Demands for renewable hydrogen and electricity to drive the EU's green iron and steel transition

Eileen Torres-Morales, Aaron Maltais, Jindan Gong

An analysis based on data from LeadIT's Green Steel Tracker of the possible renewable energy and renewable hydrogen demands for iron reduction and primary steel production in the European Union

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The Leadership Group for Industry Transition (LeadIT) gathers countries and companies that are committed to action to achieve the Paris Agreement. It was launched by the governments of Sweden and India at the UN Climate Action Summit in September 2019 with support from the World Economic Forum. In recognition of the progress made by LeadIT, India and Sweden reaffirmed their commitment to its mission and established a new work pillar for LeadIT with a focus on technology transfer and codevelopment, and a dedicated industry transition platform (ITP) between the two countries.

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Key messages

Decarbonizing steel production in the European Union will involve a significant increase in the demand for renewable electricity, particularly for production of renewable hydrogen.

If the transition from fossil fuel-based to renewable electricity-based iron and steel production is to succeed, there is a need for reliable estimates of how much renewable electricity it will demand. Such estimates are also needed so that the transition in the steel sector is aligned with developments in the energy and other industrial sectors.

In this report we assess the potential demands for renewable hydrogen and renewable electricity from announced green steel projects within the EU, based on data from LeadIT's Green Steel Tracker. The analysis evaluates two scenarios for green iron and steel production. The first scenario assumes no use of scrap in steel production, and the second assumes a 50% share of scrap. Both scenarios then also explore two routes for green steel production: one with an EU-based value chain for iron and renewable hydrogen, and another relying on iron sourced from outside the EU.

- We estimate that if all announced green iron and steel projects in the EU were to rely on **renewable electricity** by 2045 and did not use scrap, up to 135 terawatt hours of renewable energy would be needed annually. This is the most energy intensive scenario for the EU in our analysis, and the estimate amounts to about 2.8% of the additional renewable energy required between now and 2030 to meet the aspirations in the EU's Renewable Energy Directive. Although this represents a small portion of the EU's renewable target, these projects account for only one-third of current annual EU steel production (150 MTPA). Additionally, aggregate figures for renewable capacity do not account for needs that are specific to individual steel plants.

- Our estimates suggest that if no scrap is used, **green hydrogen** demand could reach 1.7 MTPA by 2030, increasing to 1.9 MTPA by 2045. This represents 19% of the EU's target for domestic production of renewable hydrogen, and would cover one-third of today's steel production.

- If EU companies were to import hot briquetted iron (HBI), thus outsourcing the most energy intensive part of hydrogen-based green steel production, the renewable energy requirements would be around one quarter of the energy needed for fully domestic green hydrogen and direct-reduced iron production without scrap.

- The significant differences in energy needs across scenarios suggest that transparent planning by the EU and steel producers is essential to meet renewable electricity demand across sectors and achieve decarbonization.

- Our assessment of company plans for sourcing renewable energy, green hydrogen, and/or hot briquetted iron (HBI) reveals that there is not sufficient transparency on how companies intend to supply these inputs for announced green steel projects. Because many companies' green steel production strategies depend on how the price of renewable energy and green hydrogen develops, more transparency would enable companies and policymakers to assess the feasibility of projects, to ensure realistic timelines, and to assess whether sufficient supply infrastructure will be in place to meet demand at competitive prices.

Executive summary

The REPowerEU plan envisions that, by 2030, at least 30% of EU-based primary steel production will be decarbonized, relying on renewable hydrogen produced with renewable energy. Achieving this will involve an increase in the demand for renewable electricity, particularly for the production of renewable hydrogen, the reduction of iron via the hydrogen-based route (H-DRI), and the subsequent use of electric arc furnaces (EAF). However, there is limited information available on the specific renewable electricity requirements needed for decarbonizing the steel sector.

To better understand the challenges of deploying renewable hydrogen and renewable electricity in low-carbon iron and steel production in the EU, this study uses LeadIT's Green Steel Tracker to evaluate projects that plan to phase out blast furnaces used in iron production.

Among these projects there are some that focus only on iron reduction, others only on steel production, and yet others that integrate both iron reduction and steel production. Production pathways also vary and include:

- use of green hydrogen (GH) for the direct reduction of iron (GH-DRI)
- use of natural gas for iron reduction, with a promise to shift to green hydrogen when price and availability make it feasible (NG-DRI to GH-DRI)
- use of GH-DRI produced locally in the EU for steel-making in electric arc furnaces (EAF), and
- use of imported briquettes of reduced iron (i.e. hot briquetted iron, or HBI) for steel-making in electric arc furnaces (HBI + EAF).

In this report we first estimate the potential renewable hydrogen-based iron and green steel capacity in the EU, if all the projects in our study that are planning to phase out blast furnaces were to employ green hydrogen and be powered with renewable electricity by 2045. Then, using scenario analysis, we evaluate the renewable electricity required to support these hydrogen capacities and estimate the share of the EU's target renewable electricity capacity that would need to be dedicated to green iron and steel production.

According to the project plans captured by the Green Steel Tracker, companies are planning to produce approximately 33 million tonnes of green iron and 42 million tonnes of green primary steel annually in the EU by 2030. By 2045, this would rise to approximately 35 million tonnes of green iron and 48 million tonnes of green primary steel.

To achieve these production plans, around 135 terawatt hours of renewable electricity would be needed each year for local renewable hydrogen production, GH-DRI iron reduction, and steel-making via EAF. In this report, this is Scenario 1, in which where no scrap is used. Demand represents around 2.8% of the additional renewable electricity production required in the EU between now and 2030 to meet the aspirations of the EU's Renewable Energy Directive.

We find that while the renewable energy demands of announced green steel projects in the most energy intensive scenario represent only a small portion of the EU's targeted increase in renewable energy production, this does not tell the full story. These aggregate figures do not reveal the availability of renewable energy supply at specific production sites. Moreover, announced green steel projects represent a little less than a third of the EU's total steel production today.

Demand for renewable hydrogen varies depending on the amount of recycled steel used in production processes. If no scrap is used (Scenario 1, in our analysis), demand for green hydrogen can reach 1.7 million tonnes per annum (MTPA) by 2030, and 1.9 MTPA by 2045 (note again that announced projects represent about a third of current EU steel production). In a scenario where 50% scrap is used alongside reduced iron for steel-making (Scenario 2), the renewable hydrogen demand decreases to around 1.05 MTPA by 2045. The use of 50% scrap and reduced iron brings down renewable energy demand to 84 TWh.

The RePowerEU plan aims for a supply of 20 million tonnes of renewable hydrogen per year by 2030, with half produced within the EU and half imported. If the 2030 renewable hydrogen demand for iron direct reduction was to be covered by the 10 MTPA envisioned to be produced within the EU by 2030, this demand would represent between 10% to 19% of the envisioned locally produced hydrogen.

This study provides an initial exploration of the differences in energy demand between different routes for green steel production. Additional energy requirements (e.g. for transportation of raw materials or energy losses in supply chains) are not considered.

When considering only renewable electricity demand, it would be much less energy intensive for the EU to use imported hot briquetted iron (HBI) to produce green steel than producing renewable hydrogen for the reduction of iron ore within Europe. This production route would require only a quarter of the energy needed to produce green hydrogen and direct reduced iron domestically in the EU. However, importing HBI also involves trade-offs, including reduced self-sufficiency in steel production and impacts on jobs in the sector.

The significant differences in energy needs across scenarios suggest that transparent planning by the EU and steel producers is essential to meet renewable electricity demand across sectors. Companies will need to secure access to renewable energy and renewable hydrogen, and develop clear strategies for closing energy access gaps.

Achieving a net-zero transition for the EU's iron and steel sector will require collaborative and coordinated efforts to rapidly expand renewable electricity infrastructure and ensure timely supply of renewable electricity for hydrogen production and steel-making. Based on an assessment of company plans for sourcing renewable energy, renewable hydrogen, and HBI, we find that more transparency is needed on how companies plan to supply these inputs for announced projects.

Glossary

BF	blast furnace
BOF	basic oxygen furnace
DR-SF	direct reduction shaft furnace
EAF	electric arc furnace
GH	green hydrogen
GH-DRI	direct reduction of iron using green hydrogen
HBI	hot briquetted iron
MTPA	millions of tonnes per annum
NG-DRI	direct reduction of iron using natural gas
SEC	specific electricity consumption

1. Transitioning to low-carbon steel production: from coal-based to green hydrogen solutions

The reduction of iron ore is a necessary step for primary steel production. Today, the most common process used for this is coal-based blast furnaces (BF) (Cavaliere, 2019). Primary steel is then produced by adjusting the carbon content and alloying the iron in a basic oxygen furnace (BOF). One alternative route, known as secondary steelmaking, involves recycling steel scrap in an electric arc furnace (EAF). Another route for making primary steel, which is less common in Europe, is the direct reduction of iron ore using natural gas, followed by further processing in an EAF to melt the iron and adjust its carbon content (Åhman et al., 2018; Hoffmann et al., 2020).

