OECD publishing

HYDROGEN IN STEEL: ADDRESSING EMISSIONS AND DEALING WITH OVERCAPACITY

OECD SCIENCE, TECHNOLOGY AND INDUSTRY
POLICY PAPERS

March 2025 **No. 174**

OECD
BETTER POLICIES FOR BETTER LIVES

This paper was authored by Michele Rimini, Adrien Corneille, Danhak Gu and Muhammad Yamin from the OECD Directorate for Science, Technology and Innovation (STI). It was approved and declassified by written procedure by the OECD Steel Committee on 30/01/2025 and prepared for publication by the OECD Secretariat.

Note to Delegations:

This document is also available on O.N.E under the reference code:

DSTI/SC(2024)19/FINAL

Table of contents

FIGURES

TABLES

Executive summary

The adoption of hydrogen in iron and steelmaking processes holds significant potential to address the carbon footprint of the steel industry, **yet the scourge of excess capacity hinders the deployment of hydrogen-based solutions and the achievement of climate goals.** Studies show hydrogen based DRI facilities could potentially curb emissions by up to 90% from the traditional BF-BOF route. However, the persistence of excess capacity, by weighing on companies' profitability, displaces potential investments in hydrogen-based solutions. Recent OECD estimates expect excess capacity to reach 630 mmt by 2026, which corresponds roughly to the amount of hydrogen-based steelmaking capacity that needs to come online to achieve net-zero goals by 2050 in the most ambitious decarbonisation scenarios for hydrogen-based steelmaking developments.

The level of investment in hydrogen-based solutions is currently modest posing limited immediate threats to the furthering of excess capacity. OECD figures show that a total of 164 mmt of DRI capacity are in the planning and construction phase until 2030, of which only 15 mmt (9.2%) are based on hydrogen, whereas the vast majority are based on natural gas DRI, with some of them gradually switching to hydrogen as it becomes available for steelmaking.

For the longer run, **the deployment of hydrogen-based solutions should not exacerbate existing imbalances**. The range of estimates for carbon neutral steelmaking by 2050 assign a prominent role for the hydrogen based DRI solutions. These range from 370 mmt to 873 mmt, corresponding to about 20% and 40% of the estimates for total production in 2050. With subdued global demand projections, the build-up of these capacities needs to be accompanied by the exit of emission-intensive facilities to avoid furthering excess capacity. Likewise, it is important that **hydrogen-based projects are located where they make most sense from a market perspective and in regions that are not plagued by excess capacity.**

Steel needs to compete with other industries in securing limited hydrogen resources, despite using hydrogen for steel being considered as a high value application. Current hydrogen production is limited, mostly based on fossil fuels, and mostly feeding production processes of other sectors. Renewable-based (green) hydrogen is only available in very limited quantities. In light of its significant potential to reduce emissions in the steel industry compared to other sectors, its use in the steel sector is considered important, calling for prioritising green hydrogen supplies to steel production. At the same time, the potential value of using hydrogen to decarbonise specific steel production pathways should be balanced against the opportunity cost of following other steel decarbonisation routes.

Hydrogen-based steelmaking currently faces significant cost and competitiveness challenges, however these will likely attenuate in the future as the technology matures. In addition to being available in limited quantities, green hydrogen is also considerably more expensive than other fuels, including gas which can also fuel DRI shafts. However, these cost differentials are likely to be reduced as access to renewable energy improves and electrolysers costs diminish, putting hydrogen on the pathway for cost competitiveness vis á vis other fuels. Policies such as feed-in tariffs and carbon prices may partially close these differentials. On their side, steelmakers may adopt gradual phase-in strategies to keep up with the pace of developments in green hydrogen markets.

Governments have adopted horizontal strategies to bring hydrogen into global markets, however these lack clarity on sectoral implementation paths. Many jurisdictions have set out a national hydrogen strategy that includes the steel industry highlighting that hydrogen will play an important role in replacing fossil fuels. Nevertheless, mentioning of steel does not necessarily imply a detailed analysis or a clear roadmap for hydrogen application specific to the steel industry. Although many governments recognise the potential of hydrogen in the steel sector, they tend to take a neutral approach, avoiding the picking a winner industry as the primary beneficiary of hydrogen. However, given expectations of limited hydrogen supply, governments may eventually need to be selective in identifying industries for hydrogen application, taking into consideration those industries such as steel where hydrogen is the only alternative that can significantly contribute to lowering emissions.

The horizontal nature of hydrogen related support measures is less likely to create market distortions compared to other forms of support for energy inputs. These include allocating public money for investment in hydrogen infrastructure and in some cases, for hydrogen application in the steel sector, setting production as well as price targets, while also attempting to address cost differentials to ensure that hydrogen production costs and prices become competitive vis-à-vis those of other fuels. In contrast, energy price relief subsidies in OECD countries are usually more reactive, offering temporary fixes for sudden price shocks. However, in non-OECD economies, energy subsidies are often long-term and are part of broader industrial policies rather than short-term responses. In regions like the Middle East, North Africa, and Southeast Asia, these subsidies keep energy prices artificially low on a permanent basis. This sustained support gives energy-intensive industries, like steel, an unfair competitive edge by significantly reducing production costs for technologies that may impede the transition to low-carbon production.

Government support to build up the ecosystem for hydrogen-based steelmaking needs to be effective in tackling emissions from the steel value chain. While the majority of DRI projects are built under the premises of using natural gas as transition fuel, it is key that support provided is conditional upon the adoption of green hydrogen at a certain stage to ensure that carbon is not locked in beyond what is desirable, in line with the COP28 UAE consensus. Similarly, the provision of energy support in the form of fossil fuel subsidies to DRI operations aimed at acquiring market shares should be avoided as it could lead to market distortions and exacerbate capacity imbalances further.

