is typically clean, well-sorted, and compositionally consistent, making it highly valuable for high-quality steel production.



Post-consumer scrap

originates from end-of-life products such as vehicles, buildings, appliances, and infrastructure. While available in larger volumes, it often contains higher levels of contaminants⁵ and mixed alloys, which can limit its direct use in high-grade steel applications without additional processing.

Scrap upgrading refers to improving scrap quality so that it can be used in higher-value steel applications. This typically includes:

1. Advanced sorting

- a. Sensor-based sorting to separate alloy grades
- b. Density and magnetic separation
- c. AI-assisted automated scrap classification

2. Dismantling and product design

- a. Better dismantling of complex products (vehicles, electronics, appliances)
- b. Design for recyclability to reduce mixed alloys and coatings

3. Removal of non-metal contamination

- a. Shredding and cleaning to remove plastics, rubber, and coatings
- b. Thermal or chemical pre-treatment for coated scrap

4. Dilution strategies

- a. Blending scrap with primary iron (DRI or HBI) to control residual levels

Higher-quality scrap

- Enables production of higher-grade steels via EAF
- Reduces reliance on primary ironmaking
- Improves energy efficiency and yield
- Supports circularity while maintaining product performance

⁵ Main contaminants include copper, tin, nickel, chromium, molybdenum, zinc, and non-metallic contaminants (e.g. plastics, rubber, coatings, oil, dirt). Unlike carbon, these elements cannot be easily oxidized out during melting, meaning contamination accumulates with repeated recycling unless scrap streams are carefully managed.

The Process

Steel production follows a [sequential industrial process](#) (Figure 1) that begins with iron ore extraction and preparation, where iron ore is mined, processed, and prepared for use in ironmaking. In the ironmaking stage, iron ore is chemically reduced to produce metallic iron. This is the most energy- and emissions-intensive step in the value chain and is currently dominated globally by coal-based blast furnace technologies. The iron is then processed in the steelmaking stage, where iron or recycled scrap steel is refined into crude steel and adjusted to meet specific chemical and performance requirements.

Finally, in downstream processing and manufacturing, steel is rolled, coated, and further processed into finished or semi-finished products used across the economy, including in construction, automotive manufacturing, machinery, energy infrastructure, and consumer goods. Different end uses require different steel grades and impurity tolerances, which means that expanding circular steel production will depend not only on scrap availability, but also on improvements in scrap sorting, upgrading, and traceability.

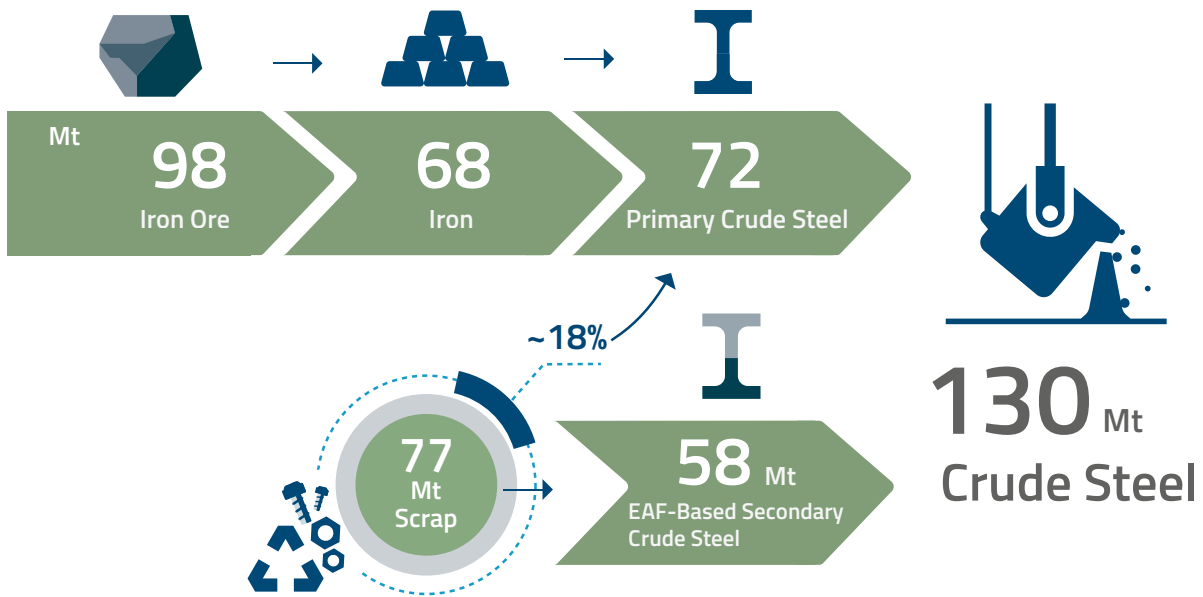


Figure 1: Steelmaking process for primary crude steel and EAF-based secondary crude steel (based on 2024 data from the [World Steel Association](#); [EUROFER](#); and Future Cleantech Architects (FCA) calculations).



The European Steel Industry in Numbers

Steel has, due to its excellent mechanical properties, become pervasive in modern society. More than half of all steel produced is integrated into essential infrastructure such as bridges, wind turbines, and buildings. The sector is also strategically important because it anchors downstream manufacturing value chains: Most industrial value-added, advanced processing, and high-quality employment in Europe **occurs in steelmaking**, finishing, and fabrication rather than in upstream iron-making.

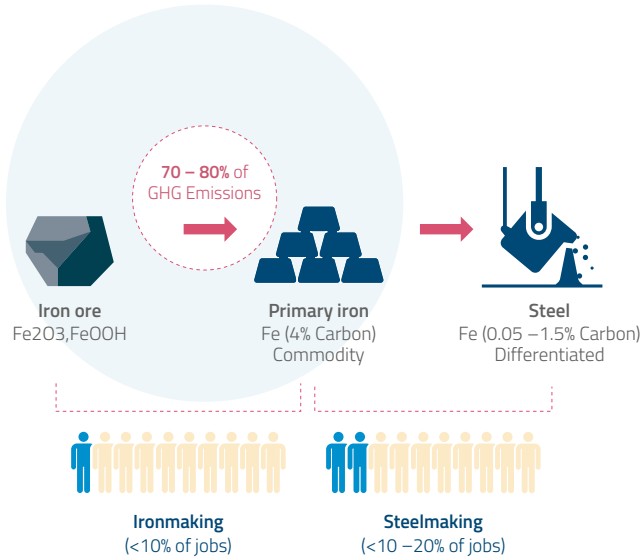


Figure 2: Ironmaking is both the highest emitting and lowest value-added step in the steel value chain.

The European steel industry directly employs **nearly 300,000 workers** (0.15% of EU employment) in steel production activities such as iron-making, steelmaking, and rolling. It indirectly supports a wider industrial ecosystem of **2.5 million jobs**.⁶ In total, the sector generates **€39 billion per year** in direct value added (0.22% of EU GDP) and an additional **€13.8 billion** indirectly. In comparison, the EU automotive sector, one of the largest steel-consuming industries, employs **13.8 million people** and generates **7% of EU GDP**, underlining the reality that most of the industrial added value and quality jobs in Europe lie in the production of steel, not iron (Figure 2). This industrial footprint is underpinned by the EU's production infrastructure, which comprises **44 blast furnaces, 2 DRI units, 96 EAFs**, and hundreds of processing plants⁷ (Figure 3).

GHG Emissions (Mt)

- < 1
- > 1-2.5
- > 2.5-5
- > 5-10

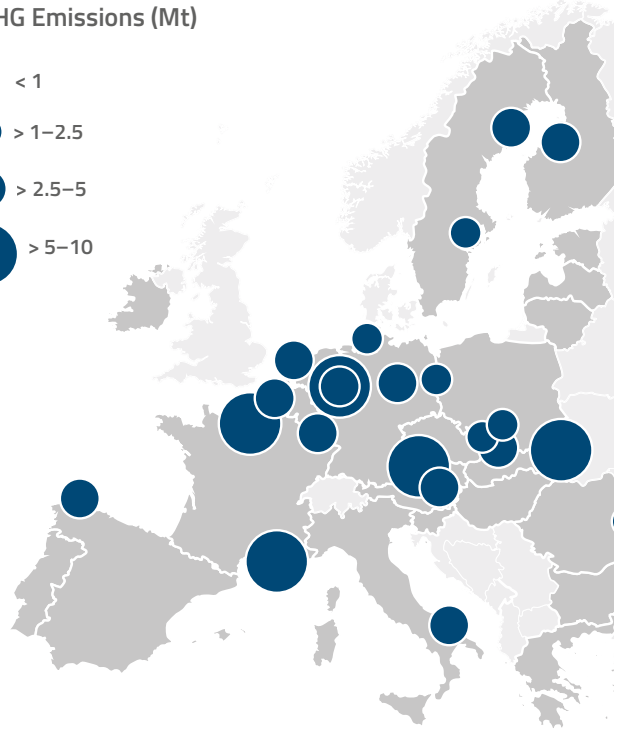


Figure 3: EU iron and steel production sites by greenhouse gas emissions (top 100) (adapted from JRC/EIGL 2025)

Globally, crude steel production in 2024 was **dominated by large Asian producers** including China Baowu Group (130 million tonnes per annum (Mtpa)), Ansteel Group (59.6 Mtpa), and Nippon Steel Corporation (43.6 Mtpa). Global iron ore production is similarly concentrated (Figure 4), with Australia (952.5 million tonnes (Mt)) by far the largest producer, followed by Brazil (418 Mt) and China (298.3 Mt). With domestic iron ore production at 32.6 Mt in 2023, the EU remains heavily dependent on imports.