The coal intensive BF-BOF process in the context of Europe emits on average 1.9 tonnes[1] of CO2 per tonne of crude steel, while the natural gas direct reduction route (NG-DRI) emits on average 1.4 tonnes of CO2 per tonne (European Parliamentary Research Service, 2021). In contrast, steel recycling in an EAF in Europe emits on average 0.4 tonnes of CO2 per tonne of steel (European Parliamentary Research Service, 2021), which is around three to four times less than the BF-BOF route. Primary steel production based on coal and natural gas positions steel-making as a high-emissions sector, responsible for about 7 to 8% of global CO2 emissions from the energy system (IEA, 2023a).

Reductions in CO2 emissions can be achieved by phasing out the use of blast furnaces and coking coal to reduce iron ore, and instead moving to a process where green hydrogen[2] is used for direct reduction of iron ore to produce green hydrogen-based direct reduced iron (GH-DRI) (Bhaskar et al., 2020; Rechberger et al., 2020; Vogl et al., 2021). The steelmaking process can then take place in an EAF, powered with renewable electricity, where GH-DRI and scrap can be melted and alloyed with coal to produce crude steel. This process is the focus of this report and is, as we describe below, central to the decarbonization plans of steel companies in the EU.

The GH-DRI and EAF processes can happen at the same site, but reduced iron can also be externally sourced. In other words, iron ore reduction using green hydrogen (or some other low emissions method) can happen at another location and be transported to the steel-making plant. To facilitate the transport process, the reduced iron is compacted, in the form of hot briquetted iron (HBI) (Lopez et al., 2023). At the EAF the HBI and scrap can be melted and alloyed with coal to produce steel.

Large amounts of renewable energy are required to produce low-CO2 emissions iron and steel using the GH-DRI process. First, renewable electricity is needed to run water electrolysis to obtain green hydrogen that will be used as the reducing agent for iron ore reduction. Second, renewable electricity is needed to provide power to both the direct reduction shaft and the EAF.

In the case of externally sourced HBI, the iron briquettes arrive at the steel plant at ambient

1 In this report, tonne refers to 1000 kilograms (sometimes called a metric ton in the US).
2 Renewable hydrogen refers to hydrogen produced through the electrolysis of water with renewable electricity. In this report, the terms renewable hydrogen and green hydrogen are used interchangeably.

temperature. This means, that the HBI needs to be heated, using renewable electricity, before it can be combined with scrap and carbon to produce crude steel.

2. The role of renewable hydrogen and electricity in the EU's industrial transition

Reducing greenhouse gas emissions from the iron and steel sector is key to mitigating the negative effects on climate of rising global temperatures. In Europe, hydrogen (H2) use in the industrial sector has been promoted as an alternative to fossil fuels (European Commission, 2022c). H2 is already necessary in industrial processes in the chemical industry and to produce fertilizers, and is increasingly recognized as playing a vital role in emerging low-emissions technologies in the iron and steel industry.

The International Energy Agency (IEA) has projected that for the European iron and steel industry to decouple from fossil fuel intensive processes it will need to rely heavily on hydrogen and electricity (IEA, 2023b). Furthermore, green hydrogen-based steel production is the route to decarbonization that European steel producers have most frequently proposed. The Green Steel Tracker, hosted by the Leadership Group for Industry Transition (LeadIT) has tracked announcements of low-emissions iron and steel production projects since 2021 (LeadIT, 2024). Most of these announced projects are in Europe, and the large majority of these are planning for the use of hydrogen and electrification to reduce emissions (LeadIT, 2024).

2.1 Renewable energy demand in the EU

To put into context the new demands for renewable energy in steel-making, this section provides an overview of current and future energy demand in the EU, and the EU's visions for renewable energy and renewable hydrogen use. It also outlines European policies that set the ambition for Europe to be a leader in the production and use of renewable hydrogen.

In 2023, total energy consumption in the EU was around 15 662 TWh (Energy Institute, 2024a). Of this, just 7%, or around 1211 TWh, came from renewable energy sources including hydropower, wind, solar and other renewables (Energy Institute, 2024b). Figure 1 illustrates changes in the mix of these renewable energy sources from the beginning of the century.

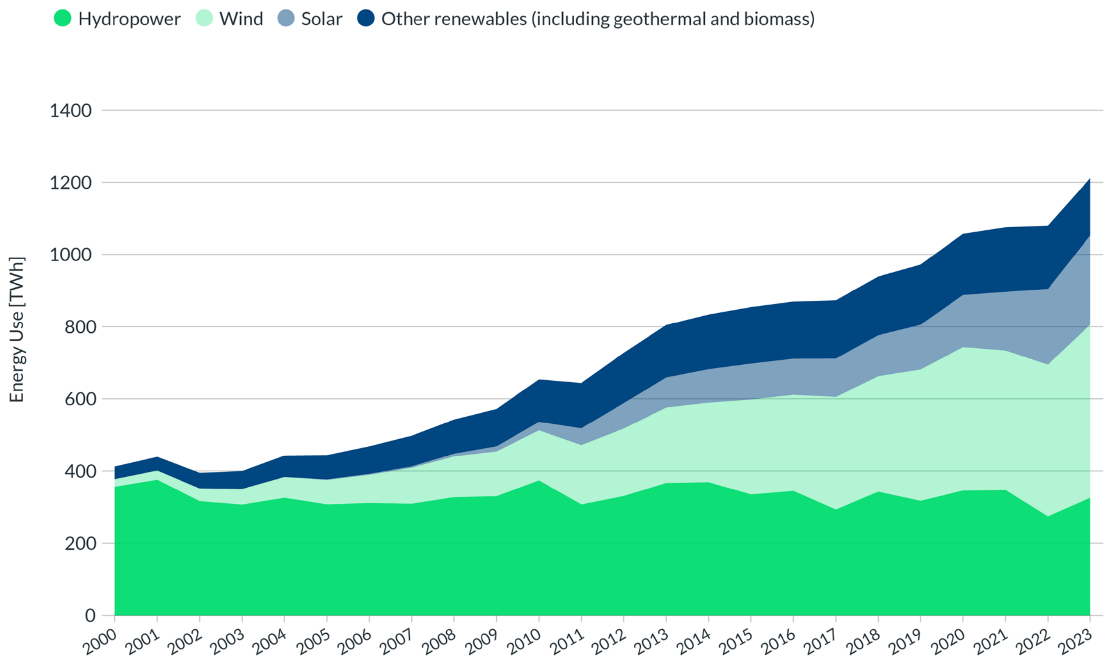


Figure 1. EU's use of renewable energy. Source: Adapted from Energy Institute (2024b)

In a future where fossil fuels are phased out, the share of renewable energy in the EU must ramp up. This has been acknowledged in the Renewable Energy Directive, which in 2022 set the goal of a share of renewable energy sources of at least 40% by 2030 (European Commission, 2022d). In 2023, the ambition was increased to a 45% share for renewable energy by 2030 (European Commission, 2023b).

The EU envisions that net greenhouse gas emissions should decrease by at least 55% by 2030 (European Commission, 2022d). The Fit for 55 legislation package prepares the ground for attaining this goal through policy alignment. Examples of energy-related policies include the Renewable Energy Directive and the Energy Efficiency Directive.

In the years to come, the EU also plans to decrease its energy demand. The Energy Efficiency Directive plans for a final energy consumption reduction of 11.7% by 2030, relative to 2020 (European Commission, 2023a). If we consider energy demand in 2023, it can be estimated that final energy demand in 2030 could be around 13 829 TWh. This represents a reduction of around 1800 TWh, compared to the 15 662 TWh consumed in 2023. If by 2030 renewables provide 45% of energy in the EU, this would mean renewables would be delivering around 6223 TWh of energy, which in turn means that at least 5012 TWh of additional production of renewable energy needs to come online between today and 2030.

2.2 The role of renewable hydrogen

The industrial sector will follow a declining trend along with the decrease in energy consumption and increase in renewable energy. This is to be accompanied by a shift in the mix of energy sources and carriers, which is where renewable hydrogen comes into play.

The renewable energy directive envisages that, "by 2030 42% of hydrogen to be used in industry should come from renewable fuels of non-biological origin and 60% by 2035" (European Commission, 2023b). Figure 2 presents the projections of total energy use in the industry by source by 2030 and 2050 that would be in line with the Fit for 55 policy package. In particular, by 2050 hydrogen and e-fuels are targeted to be part of the industry energy mix with a contribution of approximately 817 TWh per year.