1 Introduction

Net-zero scenarios suggest that low-emission hydrogen will be key to achieve near-zero emission steel by enabling deep decarbonisation of steel production. Given the critical role that hydrogen can play in decarbonising the steel industry, this report will explore its potential through a technology-neutral approach. It will also discuss potential relocations effect driven by hydrogen cost differential as well as the alignment between hydrogen strategies of steel companies and governments to support the transition to low-emission hydrogen in steelmaking.

The report also emphasises the importance of an evidence-based approach to hydrogen for the steel industry decarbonisation and investigates the links to excess capacity and the level-playing field.

To answer the question on the impact of hydrogen adoption on steel decarbonisation and excess capacity, this report examines development in the hydrogen economy with steel specificity, focusing on how they relate to the structural transformation associated with the ‘twin transition’, taking stock of technology aspect, steel producers’ strategies, policies, market factors and recent trends in steel-producing economies.

Section 2 describes the rationale of using hydrogen for decarbonising steel production and what could be the possible implications for global steel markets. Section 3 explores what hydrogen-based steelmaking developments may mean for excess capacity. Section 4 delves into company strategies vis a vis hydrogen adoption while section 5 assesses government strategies in support to hydrogen and their implication for the level playing field.

2 Hydrogen and steel decarbonisation

This section introduces the role of hydrogen in accelerating steel decarbonisation and discusses the expectations around hydrogen-based steelmaking capacity developments required to achieve climate neutrality. It also discusses the state of play regarding hydrogen market developments, and what they mean for the adoption of hydrogen in the steel sector including an overview of the announced hydrogen-based steelmaking projects.

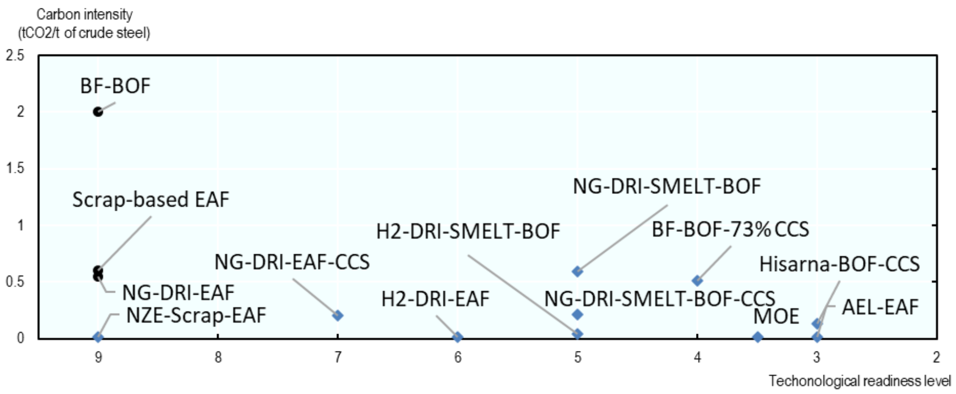
The role of hydrogen in accelerating steel decarbonisation

The steel sector is a significant contributor to carbon emissions accounting for 7-9% the total global carbon dioxide emissions and for 30% of global industrial emissions. To comply with the goals of the Paris Agreement and reach carbon neutrality by mid-century, the steel industry will need to cut carbon emissions by 30% in 2030 and 90% until 2050, compared to their levels of 2019 (OECD, 2023[1]).

Achieving net-zero emissions requires a large-scale deployment of low-carbon technologies, particularly hydrogen-based steelmaking, which has the potential to drive emissions close to zero. However, the complexity and diversity of the steel value chain mean that decarbonization pathways will vary across regions and firms, influenced by factors such as technology, production methods, and resource availability. While hydrogen-based steelmaking holds significant promise, its supply chain and commercial deployment are still in early stages, requiring further investment and development.

Figure 2.1 classifies the available set of decarbonisation solutions in steelmaking according to their abatement potential and their level of technological readiness. Compared with other technologies, the potential of renewables-based hydrogen for steel decarbonisation is significant as it is expected to bring down carbon emissions to near zero levels compared with the existing primary production routes.

Figure 2.1. Steel decarbonisation technologies and carbon intensity



Note: Estimates are ranked from the highest technological readiness to the lowest level.
Source: Authors' calculation based on (Agora Industry and Wuppertal Institute, 2023[2]); (Shahabuddin, Brooks and Rhamdhani, 2023[3]).

Hydrogen can be used as reductant to address emissions from the ironmaking processes, either as auxiliary reductant through injections into the blast furnace, or as main reductant for in the DRI shaft for Direct Iron Reduction processes.

When injected into the blast furnace hydrogen reduces the amount of coal needed and only forms water after reacting with iron ore instead of carbon dioxide. Injecting hydrogen into the blast furnace is expected to reduce emissions by 20-30%, relative to a state of the art BF-BOF plant (Bellona, 2021a[4]; Shahabuddin, Brooks and Rhamdhani, 2023[3]).

Hydrogen can be used as the main reductant in the DRI process where iron ore is reduced with hydrogen while in a solid state, to produce direct reduced iron (DRI) called sponge iron. Sponge iron is then fed into an EAF, where electrodes generate a current to melt the sponge iron to produce steel (Bellona, 2021b[5]). This process is commonly known as the H2-DRI-EAF route and is considered among the most effective methods to reduce emissions from iron and steelmaking and comply with near zero targets.

Hydrogen can also be used as a sole reductant in a direct reduction process which is then fed through a BOF via a smelter, the so called H2-DRI-SMELT-BOF route, which holds similar decarbonisation potential but has a lower technology readiness level (Mission Possible Partnership, 2022[6]; IEA, 2021[7]).

While both hydrogen-based direct reduction steelmaking routes require the use of high-grade iron ore, a H2-DRI-SMELT-BOF facility will have typically more flexibility to use a large range of iron ore compared to a H2-DRI-EAF (Agora Industry and Wuppertal Institute, 2023[2]) thus partially addressing the issue of high-grade iron ore scarcity.