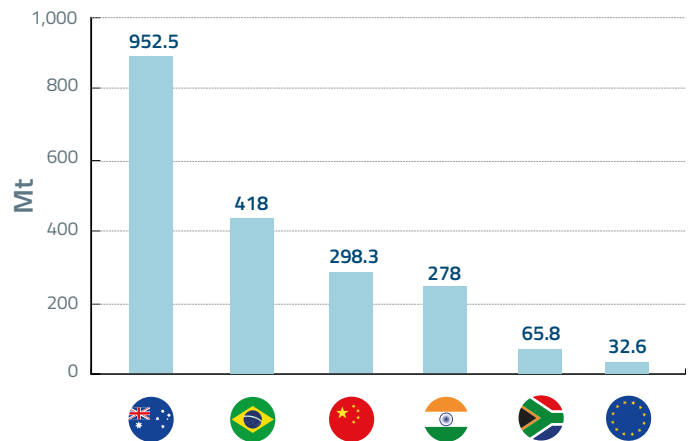


Figure 4: 2023 global iron ore production by country (based on data from the World Steel Association).

⁶ Indirect employment includes, inter alia, raw materials and energy supply, automotive, construction, machinery, defense, renewable energy, and aerospace industries, and logistics and services.

⁷ Such as rolling mills, tube and pipe mills, foundries, forging plants, finishing facilities and specialty plants.

Within the EU, production and ironmaking capacity are highly concentrated, with ArcelorMittal SA accounting for 62 Mtpa of ironmaking capacity and 65 Mtpa of crude steel production, followed at a significant distance by ThyssenKrupp AG (11.4 Mtpa iron; 10.3 Mtpa crude steel), Salzgitter AG (9.8 Mtpa iron), SSAB AB (6.7 Mtpa iron; 7.4 Mtpa

crude steel), and Voestalpine AG (6.7 Mtpa iron; 6.8 Mtpa crude steel). Figure 5 shows crude steel production in the EU for 2024, with Germany taking the lead (37.2 Mtpa), followed by Italy (20 Mtpa), Spain (11.9 Mtpa), and France (10.8 Mtpa).

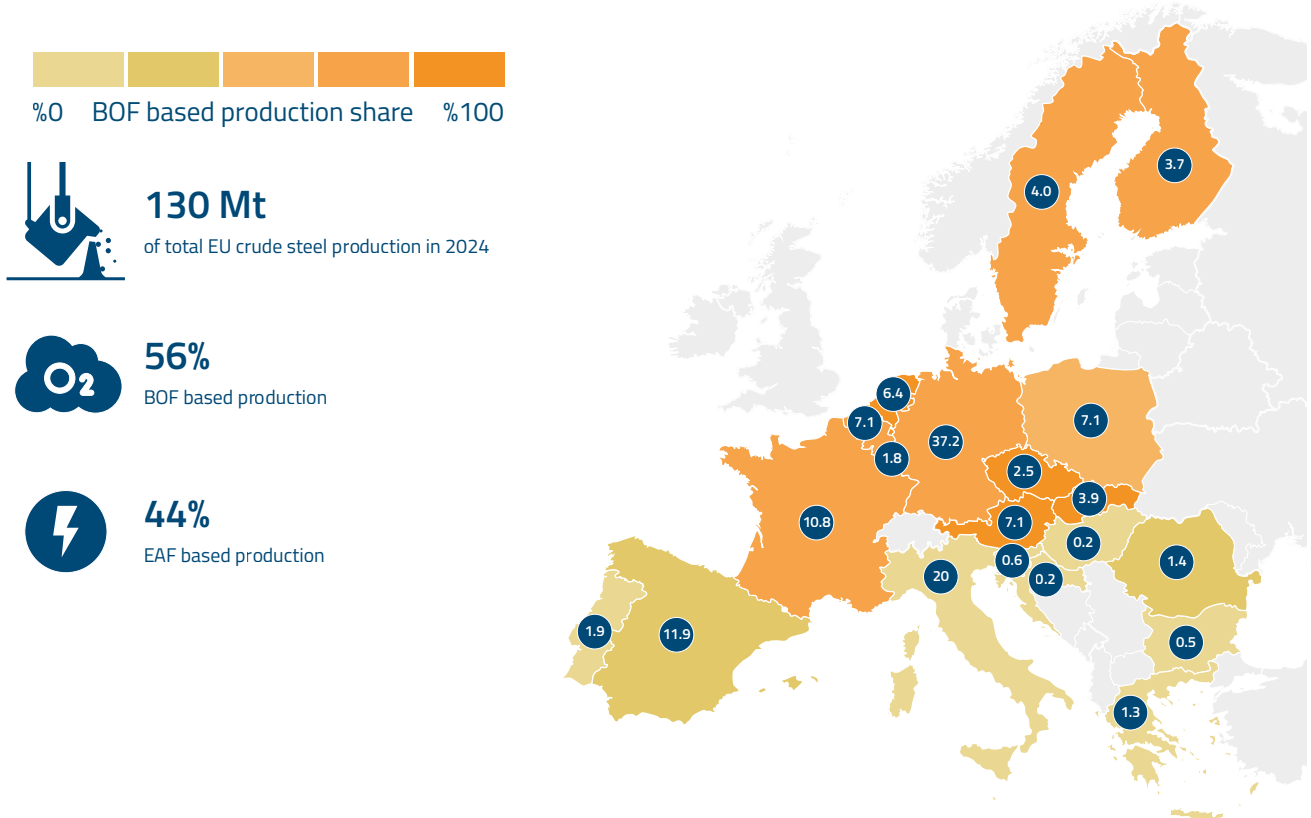


Figure 5: 2024 EU crude steel production by country (based on data from the [World Steel Association](#)).

The European Steel Industry Under Pressure

Today the EU steel industry faces three main challenges: overcapacity, high energy prices, and rising carbon costs. Together, these pressures compress margins, increase investment risk, and delay final investment decisions (FIDs) for capital-intensive deep decarbonization projects.

The global steel industry is characterized by significant and growing **overcapacity**, estimated at around five times the EU's production capacity. This structural oversupply has contributed to persistently low margins in global steel markets. In this context, the EU cannot decarbonize by simply adding higher-cost low-carbon production capacity into a low-margin global market. Instead, targeted supply-side support must be combined with strong demand-side measures to create viable markets for low-carbon steel.

Energy prices remain a structural competitiveness challenge for European steelmakers. The sector is highly energy intensive and EU producers face persistently higher input costs than global competitors. In 2024, average wholesale gas prices were **€13.26 per metric million British thermal unit (MMBtu)** in Europe compared to €2.1/MMBtu⁸ in North America and roughly **€8.42/MMBtu** in China. In absolute terms, 2024 electricity price levels were approximately **€0.10/kWh** in the EU, compared to **~€0.08/kWh** in the United States (US) and **~€0.08/kWh⁹** in China¹⁰, reflecting structural differences in generation mix, taxation, and system costs (Figure 6).¹¹ These differences reflect structural factors: US producers benefit from abundant domestic shale gas, while Chinese industrial energy prices are influenced by state regulation and long-term supply strategies. This cost differential directly undermines Europe's cost competitiveness and electrification transition, making affordable renewable power access and grid reform urgent priorities.

⁸ Based on data from the [US Energy Information Administration](#) and [International Gas Union](#).

⁹ Based on data from [Statista](#) and [China Briefing](#).

¹⁰ EU electricity price data exclude VAT and other recoverable taxes and levies. Comparable exclusions could not be determined for the US and China.

¹¹ Converted using a conversion factor of 1 US\$ = 0.924 EUR from the [European Central Bank Eurosystem](#).