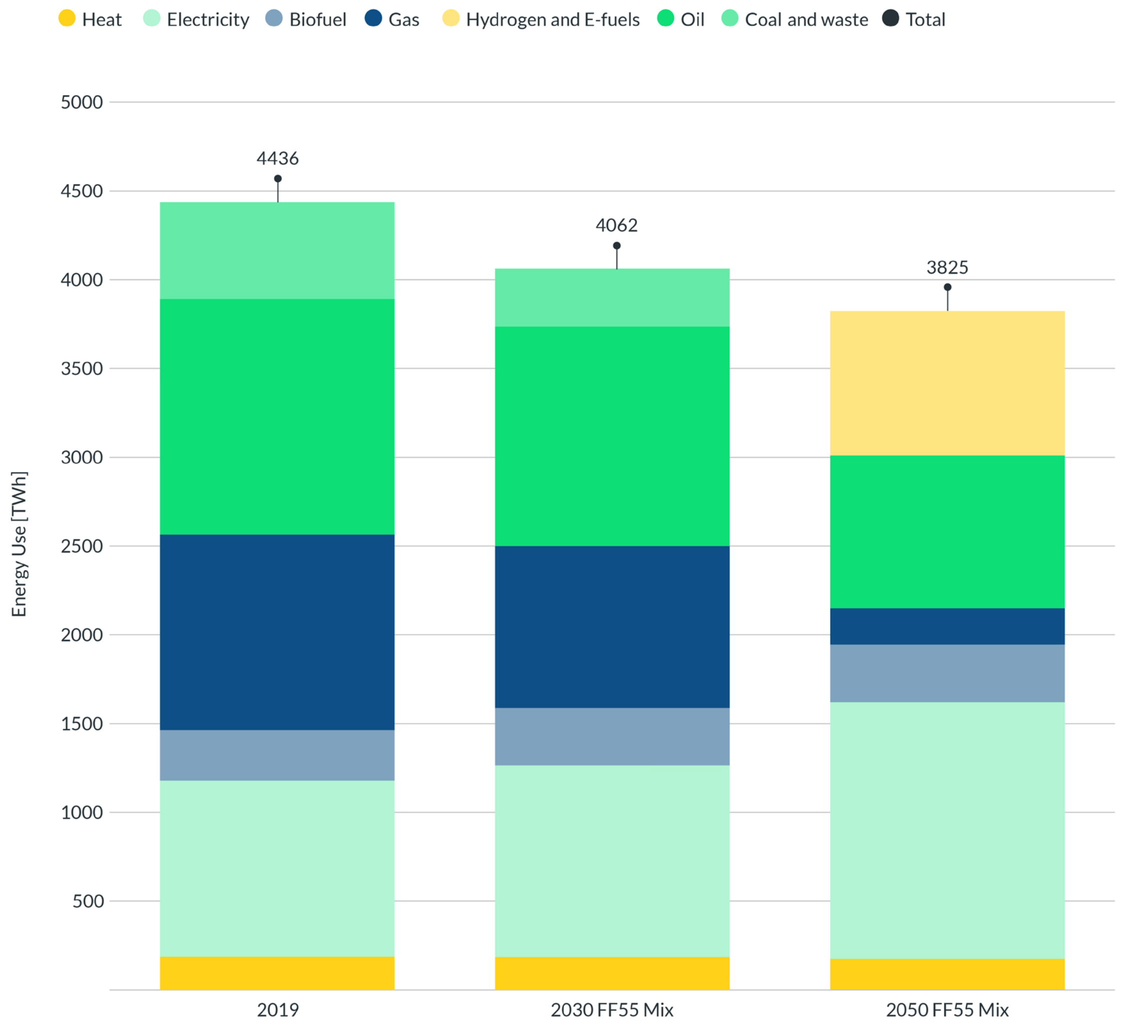


Figure 2. Energy use scenarios to 2030 and 2050 for the EU's industrial sector by fuel. The 2030 Fit for 55 Mix scenario considers a net 55% emission reduction by 2030 compared to 2019, while the 2050 Fit for 55 Mix scenario assumes that net-zero emission reduction is reached. Source: Adapted from the JRC's interactive tool (Joint Research Centre, 2020).

In 2022 the European Commission launched the REPowerEU plan with the aim to reduce dependency on fossil fuels from Russian origin. Among the action points, the Commission prioritizes the scaling of renewable energy sources for power generation (European Commission, 2022c).

Under the REPowerEU, there is a vision for 20 million tonnes of renewable hydrogen to be available by 2030 in the EU. The plan's target is for 10 million tonnes of renewable hydrogen to be produced within the EU, with the remaining 10 million tonnes being imported (European Commission, 2022e). The vision behind the 2030 renewable hydrogen target is that fossil-fuel intensive sectors such as transport and heavy industry can be decarbonized (European Commission, 2022c).

Yet the availability of sufficient renewable electricity is vital to the success of phasing out fossil fuels and broadening the use of green hydrogen in industries, including iron and steel.

To reach the 2030 target of producing 10 million tonnes of renewable hydrogen in the EU, additional capacities are required for power generation and local electrolyser manufacturing. On one hand, according to the European Commission (2022a) around 500 TWh of additional electricity power generation would be needed by 2030 to meet the local renewable hydrogen target. On the other hand, this document also foresees that local manufacturing capacity for electrolysers, in terms of hydrogen output, should be around 90 to 100 GW_{LHV} per year by 2030 (European Commission, 2022b).

Various estimates of the EU's future hydrogen demand (renewable and non-renewable) have been presented by different bodies. The comparison presented in Figure 3 shows some of these estimates.

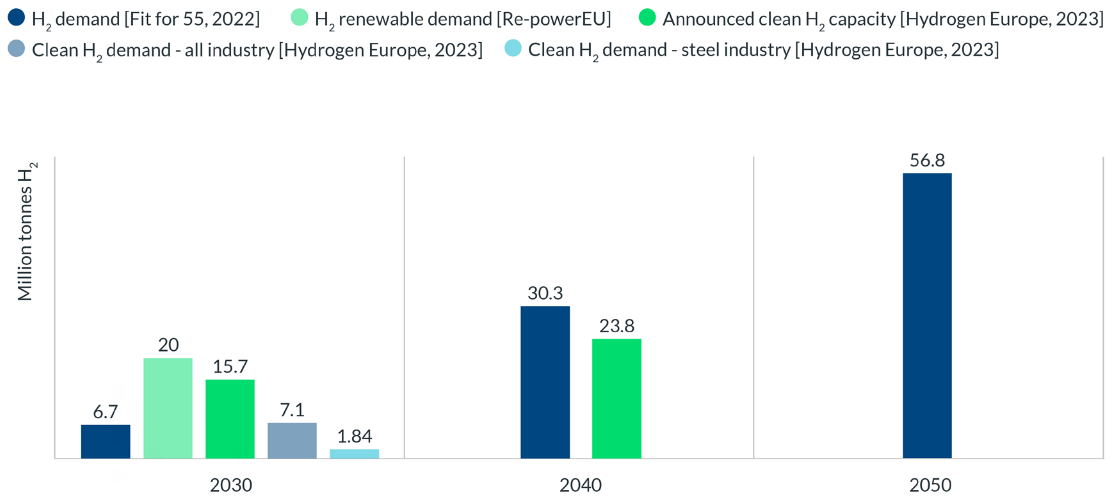


Figure 3. Assorted hydrogen demand projections to 2030, 2040 and 2050. Source: Adapted from (European Hydrogen Observatory, 2023b, 2023a; Hydrogen Europe, 2023).

Originally, the 2022 version of the Fit for 55 package aimed at increasing renewable hydrogen capacity to 6.7 million tonnes by 2030. This changed with the introduction of the RePowerEU plan, which raised the ambition to 20 million tonnes. In addition, Hydrogen Europe, the hydrogen value chain industry association, has estimated the demand for clean[3] hydrogen across the EU will be around 15.7 million tonnes by 2030. Hydrogen Europe also estimates that by 2030 demand for

3 Hydrogen Europe includes in its definition of clean hydrogen the following methods for producing it: power–to–hydrogen (electrolytic) and reforming with carbon capture (Hydrogen Europe, 2023).

clean hydrogen in the steel sector will be around 1.8 million tonnes, all of which will be new capacity. Today only 0.33% of the 11.5 million tonnes of hydrogen production capacity in the EU comes from water electrolysis powered by renewable electricity (see Figure 4) (Hydrogen Europe, 2023). This means that nearly all hydrogen produced in the EU today is fossil fuel based.

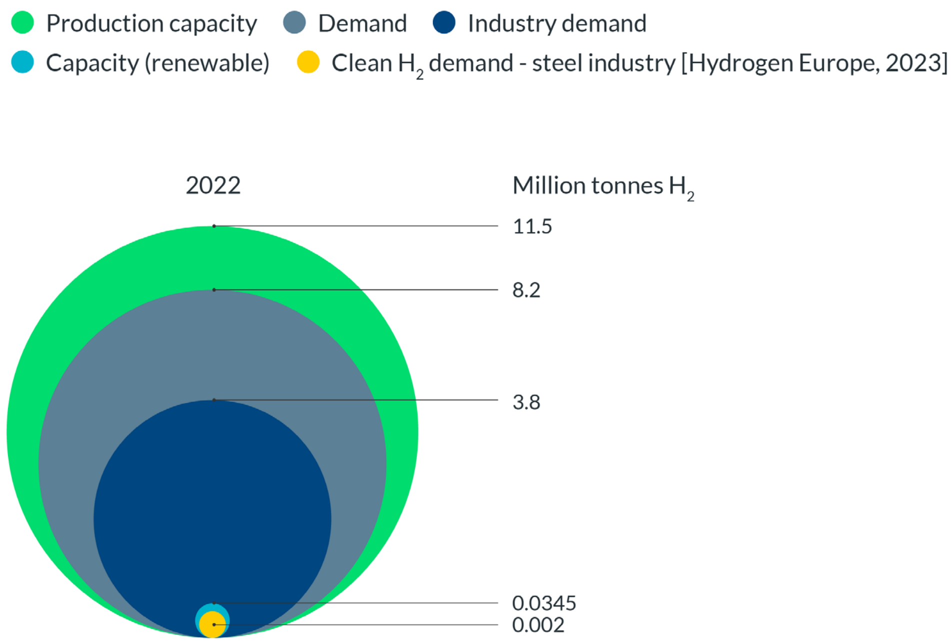


Figure 4. EU's hydrogen production capacity and demand in 2022. 0.33% of the total production capacity correspond to water electrolysis run on renewable electricity. Source: Original graph based on data from Hydrogen Europe, 2023.