In addition to availability, another element determining the carbon intensity of hydrogen-based steel production is the way hydrogen is produced. Different hydrogen production pathways have different carbon footprints, and, as a result contribute to the steel industry carbon footprint in different ways (Annex A). For the remainder of this paper, we refer to renewable-based hydrogen as green hydrogen, and to fossil fuel-based hydrogen as either grey or blue hydrogen, with the latter implying the use of Carbon Capture and Storage (CCS).

Hydrogen requirements for net zero steel production

All net-zero emission scenarios predict a pivotal role for hydrogen-based steelmaking by 2050. However, the type of hydrogen differs across scenarios. Most net-zero emission scenarios agree that green hydrogen would need to be the cornerstone for decarbonising steel production, in particular through the hydrogen-based DRI route. On the other hand, blue hydrogen, derived from natural gas and complemented with carbon capture and storage, is expected to play a supporting role in the short and medium term, providing a bridge until green hydrogen becomes cost competitive and widely available.

The role of green hydrogen in decarbonising steel varies according to the different scenarios. More conservative estimates such as those provided by World Steel Dynamics and CRU, which are not constraining their forecast to achieving net-zero goals, expect green hydrogen-based DRI steel production to reach 27.5 mmt by 2040 and 23 mmt by 2050 respectively in their most optimistic scenario (CRU, 2024[8]; World Steel Dynamics, 2024[9]).

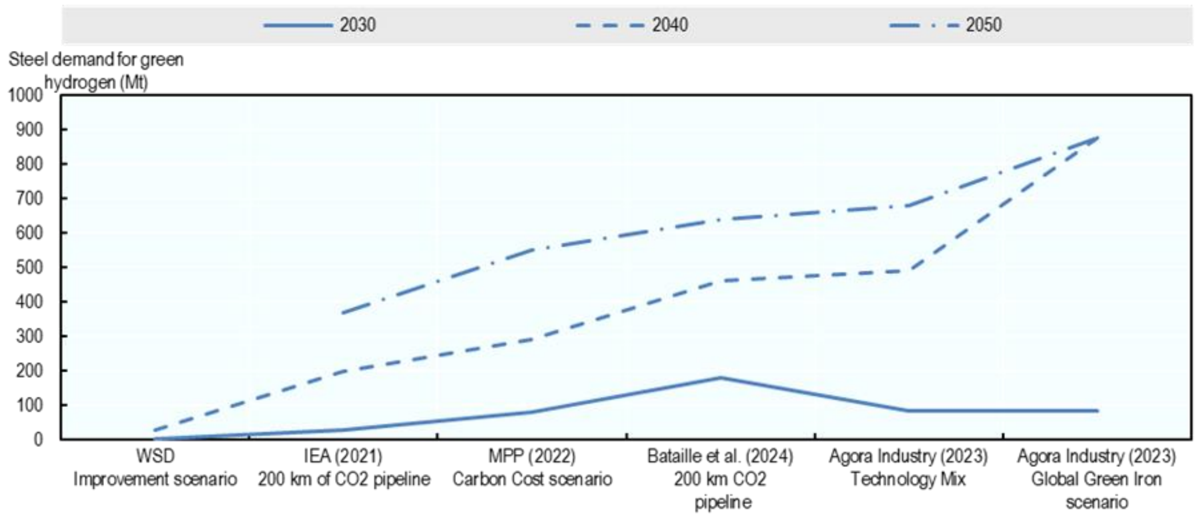
Estimates for future green hydrogen-based steelmaking production that are built under the assumption of achieving net-zero goals by 2050 assign a much greater role to this production route. For example, the IEA sustainable development scenario forecasts 10% of total steel production in 2050 to be relying on green hydrogen as the primary reducing agent (or 14% of primary production) equivalent to 205 mmt

(IEA, 2020[10]; Bataille, Stiebert and Li, 2024[11]) estimate a higher share (ranging from 25 to 39%) of global steel production to rely on hydrogen-based DRI by 2050 equivalent to 640 mmt (550-865 mmt).

According to Agora's net-zero scenarios by 2050, 683 mmt and 873 mmt of crude steel would be supplied by H2-based DRI routes, accounting for 56% and 72% of primary steelmaking, respectively (Figure 2.2). In the Bloomberg NEF new energy outlook, primary steel is mainly produced by the H2-DRI-EAF route, followed at 25% by DRI-EAF equipped with CCS technology (BloombergNEF, 2024[12]). In this scenario, hydrogen-based DR-EAF comprises 42% of global production, amounting to about 150 million tonnes of hydrogen demand. The corresponding amounts of hydrogen required for the green hydrogen-based DRI route in the above mentioned scenario range from 45 to 75 Mt in 2050, whereas hydrogen demand from the steel sector in 2030 is estimated to be ranging from 5 to 17 Mt (Agora Industry and Wuppertal Institute, 2023[2]).

The rapid increase of green hydrogen-based steelmaking from the 2030s to the 2050s is predicated upon expectations of significant cost reductions in the key technologies underpinning green hydrogen developments (e.g. renewable energy and electrolysers) from both the perspective of capital and operating costs of running such solutions. Currently, the high cost of hydrogen remains one of the primary obstacles to its widespread integration into the steel industry followed by need to ensure that steel is prioritized as end use sector for hydrogen given the significant abatement potential that using hydrogen for steelmaking has compared to other end uses.

Figure 2.2. Future demand for green hydrogen-based steel



Source: Authors' compilation based on various sources: (Agora Industry and Wuppertal Institute, 2023[2]), (Bataille, Stiebert and Li, 2024[11]); (IEA, 2021[7]); (Mission Possible Partnership, 2022[6]); (Watari and McLellan, 2024[13]).