Moreover, the **carbon cost** is rising. Under the EU Emissions Trading System (ETS), EU steelmakers pay about **€84–92/tCO₂**, with costs expected to increase as free allowances are phased out. Historically, however, the steel sector has received **substantial protection** under the ETS through the free allocation of emissions allowances intended to address carbon-leakage risks, which has significantly limited direct carbon cost exposure for many producers. As free allowances decline, this exposure will increase significantly. For the steel sector specifically, the impact of rising carbon costs is amplified by high emissions intensity. By 2030, carbon costs for conventional steel production could rise to **€120/t of crude steel**, representing a substantial share of production costs. The Carbon Border Adjustment Mechanism (CBAM) is expected to level the playing field on carbon emissions for imports into the EU market, with recent implementation measures and proposed amendments by the European Commission strengthening its effectiveness by expanding potential coverage to downstream products, introducing additional anti-circumvention tools, and refining emissions calculation

and electricity accounting methodologies. However, the CBAM remains primarily an import-focused instrument and does not directly address the competitiveness of EU steel exports. As free allocation under the EU ETS is phased down, EU producers may face carbon costs in export markets that are not borne by some international competitors, potentially affecting margins and investment incentives in globally traded steel products. The extent of this impact will depend on evolving global carbon pricing, demand for low-carbon materials, and complementary policy measures.

Due to these cost pressures, European steelmakers face an uneven playing field in global competition, with subsidized production often exported at prices that do not reflect full production costs. This reinforces the need for stronger market-creating measures in Europe, including robust product standards, green public procurement, and demand-side product requirements to accelerate the uptake of low-carbon steel.

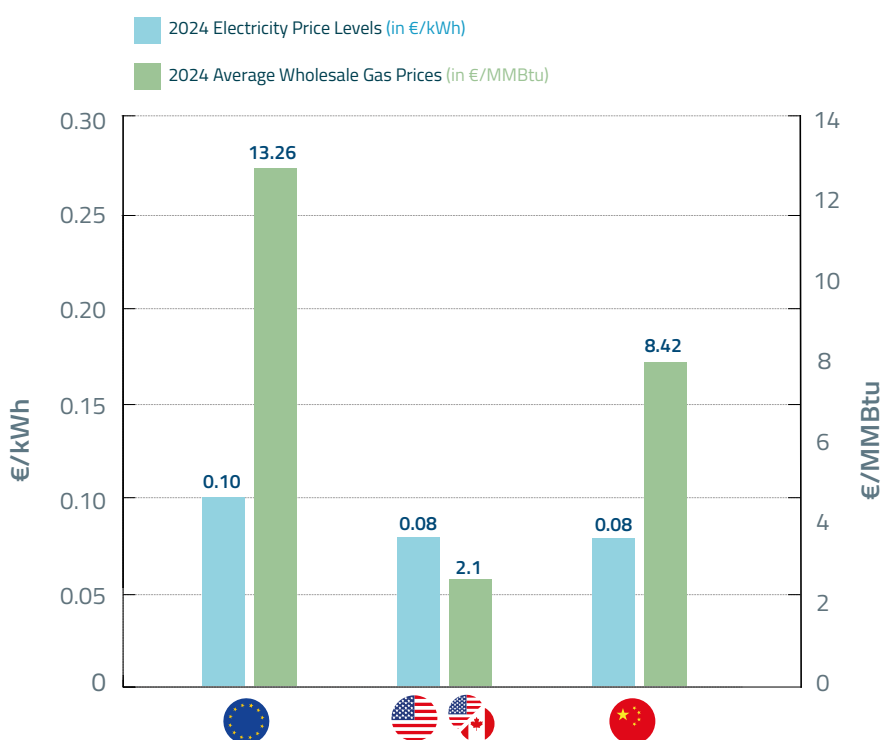


Figure 6: 2024 electricity price levels (based on data from Eurostat, US Energy Information Administration, Statista and China Briefing) and 2024 wholesale gas prices (based on data from Eurostat, US Energy Information Administration, and International Gas Union).



The Steel Industry Must Decarbonize: Existing Technologies

The global steel industry is a major greenhouse gas (GHG) emitter, accounting for roughly 7% of worldwide emissions. This is higher than the EU's overall GHG emissions, which stand at about 6%. This underlines the need for a global approach to steel decarbonization, as it is a globally traded commodity (Figure 7); most production and therefore emissions occur outside the EU, and upstream supply chains and technology deployment are inherently international. The majority of these emissions arise from the ironmaking stage, the conversion of iron ore into metallic iron, which is the most energy- and carbon-intensive step in steel production. The key driver of these high emissions is the steel sector's profound reliance on coal. It is the world's largest industrial consumer of coal, utilizing 14% of global coal consumption in 2022. Beyond the process emissions and direct combustion emissions in blast furnaces, coal-related upstream emissions, including methane

released during coal mining and emissions from coal processing and transport, further increase the steel sector's overall climate footprint and health impacts, reinforcing the case for shifting away from coal-based ironmaking routes.

The steel sector remains a comparatively under-invested sector in innovation. Between October 2022 and June 2024, the European Commission approved €9.3 billion in state aid to support transformation efforts, yet globally only 7.2% of total debt financing provided to the steel sector since 2019 has been earmarked for decarbonization, indicating that private research and development (R&D) and transition-focused investments still lag behind the scale required for deep industrial transformation.

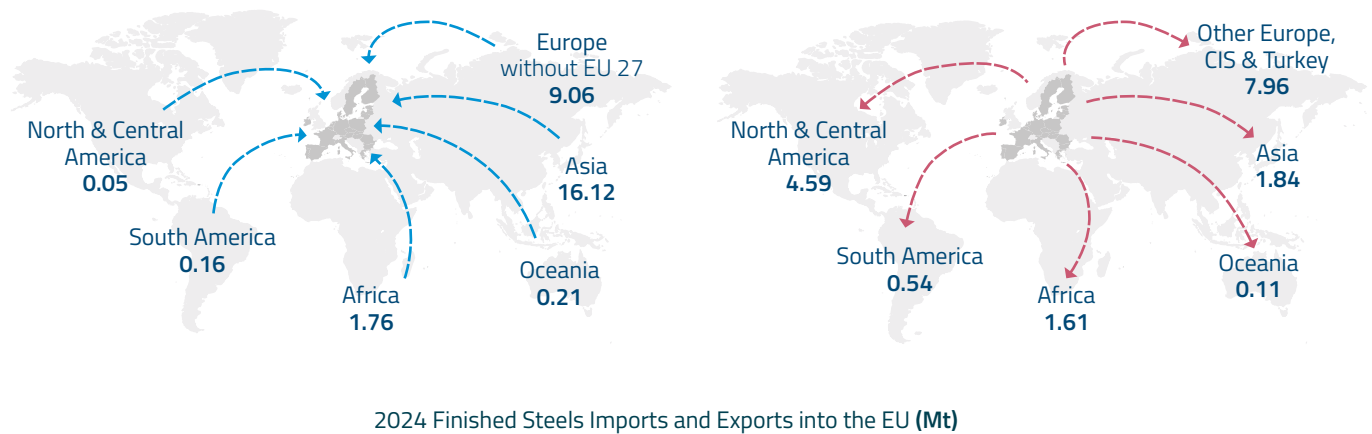


Figure 7: Trade export dependency of the EU steel sector EUROFER.

Conventional Production Pathways

Today, conventional ironmaking is dominated by the BF-BOF route. In 2024, 90% of all iron made from iron ore worldwide was produced with a blast furnace. In the EU, this share is even higher, exceeding 99%.¹² This conventional method of steelmaking (Figure 8) uses coal, in the form of coke, both as a fuel and as a reducing agent. As a result, the BF-BOF route generates on average 1.8 tCO₂/t of steel in the EU. The majority of these emissions originate from the ironmaking stage, where carbon is chemically consumed to remove oxygen from iron ore, making it one of the most carbon-intensive industrial production pathways. Historically, in the absence of carbon pricing, the BF-BOF route has been the lowest-cost primary steelmaking option. This cost advantage, combined with established infrastructure and supply chains, explains why it has remained the dominant form of steel production to date.

A key structural feature of blast furnace production is the need for periodic refurbishment, typically every 15–20 years. These relining cycles represent major capital investment decisions that effectively lock in production technology and emissions profiles for decades. Cost recovery depends on market conditions and margins, however, operators typically require extended operating periods, often in the range of around 5 to 12 years, to recover refurbishment costs. This creates a strong economic incentive to continue operating blast furnaces well into the next investment cycle, reinforcing the risk of long-term carbon lock-in. Investment decisions taken today will strongly influence industrial emissions trajectories into the 2040s and beyond, highlighting the importance of aligning reinvestment cycles with decarbonization pathways and the need for a stable regulatory framework.

¹² The blast furnace share equals pig iron production divided by total iron from ore, where total iron from ore is defined as pig iron plus DRI (based on data from the World Steel Association).