At the level of individual EU member states, challenges exist to reach the 20 million tonnes of renewable hydrogen by 2030. A recent analysis by the European Court of Auditors found that national production and import targets are misaligned with the Commission's targets (ECA, 2024). Furthermore, the minimum requirements for EU member states' national energy and climate plans (NECPs) did not explicitly ask for national targets for renewable hydrogen, leading to insufficient information on renewable hydrogen goals and targets on a national level (ECA, 2024).

The development of new renewable hydrogen production capacity must happen with a simultaneous increase in the renewable energy capacity and sufficient grid capacity (ECA, 2024). This is also applicable for the steel industry. Iron and steel producers that envision utilizing renewable (green) hydrogen for direct reduction of iron and electric arc furnaces for steel-making will need to develop clear strategies for how they will satisfy their renewable energy demand in a context where renewable energy capacity will be needed to support the decarbonization of many sectors (EEB, 2023).

3. Plans for the introduction of green iron and steel production capacity in the EU

This section presents details of those iron and steel projects that were considered for the estimates presented in the subsequent sections of this report. The analysis is based on public project announcements available in LeadIT's Green Steel Tracker.

The Green Steel Tracker is an open-source tool and dataset hosted by the [Leadership Group for Industry Transition (LeadIT)](). The tracker presents a global overview of publicly announced projects aimed at the manufacturing of primary steel with substantially lower carbon dioxide emissions. The tool focuses on primary steel production because it is tracking efforts to transition away from conventional steel making that uses coal-based blast furnaces. Within the global projects contained in the tracker, Europe is the region with the highest number of project announcements.

We studied 24 project announcements within the EU for green iron and green steel production. Only projects that consider the phase out of blast furnaces and have the potential to abate 85% or more of CO2 emissions compared to the BF-BOF route (Agora Industry et al., 2024) were considered. Carbon capture and storage (CCS) and projects dedicated to hydrogen production only were out of scope for this analysis.

To facilitate the analysis, the projects were first categorized based on the technology announced by the respective companies. Table 1 summarizes these classifications. Subsequently, the projects were categorized according to their production focus: green iron only, green iron and green steel, or green steel only. The distribution of these projects is illustrated in Figure 5.

Table 1. Technologies studied in the green iron and steel production scenarios of this report. Note: Projects focusing solely on EAF using scrap are not included in the scope.

Technology	Description
GH-DRI	Direct reduction of iron ore using green hydrogen
GH-DRI + EAF	Direct reduction of iron ore using green hydrogen, followed by steelmaking in an Electric Arc Furnace (EAF)
NG-DRI to GH-DRI	Initial reduction of iron using natural gas, with a planned future transition to green hydrogen
NG-DRI to GH-DRI + EAF	Initial reduction of iron using natural gas, transitioning to green hydrogen, followed by steelmaking in an EAF
EAF using green iron (EAF + HBI)	Transition from BF-BOF steel production to EAF using green iron, assumed to be Hot Briquetted Iron (HBI)

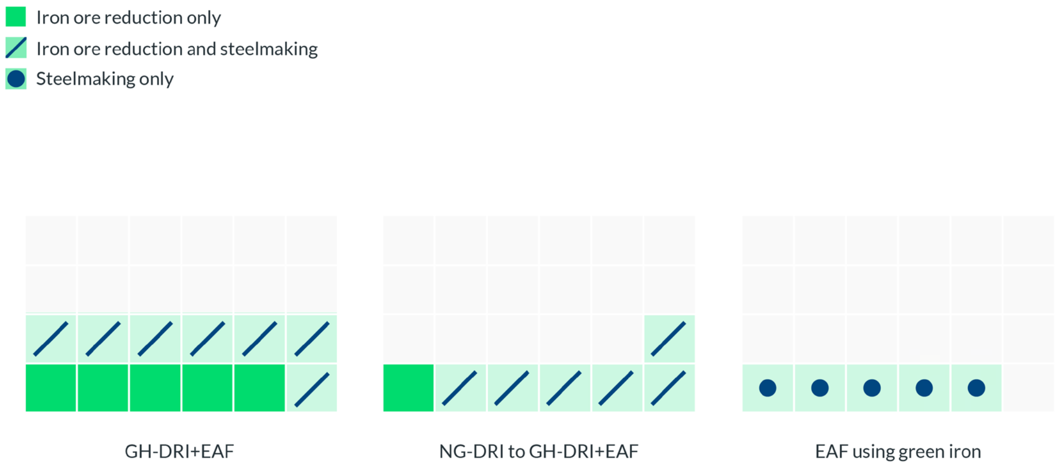


Figure 5. Iron and steel projects analysed in this study. Shaded squares indicate the 24 projects analysed. Per category this is 12 for GH-DRI+EAF; 6 for NG-DRI to GH-DRI; and 5 for EAF using green iron.

Although projects must provide some basic information[4] to be included in the Green Steel Tracker, not all companies have publicly disclosed their planned operational capacity. To address this gap, two approaches were used.

In cases where steel production capacity was known, but not the iron production capacity (or vice versa), conversion factors were employed. This method was only possible in projects involved in both iron and steelmaking.

For projects with limited information, it was assumed that the new green capacity would replace coal-intensive operating capacity scheduled for closure in the coming years. Data from Global Energy Monitor's (GEM) Blast Furnace Tracker and Global Steel Plant Tracker (Global Energy Monitor, 2024b, 2024a) were employed to estimate this replacement capacity. Details of the projects and capacities considered can be found in the Annex to this report.

The installed capacities for green iron and steel production, along with their expected operational dates, are outlined below. European companies have announced projects for both renewable hydrogen-based and natural gas-based iron ore reduction, signalling a shift away from blast furnaces (see Figure 6). For natural gas-based projects, the expectation is to transition fully to renewable hydrogen operations in the future.

By 2025 the first full-scale projects are expected to be operational, with a capacity to produce approximately 2 million tonnes per annum (MTPA) of iron. By 2030 the expected capacity is around 33 MTPA and by 2045, the EU's total new capacity for green iron could reach around 35 MTPA.

4 Including the timeline to be online (year), the technology to be used (e.g., hydrogen direct reduction) and the scale of the project (pilot, demonstration, full scale)

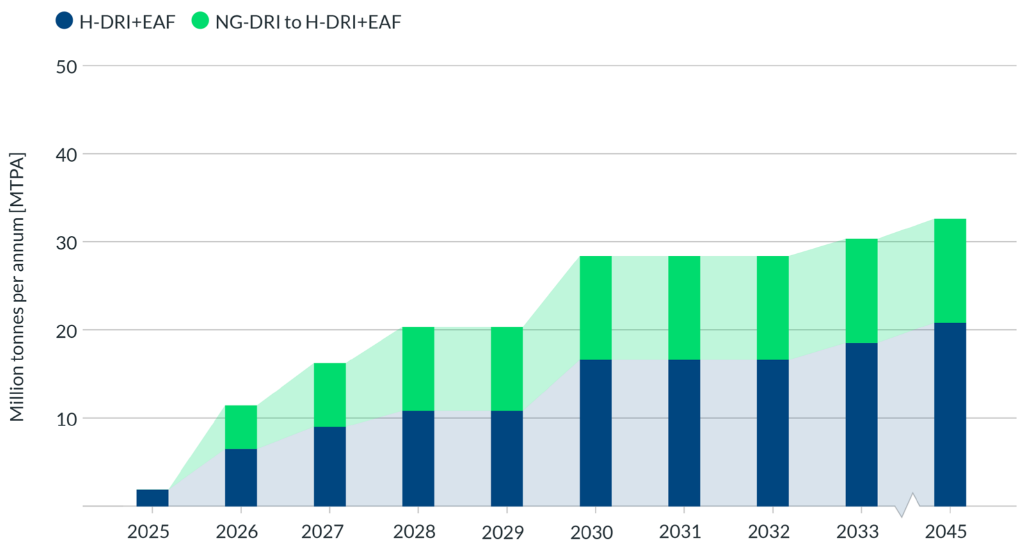


Figure 6. Timeline of cumulative announced installed capacity of direct reduced iron (DRI) using H-DRI and NG-DRI to H-DRI based on company plans. A break is used between the years 2033 and 2045 due to unchanging data between 2033 and 2044. Source: Green Steel Tracker

The crude steel production estimates based on company plans (see Figure 8) account for projects intending to source their own reduced iron for melting and alloying in electric arc furnaces (EAF), as well as those planning to import reduced iron briquettes (HBI) for the same purpose. Based on plans in the Green Steel Tracker, companies are targeting around 6.5 MTPA of green steel production capacity by 2025. By 2030 the plans indicate a capacity of around 42.2 MTPA, and the total green steel capacity in the EU plans could grow to around 48 MTPA by 2045.