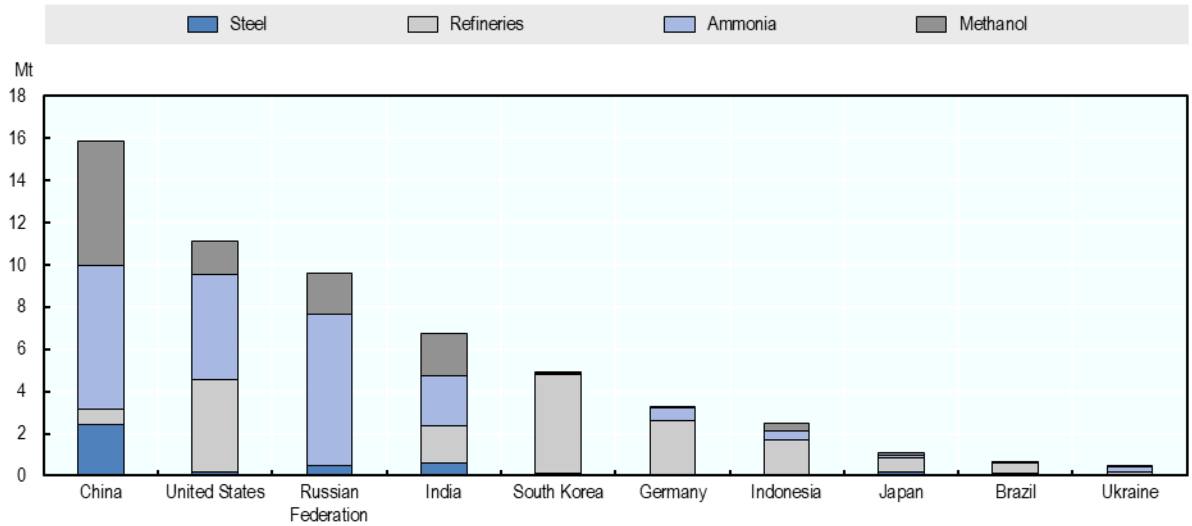
Hydrogen market outlook

Current hydrogen production is limited, mostly deriving from fossil fuels and with very limited application to the steel industry. Global hydrogen production reached 97 Mt in 2023, registering an increase of 2.5% compared to 2022 (IEA, 2024[14]). Most of the production relies on unabated fossil fuels: the natural gas route accounts for 65%, and the coal-based gasification route account for 20%, followed by hydrogen that is produced as a by-product of other chemical processes accounting for 15%. Green hydrogen production remains below 100 kt, which is slightly more than 0.1% of total production.

Demand for hydrogen remains concentrated in traditional sectors including, oil refining (41 Mt), ammonia production (33 Mt) and methanol production (16 Mt), which account for most of hydrogen demand today, while steel accounts for 5 Mt (IEA, 2024[14]).

Hydrogen use in the steel industry is primarily concentrated in a few key regions and countries. Since 2020, the People's Republic of China (hereafter "China") has been the largest consumer of hydrogen for steel production and other industrial applications (Figure 2.3), accounting for 34% of global industrial hydrogen consumption in 2023 (IEA, 2024[14]). Furthermore, while the Chinese use of renewable hydrogen is almost inexistent for steel compared to other industrial applications, recent trends show a rapid expansion of electrolyser capacity accounting for 30% of global capacity in 2022 and massive investments in green hydrogen projects relying on more resource efficient PEM electrolysis technology (Transition Asia, 2024[15]).

Figure 2.3. Main end-uses of hydrogen by sector and country, 2023

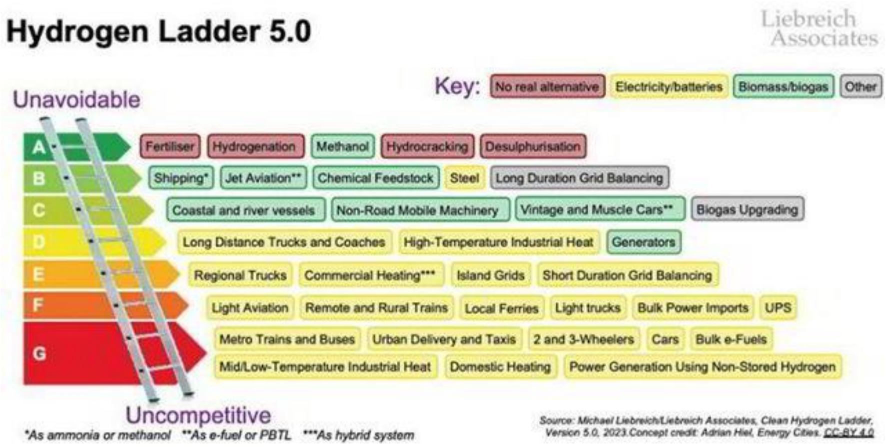


Note: The figure shows the different applications of hydrogen in steel production and other key sectors, ranked in descending order and converted from TWh/y to Mt.
Source: Authors' calculation based on (Terlouw, Rosa and Bauer, 2023[16]).

Although steel currently accounts for a minor share of hydrogen use, it is expected to claim a larger share of green hydrogen supplies as it transitions to low carbon production methods. However, securing adequate green hydrogen supplies could be challenging as steel must compete with other sectors for a resource that is and will likely remain scarce in the near future (OECD/The World Bank, 2024[17]).

In light of high potential for emissions reduction in the steel industry compared to other sectors (RMI, 2022[18]; Agora Industry and Wuppertal Institute, 2023[2]), and its limited availability, there is a strong argument to prioritise green hydrogen for steel production, both from a market and policy standpoint. As evidenced in Figure 2.4, the application of hydrogen to the steel sector compared to other downstream industries is considered as unavoidable, as, in addition to the significant abatement potential it holds, alternative technologies are still at early stages of development compared to other industries where alternatives exist and are more effective.