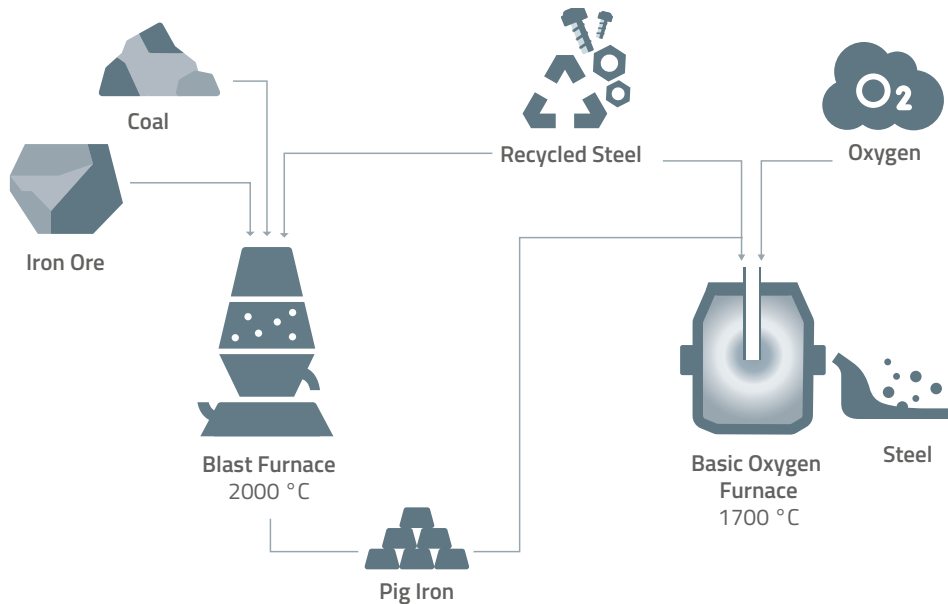


Figure 8: Traditional BF-BOF steelmaking process. This route generates on average **1.8 tonnes of CO₂**.

Alternative Production Pathways: Direct Reduced Iron Combined with an Electric Arc Furnace

The most technologically progressed alternative to the conventional BF-BOF route is the **combined DRI-EAF pathway**. DRI reduces iron ore into solid iron (sponge iron) using a reducing gas, traditionally natural gas (Figure 9) but also (renewable or low-carbon¹³) hydrogen (Figure

10), and feeds the resulting product into an EAF to produce primary steel without using coal. EAFs produce steel by melting metallic feed-stock using electricity. Depending on the production route and product requirements, EAFs can operate using 100% scrap (secondary steel-making) or a combination of scrap and primary iron units such as DRI or HBI (primary steelmaking). The exact mix depends on scrap availability, scrap quality, and the required steel grade.¹⁴

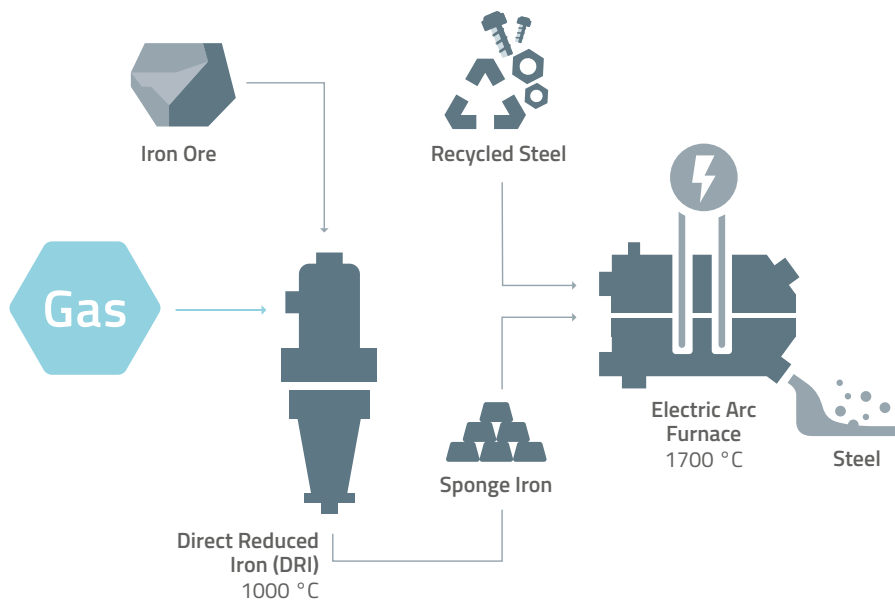


Figure 9: DRI-EAF steelmaking route using natural gas. This route generates on average **1.2 tCO₂/t of steel**.¹⁵

¹³ The Delegated Act C(2025)4674, supplementing the Gas Directive (EU) 2024/1788, defines low-carbon hydrogen in a technology-neutral way, measuring life-cycle emissions across the full value chain, including indirect ones. The key criterion is that fuels must be at least 70% below the unabated fossil-fuel comparator of 94 gCO₂eq/MJ (i.e. below 28.2 gCO₂eq/MJ).

¹⁴ The steel grade may evolve over time depending on policy and technological developments, consumer preferences, and product standards.

¹⁵ Based on IEA data, using an average EU grid emission intensity of 242 g CO₂/kWh (in 2023).

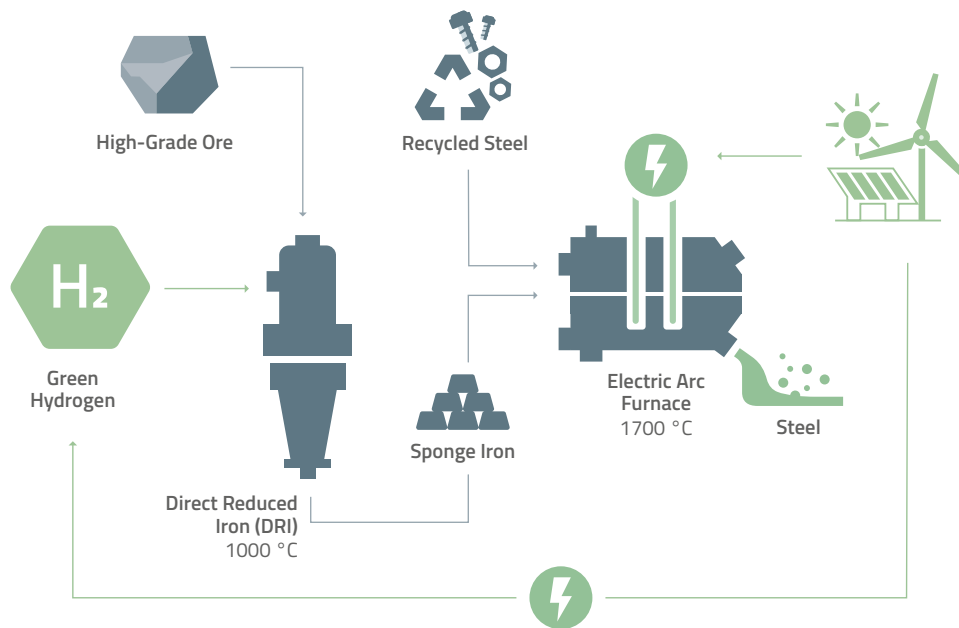


Figure 10: DRI-EAF steel making route using renewable hydrogen. This route can achieve [near-zero emissions](#).

On one hand, running an EAF on 100% recycled steel and 100% renewable electricity offers a comparatively cost-effective pathway to near-zero emissions steel production. However, scrap alone cannot meet EU steel demand or quality requirements for all applications (Figure 11). Even under optimistic scenarios, scrap availability is constrained by past production levels and long product lifetimes, and is projected to supply only around [45%](#) of steel demand by 2050, leaving a continued need for ore-based primary production.

On the other hand, DRI-EAF production pathways using natural gas¹⁶ can reduce emissions to [1.2 tCO₂/t of steel](#) and [near zero](#) when using renewable hydrogen.¹⁷ However, the scale challenge remains substantial. Today, renewable hydrogen production in Europe represents only a [very small share](#) of total hydrogen supply, while future green steel deployment scenarios imply a step-change increase in hydrogen demand over the coming decades.

In 2024, the EU imported approximately [2.75 Mt](#) of DRI, highlighting the continued role of international supply chains in supporting European steel production. In addition to feeding EAF steelmaking, DRI can be compacted into HBI, which, similar to pig iron, is a globally traded commodity with established pricing benchmarks. HBI is a dense, stable, and less reactive product that is well suited to international transport. Importing green HBI would therefore not fundamentally increase Europe’s external dependency (as the EU already relies heavily on

imported iron ore for primary steelmaking), but would instead shift imports toward lower-emission feedstocks aligned with decarbonization objectives.