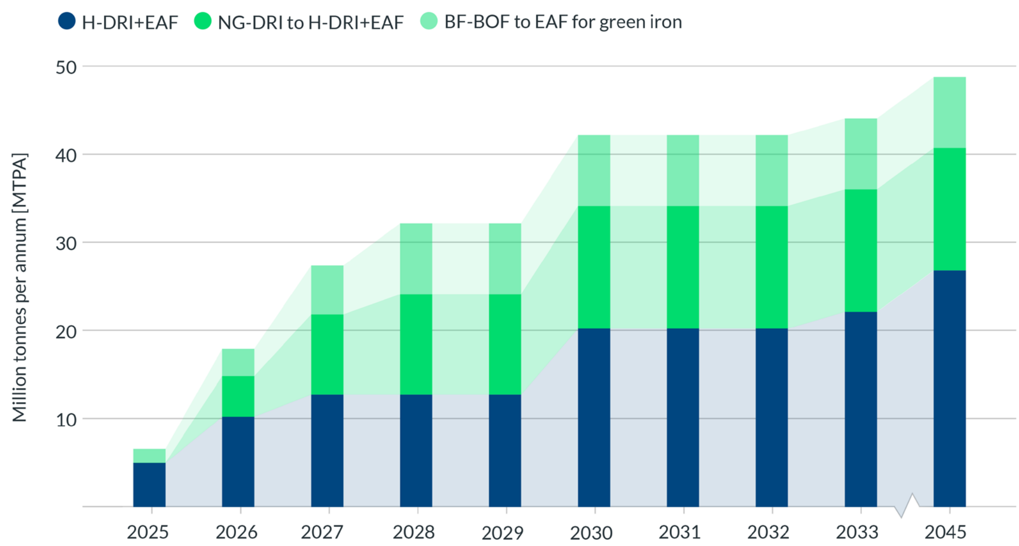


Figure 7. Timeline of cumulative announced installed capacity of green steel using a combination of H-DRI and NG-DRI to H-DRI + EAF , as well as projects shutting down BF-BOF to utilize HBI in EAF- based on company plans. A break is used between the years 2033 and 2045 due to unchanging data between 2033 and 2044. Source: Green Steel Tracker

There is a difference of about 13 MTPA between the capacities for crude iron (35 MTPA) and crude steel (48 MTPA). This difference may be attributed to factors such as the import of green iron and the use of scrap in conjunction with locally produced or imported green iron in EAFs. While these figures represent the total installed capacity expected by 2045, actual utilization of this capacity will depend on market demand. It is important to note that not all the reduced iron is transformed into crude steel. For every tonne of crude primary steel produced, around 1.1 tonnes of reduced iron is required (see assumptions in Section 4.3). If, by 2045, all announced green steel production capacity (48 MTPA) relies solely on domestic direct reduced iron, around 53 MTPA of reduced iron would need to be produced within the EU. However, if a proportion of scrap is incorporated into the alloy, the required quantity of green iron will be lower.

4. Estimates of renewable hydrogen and electricity demands for the production of green iron and steel

This section explores the possible renewable electricity demand associated with renewable hydrogen production and the direct reduction of iron using green hydrogen and steelmaking via electric arc furnace (EAF) in the EU. The study scope considers 24 announced projects that are planned to be operational by 2045. This section introduces the scenarios used and then presents the obtained results.

4.1. Scenarios used in the analysis

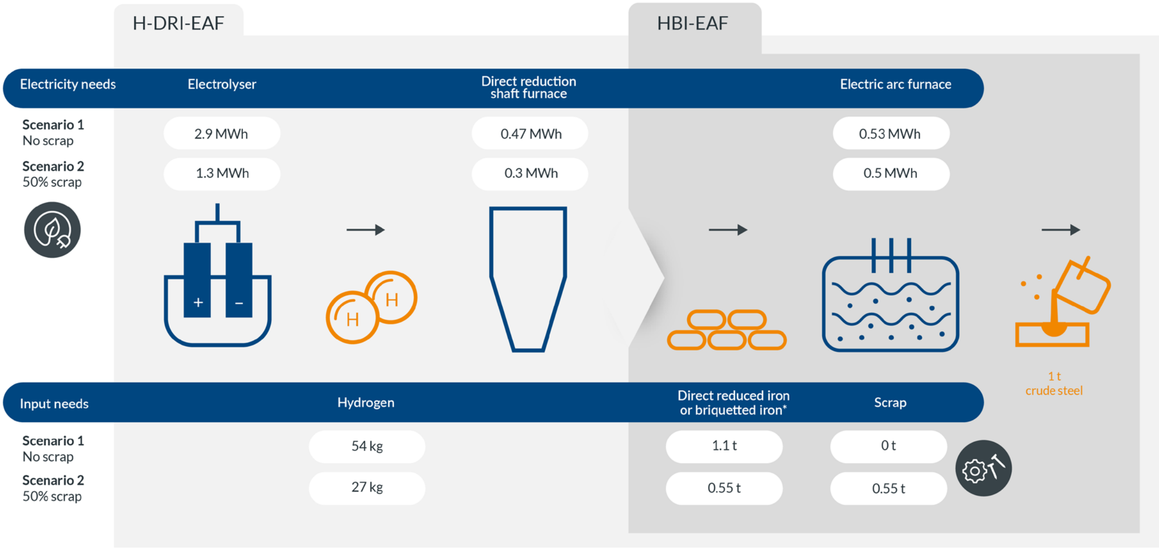
Two scenarios were used to estimate the possible renewable energy demand for primary steelmaking. The first scenario assumes no use of scrap, while the second assumes a 50% share of scrap.

Within these scenarios, two possible production sequences were evaluated, based on the sourcing of reduced iron: one with a local value chain and other allowing for iron sourcing from outside the EU. Both production processes assume the use of renewable energy across the entire process, with full utilization of the announced installed capacity.

In the Green H-DRI + EAF sequence it is assumed that renewable hydrogen production, iron reduction and steel-making occur within the EU. It is assumed that all projects will be able to operate using 100% green hydrogen before 2045.

Meanwhile, in the HBI + EAF production sequence, it is considered that the reduced iron in the form of hot briquetted iron (HBI) is imported from outside of the EU to be used for steelmaking. Upstream processes, such as electrolysis, direct reduction of iron pellets and compressing direct reduced iron (DRI) to HBI, take place outside the EU. The energy needs for transport to and within the EU, and associated losses, are not considered in the scope of the study.

An overview of the two scenarios is presented in Figure 8.



(*) note that the HBI-EAF route involves an additional 0.16 MWh of renewable electricity due to the additional heating needs of cold iron briquettes.

Figure 8. Schematic of the green H-DRI + EAF and HBI + EAF processes and the renewable electricity and input needs associated. This figure illustrates the needs for the two scenarios analysed.

4.2. Steps for the scenario analysis

The following steps were taken to estimate the renewable energy needs for both production sequences:

Green H-DRI + EAF production sequence:

1. Renewable energy is used in an electrolyser to produce green hydrogen locally in the EU (GH2).
2. The GH2 is then fed into a direct reduction shaft furnace (DR-SF) along with high quality iron ore pellets (DR-grade pellets), producing direct reduced iron (DRI) – a process that also requires additional renewable energy.
3. The DRI, produced with green hydrogen (H-DRI), is fed into an electric arc furnace (EAF) while still at high temperature, through a direct link to use as much heat from the DRI shaft as possible and reduce the need for additional heating. (In the scenario with scrap usage a share of scrap is also fed into the EAF.)
4. Renewable energy powers the EAF to produce crude steel.

HBI + EAF production sequence:

1. Hot briquetted iron (HBI) is produced outside the EU.
2. The HBI is imported, having cooled to room temperature before transport.
3. At the steelmaking facility, renewable energy is used to pre-heat the HBI to the required temperature.

4. The preheated HBI is then fed into the EAF. A share of scrap may also be fed into the EAF.

5. Renewable energy powers the EAF to produce crude steel.

4.3. Assumptions

The main assumptions of the process energy consumption are presented in Table 2.