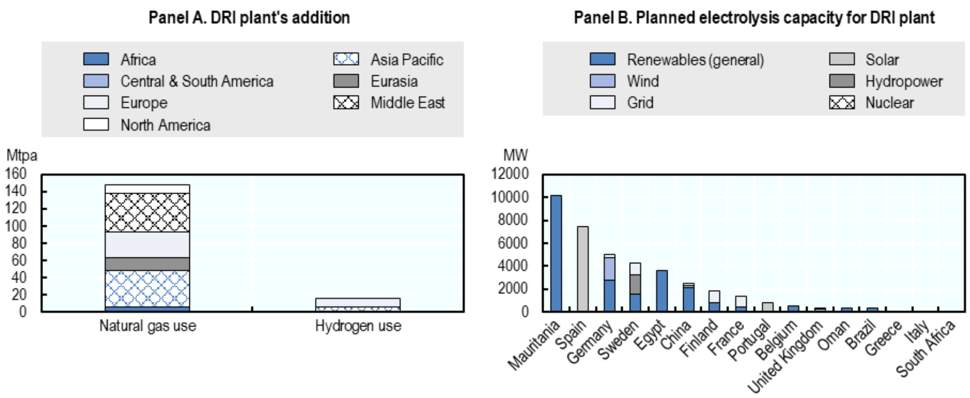
Figure 2.4. The Hydrogen Ladder



Source: Michael Liebreich Associates (2023)

Considering the constraints in current green hydrogen supplies, the majority of companies investing in DRI focus on hydrogen-ready rather than green hydrogen DRI plants, so that they may be able to switch to green hydrogen once it becomes sufficiently available in local and regional markets. In the universe of DRI projects, a small fraction of hydrogen-based DRI facilities are expected to come online in Europe and Asia Pacific (Figure 2.5, Panel A). The vast majority of DRI projects will make use of natural gas as a reducing agent (90.2%, 147 mmt). Most of the announced DRI projects are in the MENA region which accounts for almost 30% of natural gas-based capacity additions and for 40% of global DRI production.

Figure 2.5. DRI capacity developments until 2030 and energy mix



Note: Panel A presents DRI capacity additions (i.e. planned and underway projects) at the regional level over the period 2024-2030. The use of hydrogen has been identified in Germany, Spain, China, South Korea. The OECD Secretariat employs a definition of nominal crude steelmaking capacity based on maximum theoretical equipment capacity. Panel B shows electrolysis capacity to produce hydrogen-based steel based on announced projects. Most projects are at early stages or under feasibility study.
Source: Authors' calculation based on Global Energy Monitor, Global Steel Plant Tracker, April 2024 (v1) release for Panel A and IEA Hydrogen Production Projects Database, October 2024, for Panel B.

Some DRI projects are being developed with renewable hydrogen from the start. Countries like Germany, Sweden, Portugal, and Spain are planning to use green hydrogen powered by solar, wind or hydropower (Figure 2.5, Panel B). Mauritania and Egypt also have significant potential to transition their existing DRI sites with green hydrogen given their resource endowments, though project feasibility is still under review. China is the only country where companies are exploring the use of nuclear power to partially fuel DRI operations.

Hydrogen-based steelmaking faces significant cost and competition challenges, with green hydrogen currently being two to five times more expensive than fossil-based alternatives (Wurbs et al., 2024[19]). However, costs are expected to decline by 2030 due to economies of scale and technological advancements, making it more viable for Direct Reduced Iron (DRI) processes (Hasanbeigi et al., 2024[20]; OECD/The World Bank, 2024[21]).

The competitiveness of hydrogen-based steelmaking varies by country, influenced by factors such as carbon pricing, renewable energy availability, and access to high-grade iron ore (Devlin et al., 2023[22]). Supportive policies, including carbon pricing and subsidies, can help make it cost-competitive vis á vis fossil fuels alternatives and thus improve its economic viability. To navigate cost challenges, steelmakers could adopt a phased approach, gradually increasing green hydrogen use as costs decrease and infrastructure matures (Cordonnier and Saygin, 2022[23]; Hasanbeigi et al., 2024[20]).

Conclusions

This section showed that the adoption of hydrogen in iron and steelmaking processes holds significant potential to address the carbon footprint of the steel industry. Hydrogen use in iron and steelmaking could help the industry achieving near zero emissions in the long term if produced through renewable energy sources.

Hydrogen based steel making could change production processes in two main ways, with implications on the steel value chains, including potential relocation. Hydrogen can be either injected into the blast furnace as an auxiliary reductant or used as a primary reductant into the Direct Reduction Iron (DRI) shaft. It holds the largest decarbonisation potential when used as a reductant. Replacing coal with hydrogen in iron and steelmaking processes could lead to reconfigurations of some part of the steel value chain, as producers may look for the most convenient location to source hydrogen or its steelmaking derivatives.

All decarbonisation scenarios foresee an important role for hydrogen-based steelmaking, still the current production is limited. More conservative estimates expect green hydrogen-based DRI steel production to reach 23 mmt in 2050, whereas scenarios built under the assumption of achieving net-zero goals by 2050 assign a much greater role to this production route ranging from 370 mmt to 873 mmt, corresponding to about 20% and 40% of the estimates for total production in 2050. These correspond to 45-70 million tons per year of green hydrogen demand.

Steel needs to compete with other industries in securing limited hydrogen resources, despite using hydrogen for steel being considered as a high value application. Current hydrogen production is limited, mostly based on fossil fuels, and mostly feeding production processes of other sectors. The significant potential to reduce emissions in the steel industry compared to other sectors calls for prioritising green hydrogen supplies to steel production.

Hydrogen-based steelmaking faces significant cost and competitiveness challenges, mostly driven by the lack of availability and competition from cheaper alternatives. In addition to being available in limited quantities, green hydrogen is also considerably more expensive than other fuels, including gas which can also fuel DRI shafts. These cost differentials vary across jurisdictions however, if not addressed, they can hinder the diffusion of hydrogen-based steelmaking solutions. Policies such as feed in tariffs and carbon prices may partially close these differentials. On their side, steelmakers may adopt gradual phase in strategies to keep up with the pace of developments in green hydrogen markets.