Electric smelting furnaces (ESFs) are an emerging ironmaking configuration designed to process DRI using electricity to complete final reduction and melting. A key rationale for their development is their ability to integrate with existing BF-BOF sites, as ESFs can produce a hot metal-like liquid iron stream compatible with BOF converters. This allows steelmakers to partially substitute blast furnace hot metal with DRI-derived liquid iron while retaining downstream BOF infrastructure. Compared with DRI-EAF routes, which require a full shift to electric steelmaking and significant changes to plant configuration, ESFs can support more incremental decarbonization at integrated sites, potentially reducing stranded-asset risks and preserving existing converter-based operations. However, despite these integration advantages, the overall emissions profile and structural constraints of ESF-based routes remain largely determined by the upstream DRI production pathway. As a result, ESFs face many of the same structural constraints as DRI-EAF routes, including dependence on direct reduced (DR)-grade iron ore and on hydrogen or natural gas supply. In practice, only a small number of European steelmakers are actively pursuing ESF concepts, and there is [no widespread commercial deployment](#) across the EU steel fleet to date.

¹⁶ If no recycled steel is used.

¹⁷ This method is widely used in regions with cheap natural gas such as the Middle East. Some steel producers, notably in India, use coal-based syngas for their DRI. Combining this with coal-based electricity for the EAF leads to even higher GHG emissions than the traditional BF-BOF route.

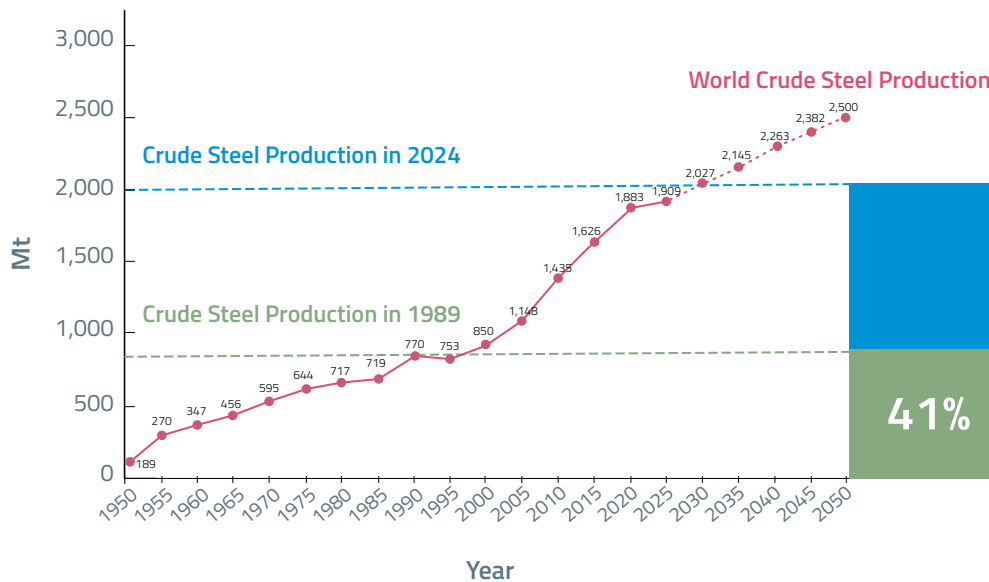


Figure 11: Global historic and projected steel demand and availability of recycled steel, including the theoretical maximum post-consumer content, with 100% recovery and recycling, no yield loss, and no erosion or wear. It can take a generation for the steel used in the construction boom to become available for recycling (adapted from [ResponsibleSteel](#) and based on data from [IRENA](#) and the [World Steel Association](#)).

Innovative Production Pathways: Molten Oxide Electrolysis and Electrowinning

Direct electrification routes offer an alternative by eliminating reliance on natural gas and hydrogen, and their required infrastructure, altogether and using electricity as the primary energy input. The two principal approaches under development are **molten oxide electrolysis (MOE)** and **iron ore electrowinning**, both of which replace conventional chemical reduction with electrochemical processes that can enable near-zero emissions ironmaking when powered by renewable electricity. However, similar to electrolytic hydrogen-based pathways, they would require substantial upgrades to grid capacity and a significant expansion of electricity generation to meet the resulting demand.

MOE operates at very high temperatures (1,600°C) and produces liquid iron directly from iron ore, releasing oxygen as a by-product and

supplying a hot metal-like stream compatible with existing steelmaking infrastructure (Figure 12). Iron ore electrowinning, by contrast, generally functions at lower temperatures and yields solid iron through an electrochemical process in an aqueous or alkaline medium. Although still at pilot and demonstration stages, these technologies could reduce exposure to fuel supply constraints and price volatility, provided that abundant, low-cost clean electricity is available at scale.

Overall, these electrification pathways represent promising long-term options, post-2035, for primary iron production in regions with abundant low-cost clean electricity, but they are unlikely to contribute materially to near-term industrial decarbonization without sustained R&D and scale-up support.

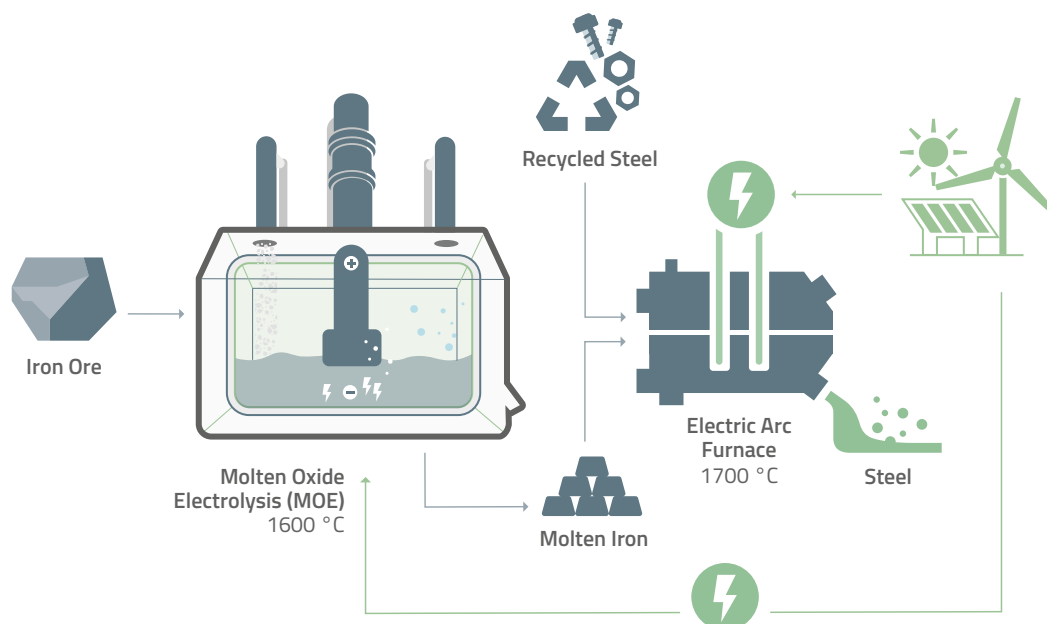


Figure 12: Directly electrified MOE-EAF steelmaking process. This route can achieve near-zero emissions.

Advantages and Challenges per Production Pathway



DRI-EAF: DRI-EAF represents a technology family that can operate using natural gas, low-carbon hydrogen, or renewable hydrogen, with emissions and costs primarily determined by the energy source rather than the core process configuration.

Advantages	Challenges
<ul style="list-style-type: none"> ▶ Significantly lower emissions than BF-BOF ▶ Commercially mature process architecture ▶ Allows staged transition from gas to hydrogen ▶ Enables global trade of low-carbon iron (HBI) ▶ Compatible with EU 2050 decarbonization targets (with renewable hydrogen) ▶ Flexible EAF input mix (DRI + scrap) ▶ Strong industry investment momentum 	<ul style="list-style-type: none"> ▶ Cost linked to gas or hydrogen price ▶ Renewable and low-carbon hydrogen currently expensive in Europe ▶ Requires large-scale hydrogen infrastructure for full decarbonization ▶ Requires substantial investment into electricity production and grid expansion in the case of electrolytic hydrogen ▶ Hydrogen transport is costly and infrastructure is slow to deploy ▶ Globally traded DR-grade iron ore supply limited (~4%) ▶ Methane and hydrogen leakage risk (for gas-based routes) ▶ Upstream emissions remain



Direct electrification (MOE and electrowinning¹⁸): While both routes bypass hydrogen by using electricity directly, MOE is designed for large-scale molten iron production at very high temperatures, whereas electrowinning operates at lower temperatures but remains at an earlier stage of technical and industrial development.