Table 2. Process reductant and energy consumption assumptions

Process	Value	Unit	Reference
Hydrogen need for the direct reduction of iron pellets	53.8	kg H2/t DRI	Average value based on (Boyle, 2021; Shahabuddin et al., 2023)
Electricity need for DRI shaft furnace operation	472	kWh/t steel	(Andersson, 2022)
EAF specific energy consumption	526.6	kWh/t steel	Assuming 0% scrap Average value based on (Andersson, 2022; Bhaskar et al., 2022; Cappel, 2021; Toktarova et al., 2021)
Electricity need for re-heating HBI	159	kWh/t steel	(Vogl et al., 2018)

The electrolyser efficiency is assumed to follow a linear function dependent on the installation year. The function varies between an efficiency[5] of 51.2 kWh/kg H2 (or 65%) for the year 2020, and 43.8 kWh/kg H2 (or 76%) for 2050, according to IRENA (2020).

The specific electricity consumption (SEC) of the EAF varies according to the share of scrap fed into the process. As presented in Table 2, if no scrap is fed, the EAF SEC is approximately 530 kWh/t steel. To estimate the SEC when 100% scrap is fed in the EAF an estimation based on the work by Vogl et al., (2018) is performed, leading to around 470 kWh/t steel, or around 11% less energy compared to when no scrap is used. The EAF SEC is assumed to follow a linear relationship between those values.

The raw material requirements to produce one tonne of crude steel are provided in Table 3.

5 33.33 kWh of energy are contained in 1 kg of H2.

Table 3. Assumed raw material consumption

Process	Value	Unit	Reference
DRI or HBI	1.1	t DRI/t steel	Assuming 0% scrap feed. Based on (Vogl et al., 2018)
Scrap	1.1	t scrap/t steel	Assuming 100% scrap feed. Value based on (Agora Industry et al., 2024)

Our estimates assume a renewable electricity capacity factor of 33%, or 2900 hours per year, considering an average of solar power, wind power and hydropower. The electrolyser operating capacity is assumed to be around 5000 hours per year based on Hydrogen Europe (2023).

4.4. Results: findings on renewable hydrogen and electricity demands

The results in this section should be interpreted as an indicative average of the EU's possible demand for renewable hydrogen and electricity. The estimates presented below do not consider access to renewable electricity for specific projects in specific locations/countries.

Green H-DRI + EAF production sequence

Our estimates indicates that by 2045, if no scrap is used, around 1.9 million tonnes of GH2 per year would be needed for the direct reduction of iron in the EU (see Figure 9). This would be equivalent to an electrolyser installed capacity, measured in terms of hydrogen output, of approximately 12.6 GW, dedicated to the production of GH2 for the iron and steel industry. Consequently, from 2045, no less than 94 TWh of clean electricity would be required annually to meet the hydrogen demand of steel projects in the Green Steel Tracker if they were to be fully realised without the use of scrap (see Figure 10).

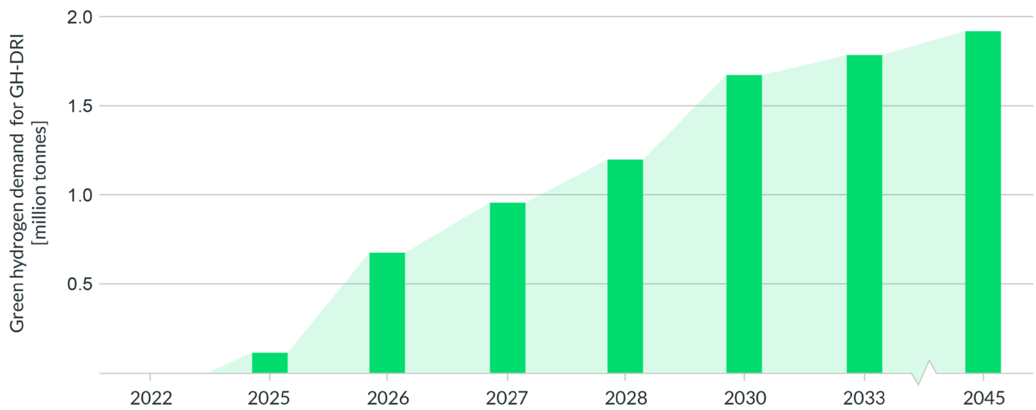


Figure 9. EU's green hydrogen demand over time for iron reduction, assuming all projects use green hydrogen. A break is used between the years 2033 and 2045 due to unchanging data between 2033 and 2044. Source: Green Steel Tracker

If a share of 50% scrap is to be utilized in all projects using the Green H-DRI + EAF production sequence, the GH2 demand would be halved for projects combining both local iron reduction and steelmaking. However, this decline would not apply for projects focused solely on iron reduction, which make up six of the twenty-four studied projects (see Figure 5).

In this scenario, with 50% scrap used, approximately 1.05 million tonnes of GH2 would be needed by 2045, equivalent to a 6.9 GW electrolyser capacity measured in terms of hydrogen output. The energy demand for producing GH2 under these conditions would require about 51.5 TWh of renewable electricity annually (see Figure 10).

In addition to the electrolyser's electricity demand, renewable electricity is required for reduction and EAF-based steel-making. Figure 10 provide close-ups of the estimated electricity demand for these three stages.

In the scenario with no scrap use, where all projects rely on locally produced GH2 and reduced iron, around 135 TWh of renewable electricity per year would be needed by 2045 to power the electrolysers, iron reduction and EAF.

In the 50% scrap scenario, this requirement drops to about 84 TWh annually.

The use of 50% scrap for steelmaking would reduce the overall renewable electricity demand by approximately 37%, largely due to decreases in the production of green hydrogen and reduced iron. However, for the EAF steelmaking process, the reduction is less pronounced, with only a 6% decrease in electricity demand.

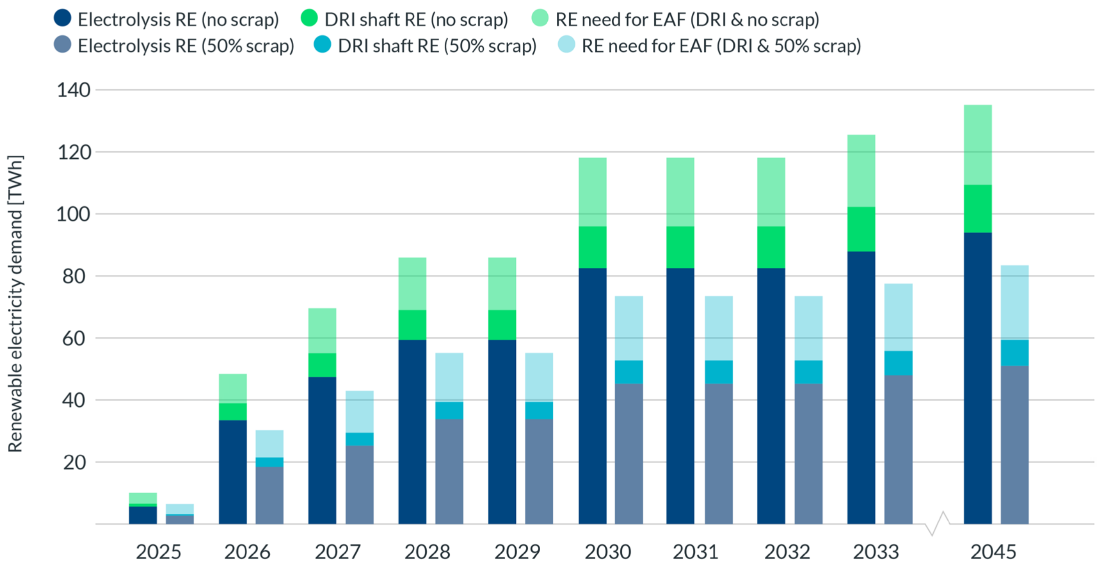


Figure 10. Renewable electricity demand for iron and steelmaking (Green H-DRI + EAF) with no scrap use and with 50% scrap use. A break is used between the years 2033 and 2045 due to unchanging data between 2033 and 2044.

HBI + EAF production sequence

The main difference of the HBI production path is the assumption that neither electrolysis nor iron reduction are takes place within the EU. This eliminates the electricity demand for producing GH2 and running the direct reduction shaft furnace. However, electricity is still needed to heat the room-temperature imported HBI before it is fed into the EAF. Therefore, the estimated electricity demand for the HBI + EAF production sequence considers the heating of HBI and the demand for running the EAF for steel production.

If no scrap is used, around 33 TWh of renewable electricity per year could be required by 2045 for steel production via the HBI + EAF route, with around 8 TWh of this energy dedicated to the heating of the cold HBI.

In the scenario where 50% scrap is used, total electricity demand drops to around 28 TWh, with about 4 TWh needed for heating the HBI.

Electricity demand in both scenarios

For both scenarios, the use of imported iron briquettes indicates a substantial reduction in renewable electricity demand compared to EU-based iron reduction with EU-based GH2. This is shown in Figure 11.

On one hand, in the no scrap scenario, the electricity demand by 2045 of the Green H-DRI + EAF production sequence is four times higher than the HBI + EAF sequence (around 135 TWh versus 33 TWh). On the other hand, in the 50% scrap scenario, Green H-DRI + EAF production sequence demand is three times higher than in the HBI + EAF sequence (around 84 TWh versus 28 TWh).