3 What do hydrogen-based capacity developments mean for excess capacity and the level-playing field?

Excess capacity hinders the adoption of hydrogen-based solutions

The transition of steelmaking assets towards low carbon production methods occurs in a context where the steel sector is affected by other major structural trends: overcapacity, the massive presence of market distortion and the resulting trade frictions. In particular, the current surge of excess capacity hinders the deployment of hydrogen-based solutions and the achievement of climate goals by extending the life of emission-intensive assets beyond what dictated by market forces and stifle investment.

Global steelmaking capacity doubled from 1 195 mmt in 1990 to 2 432 mmt in 2023, i.e. 2.3% annual growth, with a total of 1 600 plants commissioned. Global steelmaking capacity is projected to increase significantly over the next three years (2024-2026), with 46 mmt of capacity additions underway and an additional 103.5 mmt in the planning stage (OECD, 2024[24]).

Global steel excess capacity (the global gap between demand for steel and the capacity to produce steel) increased from an estimated 532 mmt in 2022 to 551 mmt in 2023, according to OECD figures. Assuming that capacity investments are realised, and considering forecasts for global steel demand, the world's capacity-demand gap might continue to increase to 630 mmt by 2026, which corresponds roughly to the amount of hydrogen-based steelmaking capacity that needs to come online to achieve net- zero goals by 2050 in the most ambitious decarbonisation scenarios for hydrogen developments (Agora Industry and Wuppertal Institute, 2023[2]) in the scenario where H2 DRI becomes the predominant production route in global steel markets.

Excess capacity undermines prices and profitability and puts the viability of the global steel industry at risk (GFSEC, 2024[25]). By depressing profit margins, it impairs companies to perform research and development activities and invest in low carbon solutions. Both activities are essential for the sector to achieve its climate neutrality goals by mid-century (Box 3.1).

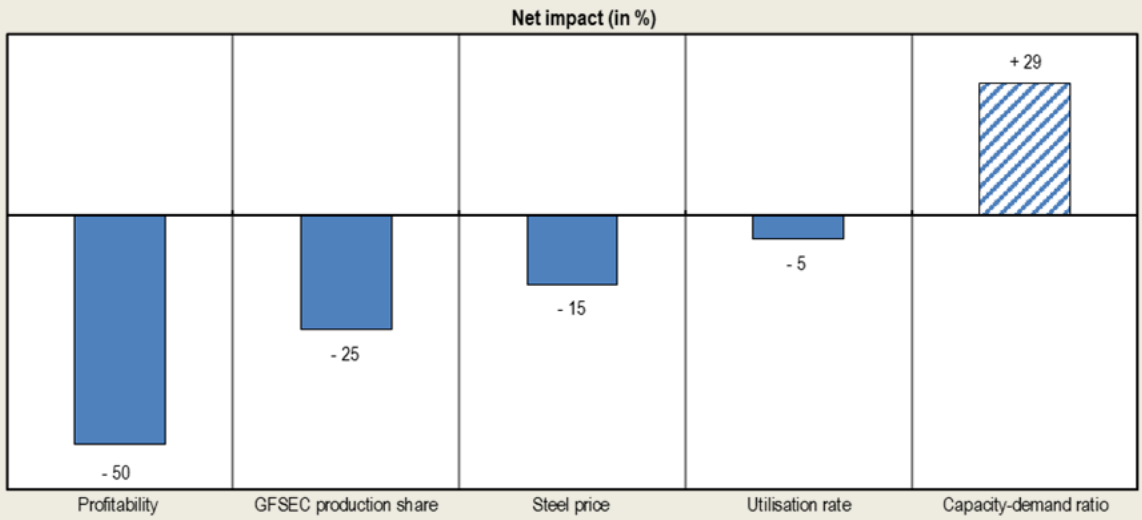
In such context, it becomes challenging for steelmakers to rapidly adapt their production base to the needs of a carbon neutral economy and scale up low-carbon technologies, including hydrogen, the adoption of which requires substantial changes in existing plants, through refurbishing or retrofitting, and sometime also the build-up of an entire facility based on DRI technologies.

Box 3.1. The effects of excess capacity in global steel markets

Global excess capacity has grown tremendously over the years and continues to affect a growing number of countries. This phenomenon is the result of a growing gap between nominal steelmaking capacity and steel demand.

The excess capacity problem affects the market conditions for a healthy and sustainable steel industry in many countries. Latest research highlights that in presence of structural imbalances between capacity and demand, domestic steel producers are facing important market share losses in their economies and underutilize their steelmaking capacities. Complementary evidence, based on a counterfactual exercise, highlights that current excess capacity negatively impacts steel prices over 15% and significantly reduces the profitability of the steel industry (Figure 3.1).

Figure 3.1. Impacts of global excess capacity on the health of the steel industry



Note: The figure presents a summary of available evidence on the impacts of excess capacity. The estimates presented here report the average effects of excess capacity on the profitability of the steel industry, production share, steel price in Global Forum on Steel Excess Capacity (GFSEC) countries or/and other economies. The ratio between crude steelmaking capacity and steel demand illustrates how much capacity exceeds demand in % given the latest available year.
Source: Authors' compilation and illustration based on various sources: (OECD, 2024[24]); (GFSEC/OECD, 2022[26]); GFSEC (forthcoming).

The situation results from the introduction of unfair and distortive market measures, which favour some companies while penalizing other companies at both the national and the international level. The surge in cross border investments for new steelmaking capacities driven by non-market factors is a key driver for distortion in the global level playing field.

Hydrogen-based DRI expansions have so far limited impact on excess capacity but may exacerbate it if transitions are not properly managed

Mindful of the existential threat that excess capacity poses to the viability of the steel industry, the diffusion of low carbon technologies including hydrogen-based solutions should be deployed in a way that does not create further market imbalances. At the same time, the range of estimates for carbon neutral steelmaking by 2050 assign a prominent role for the hydrogen based DRI solutions. These range from 370 mmt to 873 mmt, corresponding to about 20% and 40% of the estimates for total production in 2050 (Agora Industry and Wuppertal Institute, 2023[2]) in the scenario where H2 DRI becomes the predominant production route in global steel markets.