Advantages	Challenges
<ul style="list-style-type: none"> ▶ Potential for near-zero direct CO₂ emissions when powered by clean electricity ▶ Eliminates need for hydrogen production, transport, and storage infrastructure ▶ Avoids reliance on coal, coke, natural gas, or hydrogen supply chains, and associated upstream emissions/leaks ▶ Fundamentally redesigns ironmaking chemistry rather than modifying fossil routes ▶ Potential to simplify plant design and reduce process steps ▶ Potential to use a wider range of ore qualities (especially MOE, and potentially some electrowinning concepts) ▶ Potential for modular and geographically flexible deployment ▶ Builds on electrolysis experience from other metals sectors (for electrowinning) ▶ Long-term strategic option for regions with abundant low-cost clean electricity 	<ul style="list-style-type: none"> ▶ Cost linked to electricity prices ▶ Very early commercial maturity (pilot or lab stage; no full industrial reference plants) ▶ High electricity demand and need for continuous, high-quality grid connection ▶ Large-scale system integration and grid planning required ▶ Commercial cost competitiveness not yet demonstrated ▶ Significant technology readiness level (TRL) gap remains before industrial deployment ▶ Ore preprocessing requirements (especially for electrowinning) add cost and complexity ▶ Materials durability, electrolyte stability, and current efficiency still under development ▶ Production rates currently lower than conventional routes ▶ Uncertain timeline for large-scale contribution to emissions reduction (likely post-2035)

¹⁸ Key developers include [Boston Metal](#) for MOE; and Electra, ArcelorMittal (in partnership with John Cockerill), and Fortescue for [electrowinning-based](#) ironmaking technologies.

Table 1: Comparison of ironmaking technologies

Metric	BF (coal-based)	NG-DRI	H ₂ -DRI	MOE (electrolysis)
Category (framing)	Incumbent conventional route (today dominant)	Alternative route (natural gas-based)	Emerging net-zero route (hydrogen-based)	Breakthrough net-zero route (electrochemical, long-term innovation)
TRL	TRL 9 (fully commercial)	TRL 9 (fully commercial)	TRL 8 (early commercial)	TRL 4 (pilot)
Global Share of Primary Iron (2024)	~90% of primary iron	~10% of primary iron	~0% primary iron (early scale-up)	~0% primary iron (early scale-up)
Primary Reducing Agent / Energy Carrier	Coking coal » coke (primary) + pulverized coal injection (PCI)	Natural Gas (reformed to CO + H ₂)	Green Hydrogen	Electricity (no chemical reductant)
Reducing Agent Input (per t liquid steel, indicative)	505 kg/t steel (Coking coal) + 252 kg/t steel (PCI)	~275 kg NG/t liquid steel (100% DRI basis)	~60–65 kg H ₂ /t liquid steel (100% DRI metallic charge)	~3.3–4.2 MWh/t liquid steel (electricity for reduction)
Chemical energy of reducing agents (GJ/t liquid steel)	~14.2 (coking coal) + ~6.5 (PCI) = ~21 GJ/t liquid steel	~13.2 GJ/t liquid steel (100% DRI basis; reductant only)	~7–8 GJ/t liquid steel (chemical)	~12–15 GJ/t liquid steel (electricity for reduction)
Route-level emissions (tCO ₂ /t liquid steel, incl. ironmaking + steelmaking)	~2.2 tCO ₂ /t liquid steel to ~1.8 tCO ₂ /t liquid steel	~1.4 tCO ₂ /t liquid steel (IEA) to ~1.2 tCO ₂ /t liquid steel (IEA, EU electricity grid proxy)	~0.01 tCO ₂ /t liquid steel (assuming RES and green H ₂)	~0 tCO ₂ /t liquid steel (assuming RES)
Ironmaking share of route emissions (%)	~70% of integrated plant CO ₂ arises from iron production in the blast furnace	~80% of route CO ₂ arises from iron production in the DRI shaft		
Scalability Constraint	High intrinsic CO ₂ emissions; long asset lock-in; rising policy cost exposure (CBAM); upstream methane emissions from coal supply (Scope 3)	Fossil gas dependency; exposure to gas price volatility; asset lock-in risk; upstream methane emissions from natural gas supply (Scope 3)	Requires large RES and green H ₂ build-out incl. production, storage and transport infrastructure; dependence on DR-grade ore availability	Scale-up and technology maturity risk; materials and electrode durability constraints; high electricity demand and dependence on low-cost renewable power
Role in EU Green Steel Policy	Defines baseline to be replaced	Transitional route; potential platform for H ₂ conversion	Anchor technology for EU primary green steel, possibly combined with green iron imports	Long-term innovation option beyond 2035; limited near-term deployment potential

Six Recommendations to Policymakers

Delivering a competitive and climate-neutral steel sector will require a coherent policy framework that addresses both near-term decarbonization and long-term industrial transformation. In line with the EU's climate objectives for 2030, 2040, and 2050, the following recommendations aim to close remaining gaps by accelerating emissions reductions and resource efficiency in today's production system, strengthening market and regulatory signals for green steel, and enabling the scale-up of next-generation production technologies. While these measures are complementary and can be most effective when implemented together, they do not need to be applied uniformly or simultaneously. Their relevance and feasibility will vary across member states depending on national circumstances, although most actions are broadly applicable across the EU. Together, they are designed to reinforce Europe's industrial resilience, safeguard high-value manufacturing, and position the EU as a global leader in green steel.



1. Set a Clear Coal Phase-Out Trajectory for Ironmaking

The EU should establish a binding phase-out of coal-based ironmaking to prevent new carbon lock-in and align primary steel production with the European Climate Law. Around 90% of global primary steel production still relies on coal-based BF-BOF routes. These assets are highly capital intensive, with refurbishment cycles and lifetimes of 15–20 years. Allowing further reinvestment in coal-based blast furnaces risks locking in emissions well beyond 2040, directly undermining the EU's legally binding climate objectives. A phase-out should be accompanied by targeted support for the deployment of alternative pathways.

- ▶ **Refuse to permit coal-based blast furnace life extensions beyond 2030.** Installations facing refurbishment or permitting decisions before 2030 will rely on the most mature low-carbon option available today, notably DRI-EAF, while sites with longer timelines may deploy emerging breakthrough technologies such as direct electrification. Maintaining mandatory transformation plans under the revised 2024 Industrial Emissions Directive ensures alignment between permitting decisions, EU climate targets, and investment certainty, while avoiding long-term fossil lock-in.
- ▶ **Align EU ETS phase-out and funding instruments with steel decarbonization investment needs.** A predictable regulatory and financial framework is needed to enable replacement of the existing EU blast furnace fleet, as greenfield hydrogen DRI-EAF investments are estimated at US\$1,228/t of crude steel capacity.¹⁹ This requires maintaining and synchronizing the gradual phase-out of EU ETS free allocations with the investment and commissioning timelines of low-carbon assets, ensuring early and increased availability of funding through EU funding instruments and state aid frameworks, and providing revenue certainty through carbon contracts for difference.

¹⁹The US\$1,228/t of crude steel was derived based on data from [Agora Industry](#) assuming 1.2 t DRI/t crude steel and reflects estimated direct plant capital expenditure for a greenfield hydrogen DRI-EAF facility only and does not include wider system and enabling infrastructure cost (i.e. renewable power generation, electrolysis capacity, hydrogen transport and storage, grid reinforcement, and rail and logistics upgrades).

²⁰ 129 Mt CO₂ is calculated as 1.8 x 71.8 Mt of 2024 primary steel (based on data from [JRC](#) and [EUROFER](#)).

²¹ Based on [IEA](#) data, using an average EU grid emission intensity of 242 g CO₂/kWh (in 2023).

²² Assuming total metallic charge requirement of 1.2 t/t of crude steel; 20% scrap share in the metallic charge; and hydrogen consumption of 50 kg hydrogen per tonne of DRI. This corresponds to ~60 kg hydrogen per tonne of steel in a fully DRI-based charge (0% scrap), and ~48 kg hydrogen per tonne of steel under the 20% scrap assumption applied here. Further assumptions: 55 kWh/kg hydrogen for electrolysis; 489 kWh/t steel for EAF steelmaking; 177 kWh/t DRI for DRI auxiliaries; and 828 kWh/t DRI for DRI process heat.

²³ Ensuring access to affordable and abundant clean hydrogen for the steel sector should be pursued within a [broader system optimization approach](#), where limited clean power is allocated efficiently across sectors

- ▶ **Update best available techniques (BAT) benchmarks to reflect technological progress.** Iron and steel reference documents (BREFs) should be revised to recognize hydrogen-based DRI-EAF (and over time, other breakthrough technologies) as BAT benchmarks. This would progressively make unabated coal blast furnaces incompatible with environmental permitting, reinforcing the phase-out through existing regulatory tools.

Impact of the recommendation: A binding coal phase-out would prevent new fossil lock-in and deliver substantial climate benefits. Each tonne of steel produced via renewable hydrogen DRI-EAF or direct electrification could avoid 1.8–2.2 tCO₂ compared to coal-based BF-BOF. At EU scale, a full transition of primary steelmaking could abate up to 129 Mt of CO₂ per year.²⁰ DRI-EAF using natural gas would avoid 0.6–0.8 tCO₂/t of steel, depending on whether the process uses grid²¹ or renewable electricity.