The key driver of the differences in electricity demand is whether the GH2 production and the shaft furnace iron ore reduction are located inside or outside the EU, because these processes on average account for more than two-thirds of the Green H-DRI + EAF total electricity demand.

When comparing the electricity demand of the HBI + EAF sequence in the two scenarios, the difference is relatively small. The 50% scrap scenario requires around 5 TWh less electricity than the fully HBI-reliant scenario.

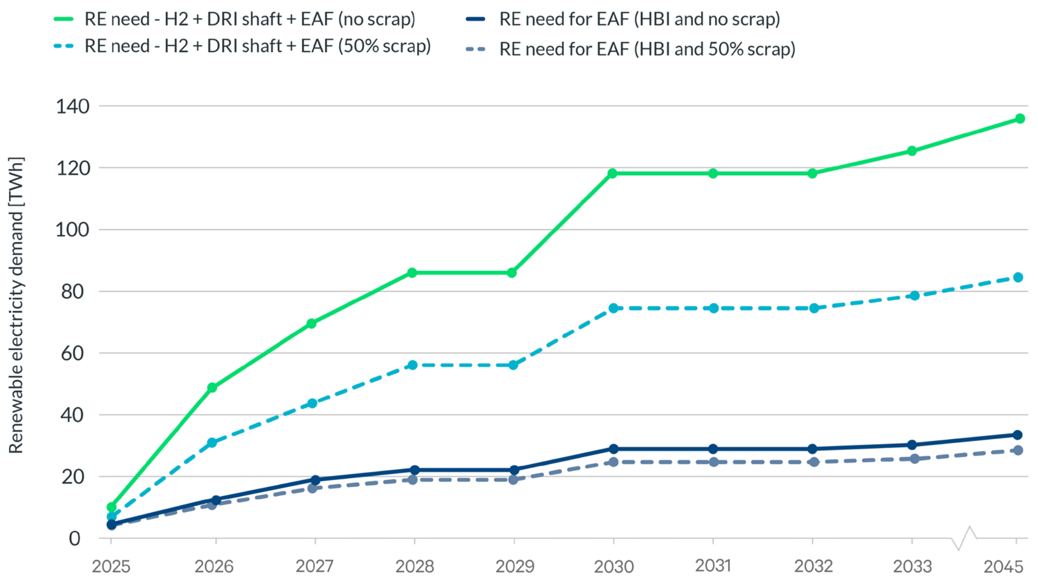


Figure 11. Projected renewable electricity needs for the iron and steel sector in the EU when no scrap is used (solid line), and when 50% scrap is used (dashed line). A break (also known as kink) is used in between the years 2033 and 2045 due to unchanging data between 2033 and 2044.

5. Existing corporate strategies for the transition to green iron and steel production

Publicly available reports and online resources from twelve steel producers and one iron producer were reviewed to better understand their strategies for renewable hydrogen, renewable electricity, and DRI sourcing. These companies are responsible for the projects analysed in this report. The review provides a snapshot of where these companies stand today, but the limited sample of thirteen companies is insufficient to draw broader conclusions about the direction of the iron and steel sector in Europe.

Of the thirteen companies, eight are established producers, while five are emerging companies with no prior iron or steel production. Table 4 summarizes these companies' strategic plans.

All thirteen companies have publicly expressed some degree of interest in using renewable hydrogen for direct iron ore reduction. Out of the thirteen, seven companies have indicated plans in corporate reports and press releases to locally produce hydrogen by integrating electrolysers into their production facilities. Three companies plan to source renewable hydrogen externally, while little information is available about hydrogen sourcing strategies for the remaining three.

However, the levels of interest and commitment vary. Some, like the Swedish companies SSAB and LKAB, have collaborated on developing and testing a pilot H-DRI unit using green hydrogen. However, at least three of the eight established companies have stated in their annual reports or public press releases that H-DRI project development will hinge on the affordability of renewable hydrogen.

This cost-related conditionality on use of green hydrogen has led some EU-based companies to propose a two-step approach in transitioning away from coal-based blast furnaces for iron reduction. Such strategies involve starting with a transition to iron reduction using natural gas, with the potential to switch to renewable hydrogen reduction when it is judged to be cost competitive. These companies make it clear in their public reports that such a shift will only occur when they consider the costs of renewable hydrogen to be competitive for the business.

Ensuring access to renewable electricity is also part of the transition strategies for some of the studied companies. Eight companies have publicly announced agreements with electricity providers and grid operators to secure their future energy needs. However, the level of detail in these announcements varies, making comparisons difficult. Some companies only mention partnerships with utilities, while others provide specific timelines and energy quantities to be contracted.

For emerging companies, there is often little to no public information on their strategies for accessing renewable electricity. These companies lack transparency about their future renewable electricity requirements, or any anticipated power purchase agreements or contracts, making it challenging to assess their preparedness for the transition to renewable electricity. The only exception is Stegra, which has provided some clarity on its plans.

Information remains limited on the sourcing and trade of hot briquetted iron (HBI). Only one company, voestalpine, has indicated plans to import HBI from outside Europe, while SSAB expects to source HBI from its partner LKAB within Sweden. However, information on quantities and trade strategies is insufficient for a more detailed assessment of the implications for EU's renewable electricity needs.

Table 4. Summary of findings from desktop research of corporate strategies for the transition to green iron and steel production

		Renewable hydrogen			Renewable electricity		HBI
Company name	*Has a public plan for introducing renewable H-DRI?*	*Company planning to produce their own H2*	*Company planning to externally source H2*	*Company is unclear with their H2 sourcing*	*Has a plan for sourcing renewable electricity*	*No information available on renewable electricity sources*	*Has a public plan for sourcing HBI*
ArcelorMittal[1]	■			■	■		
Tata Steel (Europe branch)[2]	■		■		■		
Thyssenkrupp[3]	■		■		■		
voestalpine Group[4]	■	■			■		■
SSAB[5]	■	■				■	■
Salzgitter Group[6]	■	■			■		
Stahl Holding Saar GmbH[7]	■		■		■		
LKAB[8]	■	■				■	
Blastr Green Steel[9]	■	■			■		
GravitHy[10]	■	■				■	
Stegra (formerly H2 Green Steel)[11]	■	■			■		
Hydnum Steel[12]	■	■		■		■	
HyIron[13]	■			■		■	

Sources:

1 ArcelorMittal, 2020, 2021, 2022, 2023b, 2023a; Dunkerque Promotion, 2024; Kolisnichenko, 2024; Mandel, 2021a, 2021b)
2 (Gulati, 2024; Tata Steel Europe, 2023)
3 (thyssenkrupp, 2020, 2023, 2024)
4 (voestalpine, 2023, 2024a, 2024b)
5 (SSAB, 2022a, 2022b, 2023, 2024)
6 (Salzgitter AG, 2023)
7 Burgess, 2024; Collins, 2024; Martin, 2024; Ørsted, 2024; Saarstahl, 2022; SHS – Stahl Holding Saar, 2024)
8 (LKAB, 2023a, 2023b)
9 (Blastr - Green Steel, 2024b, 2024a; Fortum, 2023a)
10 (EGHAC, 2023; GravitHy, 2022, 2023, 2024a, 2024b; Parkes, 2022)
11 (Fortum, 2023b; H2 Green Steel, 2023; Stegra, 2023, 2024)
12 (Chiavegatto, 2023, 2024a, 2024b)
13 (HyIron, 2022, 2023)

6. Discussion

6.1. Prioritizing renewable hydrogen and electricity planning in green iron and steel projects

EU-based projects aiming to produce green iron and steel must consider renewable electricity demands early to ensure sufficient power for iron reduction and steel production. With project timelines set for the next five years (2025–2030), this planning is urgent. By 2030, nearly 30 million tonnes per annum of direct reduction iron (DRI) and around 42 MTPA of steelmaking capacity are planned to be operational in the EU.

The lack of specificity in current corporate strategies, and the considerable developments that need to be made during the next five years, present an opportunity to establish strategies for green iron and steel production in the EU. Two main pathways are being proposed by companies in the EU: an integrated process where renewable hydrogen, reduced iron, and steel are produced locally within the EU, or an alternative process, only described by a few companies, using imported hot briquetted iron (HBI) from outside the EU for steelmaking. The choice of pathway will significantly influence the EU steel sector's demand for renewable electricity and green hydrogen.

Currently, renewable hydrogen demand in the steel industry is minimal. Yet, if the renewable hydrogen-based reduction route is chosen, demand would rise sharply from today's 0.002 MTPA to 1.78 MTPA by 2030, and up to 1.9 MTPA by 2045.

Our study indicates that approximately 2.8% of the additional renewable electricity that the EU hopes will be generated by 2030 will need to be allocated to the analysed projects if they were to rely on local renewable hydrogen-based iron reduction and renewable-powered electric arc furnaces (EAF). This figure suggests that meeting the energy needs of currently planned green steel production could be quite feasible. However, a number of issues need to be considered to better understand what our analysis shows.