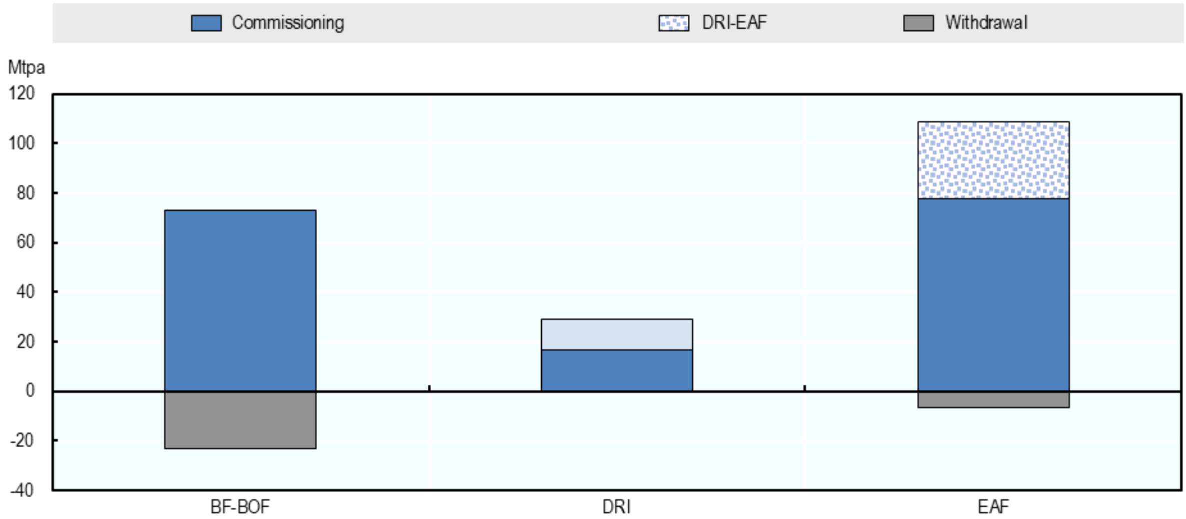
With global demand for steel expected to remain subdued in the future, also considering the effects of increased material efficiency, this means that similar amounts of emission intensive capacities will need to be withdrawn from the market, in order not to exacerbate the ongoing excess capacity situation and ensure that steel markets remain, to the extent possible, in check.

Diffusing hydrogen-based DRI solutions is expected to have a significant impact on capacity developments as the adoption of such technologies usually requires the build-up of new iron and steelmaking facilities, the DRI shaft for the ironmaking process, and an EAF facility for steelmaking. These developments can be the result of decarbonisation strategies (OECD, 2024[27]) of companies with an existing emission intensive asset base or greenfield investments by companies that see low-carbon steel as an emerging business opportunity. Companies with an existing asset base are likely to replace the corresponding BF-BOF assets to ensure that the total steelmaking capacity doesn't increase significantly. When it comes to greenfield investments, and in particular those occurring in partner economies, it is essential that these investments are driven by market fundamentals. In other words, for hydrogen-based steelmaking developments not to exacerbate excess capacity the build-up of such capacities needs to be accompanied by the phase out of emission intensive plants somewhere in global steel markets.

OECD projections indicate that the total amount of DRI ironmaking capacity expected to come online by 2026, either already underway or planned amounts to 59.9 mmt, of which a minimal part is expected to use hydrogen from the start. The build-up of DRI ironmaking capacity has direct and indirect impacts on steelmaking capacity. When the DRI shaft is built jointly with a new EAF furnace it directly increase steelmaking capacity, the case, for example, of the 32.5 mmt of DRI-EAF additions in Figure 3.2. (representing approximately 30% of total EAF additions). In some instances, announced DRI projects are not related to any new EAF projects, but may be indicative of future increases in DRI-EAF steelmaking capacity if these are greenfield projects (i.e. in a location where steelmaking assets do not exist), corresponding to 16.7 mmt. In some other instances, the build-up DRI ironmaking capacity is intended to feed existing EAF furnaces, which would seem to be the case for 12.3 mmt of DRI projects in our projections[i].

As a result, when looking at steelmaking capacity developments, DRI based additions account for 32.5 mmt. In comparison, the amount of BF-BOF and scrap-based EAF capacity expected to come online over the same period is 73 mmt and 76.1 mmt respectively. In relative terms, this means that only 18% of steelmaking capacity additions coming online by 2026 can be attributed to the DRI route, of which a mere 2% corresponds to hydrogen-based DRI projects. In parallel, when considering phase outs, only 23 mmt of BF-BOF capacity are expected to be withdrawn from the market over the same period, showing an apparent disconnection between phase ins of DRI and phase outs of BF-BOF capacities (Figure 3.2).

Figure 3.2. Capacity developments by technology route by 2026



Note: DRI capacity additions only include announced DRI projects that are lacking a corresponding EAF project announcement for steelmaking. In these cases, companies may have delayed the announcement of a corresponding EAF (darker color) or intend to channel DRI outputs to existing EAFs (lighter color).
Source: OECD elaborations on OECD capacity data.

This apparent disconnection may be partially explained by the geographical distribution of planned DRI assets, which are mainly concentrated in the Middle East and North Africa (MENA) and South-East Asia regions, suggesting that the main driver for DRI developments is the expectation of stronger demand in the future. On the other hand, several DRI developments in Europe located in existing sites suggest that some companies are planning an upgrade of their capacity fleet to low carbon production methods.

The geographical distribution of DRI projects reinforces existing regional trends in capacity developments, with significant capacity growth in MENA and Southeast Asia over the last 5 years (OECD, 2024[28]). In the case of the MENA region, comparative advantages in gas production can be seen as a driver for a more accentuated focus on gas based DRI solutions. At the same time, the share of new capacity additions directly attributable to hydrogen-based solution represents a minimal fraction of the total amount of capacity that will come online over the next two years, thereby not constituting a major concern for the worsening of the excess capacity situation in the immediate future.