2. Secure Affordable and Clean Electricity

Both hydrogen-based and directly electrified steelmaking routes are highly electricity intensive, and Europe faces structurally higher electricity and gas prices than many of its global competitors. Producing around 71.8 Mt of green primary steel via hydrogen-based DRI-EAF would require ~294 TWh of electricity.²² This highlights the system-wide implications of hydrogen-based steelmaking, as clean electricity must also support building heating, transport electrification, and other industrial uses.²³ Without sufficient volumes of affordable and abundant clean power, industrial decarbonization risks crowding out higher-value uses and placing sustained pressure on Europe's power system.

- ▶ **Upgrade and strategically expand renewable generation and grid transmission capacity in regions with structurally low-cost renewable resources.** Direct infrastructure planning and industrial siting toward these regions to reduce system stress, lower production costs, and diversify hydrogen supply across the EU.
- ▶ **Establish a framework for efficient renewable electricity allocation across sectors.** Integrate allocation principles into infrastructure planning, state aid, and funding decisions to ensure each kilowatt-hour of clean electricity delivers maximum emissions reductions, while explicitly accounting for opportunity costs between competing uses.

Impact of the recommendation: Electricity costs, including electricity for hydrogen production, are set to become the [key driver](#) of green steel competitiveness. As the sector shifts away from coal, and toward hydrogen-based steelmaking, electricity can account for 20–50% of production costs depending on electricity prices (€20–80 per MWh).

Six Recommendations to Policymakers



3. Strategically Redesign the Green Steel Global Value Chain

Where steel is made matters just as much as how it is made. In 2024, the EU imported 75% of its iron ore (73 Mt) and coking coal (29.4 Mt) demand, while total steel production reached 129.7 Mt. Of that, 71.8 Mt was primary steel, underscoring the continued need for virgin iron alongside circular production routes. Europe lacks domestic access to high-grade iron ore, and global iron and steel production is already highly concentrated. As a result, Europe will remain structurally dependent on primary iron, even under ambitious circular economy scenarios. Resilience will therefore depend less on full value chain localization and more on anchoring high-value downstream activities in Europe while securing diversified supplies of low-carbon primary iron.

- ▶ **Avoid imposing strict local content requirements on upstream ironmaking.** Forcing full ironmaking into Europe would raise costs, increase raw material dependency, and deliver limited employment benefits, given that ironmaking accounts for the majority of life-cycle emissions but a small share of the steel workforce.
- ▶ **Redesign the steel value chain to combine diversified green iron imports with strong downstream production in Europe.** Deepen partnerships with countries that combine abundant renewable potential and iron ore resources (e.g. Brazil, Australia²⁴), while anchoring steelmaking, finishing, recycling, scrap upgrading, and high-value manufacturing in the EU to strengthen resilience and industrial competitiveness.
- ▶ **Establish green iron corridors.** Support investment in renewable hydrogen and HBI production in partner countries, tied to robust sustainability standards, to secure low-carbon iron feedstock while maintaining downstream value creation in Europe.
- ▶ **Align trade policy with steel decarbonization objectives.** Explore conditional tariff preferences for green iron and certified low-carbon steel in future trade agreements. Pilot such differentiation with like-minded partners to incentivize lower-emission production while maintaining a level playing field for EU industry. Strengthen traceability and life-cycle verification in line with the Ecodesign for Sustainable Products Regulation (ESPR) and the Construction Products Regulation (CPR), and ensure coherence with the CBAM to protect EU industry while accelerating global decarbonization.

Impact of the recommendation: Building green iron corridors and diversifying supply through low-carbon imports can significantly reduce the overall cost of decarbonizing Europe's steel value chain. Producing HBI in renewable-rich regions with favorable solar, hydro, and wind conditions and importing to Europe can lower HBI production costs by 26% and steel production costs by 12–15%. While additional costs arise from processing and transporting HBI, these are marginal compared to the costs of electricity and hydrogen infrastructure, and are offset by lower system-wide infrastructure needs in Europe.

Australia and Brazil

Box 3

Australia exported nearly 900 Mt of iron ore in 2024, making it the largest global supplier. It is rapidly positioning itself as a green iron powerhouse, leveraging vast reserves, abundant renewables, and emerging hydrogen infrastructure.

Key initiatives:²⁵

- ▶ **Green Steel of WA** is developing an AU\$2.5 billion DRI plant near Geraldton using ENERGIRON technology, intended to convert WA iron ore into green DRI for export and transition from natural gas to renewable hydrogen.
- ▶ **Green Steel Australia** aims to establish a green iron production facility powered by renewable energy and using hydrogen-based direct reduction and ESF technologies.
- ▶ **Fortescue Metals Group** is developing a green iron plant at Christmas Creek with ESF technology powered by renewables.
- ▶ The **Australian National University-led H2DRI program** conducts R&D into hydrogen-based ironmaking for Pilbara ores, supported by the Australian Renewable Energy Agency.
- ▶ The **Future Made in Australia Act** includes a **Hydrogen Production Tax Incentive** of AU\$2/kg.

Brazil exported 389 Mt of iron ore in 2024, ranking second globally. Its ore is among the highest grade (60–67% Fe), ideal for hydrogen-based DRI. The EU imported US\$1.35 billion worth of Brazilian iron ore and steel products in 2024. Brazil's energy mix is 90% renewable, led by hydropower (60%), with growing solar and wind capacity. This positions Brazil to produce renewable hydrogen competitively, a key input for low-carbon steelmaking. While 76% of Brazil's steel capacity still relies on BF-BOF technology, the country is actively seeking to transition to cleaner ironmaking pathways.

Key initiatives:²⁶

- ▶ **Carbon-neutral certifications** have been issued to Aço Verde do Brasil, Aperam, and Vetorial.
- ▶ Brazil's 2024 **New Industry Plan** (Nova Indústria Brasil) targets a 10% reduction in industrial CO₂ emissions per unit of value added by 2026 and 30% by 2033.
- ▶ At COP30, certification bodies announced early-stage cooperation to align or make compatible global green steel standards, which could accelerate market uptake by simplifying how steel is certified as "green".

²⁴ Australian iron ore exports are predominantly composed of BF-grade hematite ores with relatively high gangue content, and only a limited proportion currently meets DR-grade specifications without additional beneficiation. Consequently, large-scale green DRI or green iron production in Australia would likely require further ore upgrading or alternative processing pathways, whereas Brazil already supplies a substantial share of DR-grade iron ore to global markets.

²⁵ For further information on these initiatives: [Green Steel of WA](#); [Green Steel Australia](#); [Fortescue Metals Group](#); [Australian National University-led H2DRI program](#).

²⁶ For further information on these initiatives: [carbon-neutral certifications](#); [New Industry Plan](#).

Six Recommendations to Policymakers



4. Create Lead Markets and Trusted Global Standards for Green Steel

Supply-side action must be matched by credible demand signals. Today, inconsistent terminology around green steel creates greenwashing risks and weakens demand. While existing instruments such as the EU ETS and the CBAM penalize carbon intensity, they do not in themselves create lead markets or investment certainty for early movers. A transparent, performance-based classification of low-carbon steel with gradually tightening thresholds, is therefore essential to create market uptake, reward genuine emissions reductions, and maintain EU industrial competitiveness.

- ▶ **Adopt a sliding scale approach²⁷ for labeling, instead of separating secondary and primary steel.** A single label would avoid creating incentives for relocation of primary steelmaking by rewarding hybrid DRI-EAF configurations and dynamic scrap use. Set time-dependent thresholds aligned with net-zero pathways to drive continuous improvement and prevent greenwashing.
- ▶ **Embed this harmonized classification across EU product, trade, and market regulation.** Align it with the ESPR, the CPR, and public procurement rules, and promote international comparability. To create demand through strategic EU targets, the EU could extend the Net Zero Industry Act's (NZIA) principle of strategic autonomy by setting a clear target that, by 2030, at least 40% of EU annual deployment needs for green steel in strategic projects, including infrastructure, renewable energy, mobility, and defense, are met by clean EU production. This could be operationalized through mandatory green public procurement under the Industrial Accelerator Act and competitive auctions, with remaining cost gaps bridged through carbon contracts for difference.
- ▶ **Increase structural and material efficiency across steel value chains.** Incentivize low-material design, modular construction, and high-performance applications, and introduce structural efficiency metrics (e.g. stress volume per square meter) to enable benchmarking and continuous improvement. Greater reuse, adaptability, and design for disassembly of construction elements should be incentivized, where safety allows, to reduce primary steel demand and associated life-cycle emissions.

.....
Impact of the recommendation: Meeting a 40% annual deployment target could in theory secure at least 52 Mtpa²⁸ of green steel supply in the EU by 2030, strengthening resilience, strategic autonomy, and Europe's leadership in the global transition to low-carbon steel. Material efficiency strategies, including optimized design, more efficient use of steel, and reuse, could reduce EU iron ore demand by 27%. Designing buildings, infrastructure, and products to use less steel in the first place directly reduces the volume of primary iron required, lowering total electricity demand and accelerating emissions reductions even before full technology rollout.
.....