First, our analysis is based on announced plans and does not assess what would be required to convert all the EU's current steel production to the green H-DRI + EAF route. The EU's average annual steel production over the past decade is around 150 MTPA (EUROFER, 2023). This is more than three times the amount of steel production than is currently found in the Green Steel Tracker for the EU, and would require much higher levels of green hydrogen production to decarbonize (EUROFER, 2019). There is still a lot of uncertainty about how the geography of steel production will change in the drive to net-zero by 2050, and, in turn about how much steel will be produced in the EU by mid-century. Our figures provide important insights into the initial ramp-up phase of this transition in Europe based on plans announced by the companies covered in this study.

Second, our assessment looks at projected aggregate DRI and steel in relation to aggregate EU targets for renewable energy power production. However, the energy demands for local green hydrogen, DRI, and steel production will occur at specific sites, and the conditions for delivering the needed renewable energy can vary very significantly at different locations. Thus, the challenges in meeting renewable energy needs for each specific project must be based on assessments of the specific conditions at those sites. This is one of the main reasons this report is calling for more transparency on how companies plan to meet their needs for hydrogen, renewable energy, or HBI resources to implement their decarbonization plans.

Finally, any assessment of the renewable energy and hydrogen demands for implementing green steel production is based on a set of assumptions, covering parameters like equipment efficiency, capacity factors (in terms of hours of operation per year), and scrap usage. In our study we make assumptions about the amount of hydrogen required to reduce iron pellets, the specific electricity consumption of the DRI shaft furnaces, electric arc furnaces, and for heating HBI, together with the annual capacity factor of the renewable energy sources and electrolyser. Changes to the capacity factors and parameters related to hydrogen production can have large effects on projections of energy and hydrogen needs and can lead to difficulties in comparing studies. A valuable area for continued research is to refine understanding of the most significant parameters that affect renewable energy and hydrogen demands for the steel transition when developing scenario analyses.

The EU's target of a 45% renewable energy share by 2030 is ambitious, and reaching it could be challenging without putting in place the right incentives for planning across sectors, for finance, and for renewable capacity expansion and coordination with industrial players (Finke et al., 2023; Johannsen et al., 2023; Klaaßen & Steffen, 2023; Sasse & Trutnevyte, 2023).

Energy security is an overarching issue that needs to be considered by the EU and companies when designing strategies for producing green iron and green steel. It is critical to ensure a reliable supply of renewable energy and storage for sectors relying on it for decarbonization – including iron and steel, and for energy security more generally. It is crucial that strategies are in place to ensure a steady flow of renewable electricity even during periods of fluctuating generation. For example, through the storage of hydrogen in periods of abundant, cheap, electricity production.

Our analysis indicates that when no scrap is employed, the use of HBI for steel-making is four times less energy intensive than the route involving GH-DRI + EAF. For companies opting to import HBI instead of producing reduced iron locally, additional security considerations arise: while outsourcing HBI production would reduce reliance on renewable hydrogen and thus reduce the amount of renewable electricity needed to transition the steel sector, it introduces new risks. Offshoring iron ore processing could affect EU-based jobs and economic activities related to iron production, diminish industry expertise, and increase dependence on external suppliers. Moreover, the import process would require reliable guarantees for the supply of HBI to ensure stable operations of the steel sector. This interplay between energy security and "productive capacity" security is in turn linked to the cost and pace of the energy transition itself. How to balance these multiple objectives is an important challenge that calls for public-private dialogue on the most strategic way forward.

To meet REpowerEU's policy target of 10 MTPA of local production of renewable hydrogen, national plans must be developed in a timely manner, ensuring they account for the diverse sectoral uses of this hydrogen. This should include plans for how the 10–19% renewable hydrogen demand for steel-making will be met alongside other sectors. It is also vital to secure sufficient electrolyser capacity.

6.2. Enhancing transparency in company strategies

Transparency in how EU-based companies plan to source renewable electricity, high quality iron ore and HBI is lagging. To meet net-zero emissions targets, the EU could signal increased interest in the transparency of company strategies for the transition for producing green iron and steel. As green production capacity ramps up starting in 2025, it is crucial that steel producers clearly communicate their sourcing strategies, whether for renewable electricity, green hydrogen, or HBI. Given that the choice of sourcing strategy significantly influences the steel sector's renewable electricity and green hydrogen demand, enhanced transparency can reduce uncertainties during project development and close access gaps for these resources.

Transparent reporting on renewable electricity, hydrogen supply strategies, and HBI import plans would make projections more realistic and useful for stakeholders in the iron and steel sector, as well as for policymakers. Our research into corporate strategies also reveals that decisions on decarbonization in the steel industry largely depend on the cost of renewable hydrogen. In order to assess if the steel sector is on track to cut its emissions in line with EU targets, there is a need to better understand company transition plans, especially in relation to hydrogen costs. More collaboration, partnerships and shared strategic planning between companies, power providers, grid operators, and public authorities is needed to ensure that the steel transition moves effectively from planning to implementation.

Finally, assessments of the ranges of variability in key parameters when evaluating green iron and steel projects can help decision-makers to identify the most critical areas for investment, plan for potential resource constraints, and develop more robust strategies for the steel industry's transition.

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Annex

Project announcements analysed

Project name	Company	Year to be operational	Project Scale	Technology announced by producers	Iron (DRI) [mtpa]	Crude Steel [mtpa]	Production in project
Pure Steel+	Stahl Holding Saar GmbH	2045	Full Scale	H-DRI+EAF	2.5	4.7	Iron and steel
Stegra Boden (formerly H2 Green Steel)	Stegra	2025	Full Scale	H-DRI+EAF	2.1	5	Iron and steel
Hamburg H2	ArcelorMittal	2026	Demo	H-DRI+EAF	0.1	0	Iron
Heracless (Hydrogen-Era-Carbon-Less)	Tata Steel	2030	Full Scale	H-DRI+EAF	6.31 (1) *	7.5 (1) **	Iron and steel
HYFOR	voestalpine Group	2021	Pilot	H-DRI+EAF	0.00175	0	Iron
SALCOS	Salzgitter Group	2033	Full Scale	H-DRI+EAF	2.1	1.9	Iron and steel
HYBRIT (Phase 1)	LKAB	2026	Demo	H-DRI+EAF	1.3	0	Iron
GravitHy	GravitHy	2028	Full Scale	H-DRI+EAF	2	0	Iron
The Blastr Green Steel Project	Blastr Green Steel	2027	Full Scale	H-DRI+EAF	2.73 ‡	2.5	Iron and steel
Hydnum Steel (Phase 1)	Hydnum Steel	2026	Full Scale	H-DRI+EAF	1.64 ‡	1.5	Iron and steel
HyIron - GEiSt (Green Iron in the steel industry)	HyIron	2023	Pilot	H-DRI+EAF	0.00117	0	Iron
Stegra Iberia (formerly H2 Green Steel)	Stegra	2026	Full Scale	H-DRI+EAF	2	3.75	Iron and steel
Bremen DRI (Steel4Future)	ArcelorMittal	2026	Full Scale	NG-DRI to H-DRI+EAF	1.25 (2) *	1.75	Iron and steel
Eisenhüttenstadt DRI (Steel4Future)	ArcelorMittal	2026	Full Scale	NG-DRI to H-DRI+EAF	1.83 (3) *	1.75	Iron and steel
H-DRI Dunkirk	ArcelorMittal	2027	Full Scale	NG-DRI to H-DRI+EAF	2.5	4.5 (4) **	Iron and steel
Gijón DRI and EAF	ArcelorMittal	2026	Full Scale	NG-DRI to H-DRI+EAF	2.3	1.1	Iron and steel
ArcelorMittal Belgium DRI	ArcelorMittal	2030	Full Scale	NG-DRI to H-DRI+EAF	2.5	2.5 (5) **	Iron and steel
tkH2Steel	Thyssenkrupp	2028	Full Scale	NG-DRI to H-DRI+EAF	2.5	2.3	Iron and steel
µDRAL (Demo for SALCOS)	Salzgitter Group	2022	Demo	NG-DRI to H-DRI+EAF	0.00073	0	Iron
Sestao (DRI from Gijón)	ArcelorMittal	2025	Full Scale	BF-BOF to EAF for green iron	0	1.6	Steel
Greentec steel - Linz	voestalpine Group	2027	Full Scale	BF-BOF to EAF for green iron	0	1.6	Steel
Greentec steel - Donawitz	voestalpine Group	2027	Full Scale	BF-BOF to EAF for green iron	0	0.85	Steel
Oxelösund mini-mill	SSAB	2026	Full Scale	BF-BOF to EAF for green iron	0	1.5	Steel
Luleå mini-mill	SSAB	2028	Full Scale	BF-BOF to EAF for green iron	0	2.5	Steel

* Assuming full transformation of the blast furnace capacity to be closed – Data source: Global Energy Monitor's Global Steel Plant Tracker

** Assuming full transformation of the basic oxygen furnace steelmaking capacity to be closed – Data source: Global Energy Monitor's Global Steel Plant Tracker

‡ Estimated assuming a conversion factor of 1.1 tonnes of DRI per tonne of steel

Detail of Global Energy Monitor's sources used

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