²⁷ A [sliding scale approach](#) evaluates all steel production pathways under a single framework, based on verified GHG intensity and the share of scrap content, rather than relying on route-based distinctions.

²⁸ Based on 2024 EU steel production of 129.6 Mt.

Cost Premium of Green Steel

Box 4

Emerging evidence suggests that the cost premium of low-carbon steel compared to conventional steel may be relatively limited in many applications (i.e. automotive and building sectors), often estimated in the range of roughly 1–2% of the final product cost for downstream goods. This can also help distribute costs across the value chain as these impacts may be uneven and, at scale, still represent significant cost increases for certain sections. At the same time, this headline figure should not obscure the broader challenge of bringing low-carbon steel to market, as outlined throughout this brief. This reinforces the case for demand-side measures, standards, and market-creation policies to accelerate early deployment and scale-up of low-carbon production.



5. Circumvent Hydrogen: Invest in Innovative Primary Steel Production Pathways

Achieving climate neutrality in the steel sector will require continued investment in innovative primary steel production pathways that go beyond hydrogen-DRI and address resource constraints and long-term system efficiency. While hydrogen-based routes will play a central role in the 2030s, breakthrough technologies, such as direct electrification of ironmaking and advanced hybrid configurations, are essential to fully eliminate unabated fossil inputs, reduce reliance on scarce resources, and maintain Europe's technological leadership in global steel markets. Public policy should therefore support a diversified innovation portfolio that spans early-stage R&D and scale-up.

- ▶ **Scale up EU auctions for low-carbon products to de-risk breakthrough steelmaking.** Support first-of-a-kind and early commercial deployment of innovative primary production routes, such as MOE, enabling cost discovery and directing public funding toward projects with the highest emissions-reduction and learning potential.
- ▶ **Actively de-risk industrial electrification.** Ensure accelerated grid connection permitting, including the pre-identification of suitable industrial sites, enable long-term power purchase agreements, and deploy competitive carbon contracts for difference.
- ▶ **Reinvest EU ETS and CBAM revenues into long-term steel decarbonization innovation.** Earmark carbon pricing revenues to accelerate next-generation iron production technologies and reinforce the transition of the EU steel sector, through coordinated use of both EU-level and national funding schemes. Clear guidance on revenue use will be essential to maximize impact, avoid fragmentation, and ensure alignment with EU-wide decarbonization objectives.

Six Recommendations to Policymakers

► **Condition public funding on credible transition plans and industrial safeguards.** Link support to commitments on decarbonization, safeguards against delocalization, and maintenance of production capacity and jobs in Europe, while prioritizing investment in advanced scrap recovery, sorting, traceability, and high-quality recycling systems.

Impact of the recommendation: Targeted investment in innovative primary steelmaking pathways, particularly direct electrification, could substantially reduce the cost, scale, and system stress of steel decarbonization in Europe. Unlike hydrogen-intensive routes, direct electrification circumvents the need for large-scale renewable and low-carbon hydrogen production, and associated transport and storage infrastructure. Current EU planning foresees a hydrogen market of 20 Mt by 2030²⁹ and a pan-European backbone of around 53,000 km by 2040, with estimated cumulative investment needs of €80–143 billion, largely based on repurposing existing natural gas infrastructure. Transport costs under these assumptions are estimated at approximately €0.11–0.21 per kg for 1,000 km of onshore infrastructure and €0.17–0.32 per kg for 1,000 km of subsea pipeline. For hydrogen-based DRI pathways, these costs add to substantial upstream investments in electrolysis, renewables, storage, and system balancing. Prioritizing investment in electricity grid expansion and system flexibility could therefore offer a more efficient pathway for steel decarbonization.

► **Enable higher-quality scrap use in hybrid DRI-EAF operations to reduce system energy demand.** Align funding, standards, and design incentives to lower primary iron requirements, thereby reducing hydrogen and electricity demand and overall system costs. .

Impact of the recommendation: At EU scale, improved scrap quality could unlock an additional ~20–40 Mt of high-quality material annually, displacing the need for virgin iron inputs and translating into substantial cumulative CO₂ abatement. These reductions can be achieved without the need for immediate large-scale investment in new primary steelmaking capacity. Improvements in scrap upgrading, sorting, traceability, and end-of-life handling reduce emissions by lowering future demand for primary iron, thereby moderating requirements for hydrogen and clean electricity infrastructure. While scrap-based production relies on legacy primary steel, improving scrap quality can reduce the scale and urgency of new primary capacity deployment in the near to medium term, complementing rather than substituting long-term primary steel decarbonization.

6. Make Europe a Leader in Scrap Quality Upgrading

Innovation in primary steelmaking must be complemented by a step change in high-quality recycling to use for EU products.³⁰ While recycling alone cannot meet future demand for primary steel, improving scrap quality and availability is critical to reducing overall emissions and enabling efficient hybrid DRI-EAF operations. Today, a significant share of EU scrap is either exported, mainly to Türkiye, or downcycled due to contamination with copper and other tramp elements, despite this being technically preventable.

► **Scale up support for advanced scrap sorting and processing technologies.** Prioritize sensor-based sorting, robotics, and AI-enabled systems that improve scrap purity and enable higher-value use in high-grade steel applications.

► **Condition EU and national funding on measurable improvements in scrap quality and traceability.** Direct EU ETS and CBAM revenues toward projects that demonstrably enhance purity, circularity, and material recovery performance, rather than simply increasing scrap volumes.

► **Strengthen implementation of digital material traceability systems for steel.** Ensure product-level material information tools, including digital product passports under the ESPR, effectively improve scrap traceability, and reduce contamination risks. Expand controlled dismantling requirements, clean scrap processing standards, and eco-design rules to minimize tramp element contamination and prevent downcycling.



²⁹ REPowerEU sets a target of 10 Mt of domestic renewable hydrogen production and 10 Mt of renewable hydrogen imports by 2030.







³⁰ The construction sector is the largest consumer of finished steel products, primarily long products, accounting for 38% of total consumption in the EU. It is followed by the automotive sector (16%), which utilizes a significant share of flat products, and mechanical engineering (15%).

Conclusions

Decarbonizing Europe’s steel sector is both a climate imperative and a strategic industrial challenge. Steel underpins Europe’s economy, security, and infrastructure, yet its current production model remains incompatible with the European Climate Law. Meeting this challenge

requires more than incremental improvements: It demands a coherent policy framework that prevents new unabated fossil lock-in and fosters innovation, mobilizes investment at scale, and aligns supply, demand, and infrastructure decisions around a credible pathway to low-carbon steel.

Future Cleantech Architects advocates for the adoption of the following measures:

1.	2.	3.	4.	5.	6.
<p>Set a clear coal phase-out trajectory for ironmaking</p> 	<p>Secure affordable and clean electricity</p> 	<p>Strategically redesign the clean steel global value chain</p> 	<p>Create lead markets and trusted global standards for green steel</p> 	<p>Circumvent hydrogen: Invest in innovative primary steel production pathways</p> 	<p>Make Europe a leader in scrap quality upgrading</p> 
<p>Low-carbon/ renewable hydrogen DRI-EAF and direct electrification can cut 1.8–2.2 tCO₂/t of steel compared to coal-based BF-BOF, while natural gas DRI-EAF saves 0.6–0.8 tCO₂/t of steel. A full EU transition could abate up to 129 Mtpa of CO₂.</p>	<p>Electricity costs are set to become the key driver of green steel competitiveness. Electricity can account for 20–50% of production costs in hydrogen-based steelmaking depending on electricity prices.</p>	<p>Producing HBI in renewable-rich regions with favorable conditions and importing to Europe, can lower HBI production costs by 26% and steel production costs by 12–15%.</p>	<p>A 40% green steel target could in theory secure at least 52 Mtpa of supply in the EU by 2030. Material efficiency strategies could reduce EU iron ore demand by 27%.</p>	<p>Direct electrification of steelmaking avoids the need for large-scale hydrogen production, transport, and storage. Investing in electricity grid expansion and flexibility could offer a more efficient decarbonization pathway than the €80–143 billion hydrogen infrastructure planned for 2030 to 2040.</p>	<p>Improved scrap quality could unlock an additional ~20–40 Mt of high-quality material annually in the EU, reducing the need for virgin iron.</p>



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The contents of this report represent the views of Future Cleantech Architects and should not be taken to represent those of the reviewers or the organizations to which they are affiliated.

About Future Cleantech Architects:

We are a climate innovation think tank. We exist to close the remaining innovation gaps to reach net-zero emissions by 2050. To reach this objective, we accelerate innovation in critical industries where sustainable solutions are still in very early stages. .

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