For the longer run, the management of existing assets - especially plant replacement strategies - will be critical. As companies and governments elaborate their decarbonisation strategies, it is key that at the global level, the new hydrogen-based capacities coming online are not built on top of the existing emission intensive asset base and that the latter is gradually phased out from the market, more so in regions that are major sources of excess capacity and market distortions.

Beyond replacing existing BF-BOF assets, other options for hydrogen-based solutions to contribute addressing the emission intensities of steel plants exist, albeit with limitations on carbon abatement potential and technology maturity. Hydrogen injections into the blast furnace can, for example, reduce emissions by 20-30% compared with a state-of-the-art BF-BOF, which means salvaging the existing iron and steelmaking asset and reduce emissions. Another option to salvage part of the existing asset base is to connect a BOF with a smelter and a hydrogen-based DRI, via the H2-DRI-Smelt-BOF production route, which is a near zero compatible technology, but at an earlier stage of technological readiness. These options are more palatable in the case of a younger BF-BOF fleet, for which a full replacement may not make full economic sense. However, such facility's transformation has important market implications, such as a temporary shutdown of operation, additional investment costs and possible losses in profitability (Steward et al., 2023[29]).

Ultimately, the adoption of hydrogen-based solutions needs to be consistent with achieving near zero emissions in the long run. In the case of hydrogen injections into the blast furnace, the emission reduction potential remains limited, presenting a trade-off between obtaining limited emission reductions in the short medium run and risking locking carbon in for a longer period. A similar concern relates to the build-up of gas based DRI solution that we are currently witnessing in the Middle East in particular, where gas is used as a strategic input for steelmaking and questions remain on the extent to which it will be used as a transition fuel.

The build-up of hydrogen-based capacities should be driven by comparative advantages and in regions not plagued by excess capacity

While the adoption of hydrogen-based solutions responds to the policy-driven imperative of addressing the steel industry carbon footprint, it needs to follow market principles in both hydrogen and steel markets. On the hydrogen side, countries benefitting from national endowments of abundant solar and wind and, as a result, from comparative advantages in renewable energy and green hydrogen production, may consider developing a hydrogen-based steelmaking asset base. At the same time, other countries may leverage abundant natural gas resources to position themselves in hydrogen-ready DRI production.

Hydrogen abundance and its use as a source of comparative advantages, whether market driven or policy induced, needs to be juxtaposed to the existing and future market conditions for steel. That is, building hydrogen-based assets in a location where steel demand is expected to grow and or where comparative advantages in hydrogen-based production extend to the steel value chain, can improve efficiency in the sector and contribute to achieving the global climate goals of the industry.

As a secondary effect, the build-up of new hydrogen-based steelmaking capacity in such countries and regions can contribute to a lower geographical concentration of steelmaking assets and to more resilient and diversified steel value chains.

In countries where the development of hydrogen-steelmaking solutions is justified by market fundamentals (strong demand prospects and comparative advantages), and where market forces are at full play in the steel industry, the provision of horizontal support to hydrogen development may help address some of the market failures hindering the development of the hydrogen infrastructure.

Among the market failures in hydrogen developments, it is worth mentioning the inability for markets to scale up hydrogen solutions because of the high initial costs and uncertain returns associated with investing in these solutions, the inability to escape path dependency with the existing energy infrastructure, which prevents consumers to freely choose between energy sources, as well as the need to address network effects and coordination failures in building up hydrogen infrastructures (OECD, 2024[30]).

The overarching objective of such horizontal policies should be to make hydrogen a cost-competitive with fossil fuels, so that the market failures associated with hydrogen production and adoption are addressed and consumers that adopt hydrogen-based solutions are not at disadvantage. Once the technology is scaled up and hydrogen is available at competitive prices any form of support should be withdrawn for it not to become market distorting.

However, in excess capacity countries with significant market-distorting government support, even horizontal support to hydrogen may provide a further layer of distortions to the level-playing field. This is because the cost structure of emission intensive steel production in these countries is already maintained artificially low by the massive presence of government support measures. Horizontal policies that aim to reduce the cost differential between hydrogen-based and emission intensive production in these countries will inevitably result in market distortions in the hydrogen-based production route, even if the support provided is time bounded to the achievement of cost parity between the low and high carbon option as they will bring hydrogen-based production at cost parity with subsidised production.

Section 5 discusses the characteristics of horizontal support provided to hydrogen production and consumption in the main steel producing economies more in detail.

Conclusions

This section showed that excess capacity weighs on the ability of companies to adopt low-carbon steelmaking technologies including hydrogen by hindering investment as well as research and development activities that are needed to bring hydrogen-based steelmaking solutions to markets.

The level of investment in hydrogen-based solutions is currently modest posing limited immediate threats to the furthering of excess capacity. OECD data shows that only 20% of new capacity additions coming online by 2026 can be attributed to the DRI route, of which a mere 2% corresponds to hydrogen-based DRI projects. In light of the important role that hydrogen-based steelmaking solutions are expected to play in a decarbonised future, the deployment of hydrogen-based solutions should not exacerbate existing imbalances.

Horizontal support to hydrogen in regions where market fundamentals favour this decarbonisation pathway are not expected to bring major distortions to global steel markets, due to their temporary and horizontal nature. In contrast, support to hydrogen-based steelmaking in countries and regions plagued by excess capacity is likely to bring further distortions to global steel markets and exacerbate excess capacity.

4 Assessing steel companies' hydrogen strategies

While the market outlook section (1) of the paper introduced the major developments in hydrogen based steelmaking projects, this section presents an assessment of steel company strategies for hydrogen generation as well as implementation of hydrogen-applied steel technologies to identify how steel companies are adapting their decarbonisation strategies in the context of hydrogen market developments. Furthermore, this section identifies key challenges that companies encounter, that are associated with hydrogen in the steel industry decarbonisation.

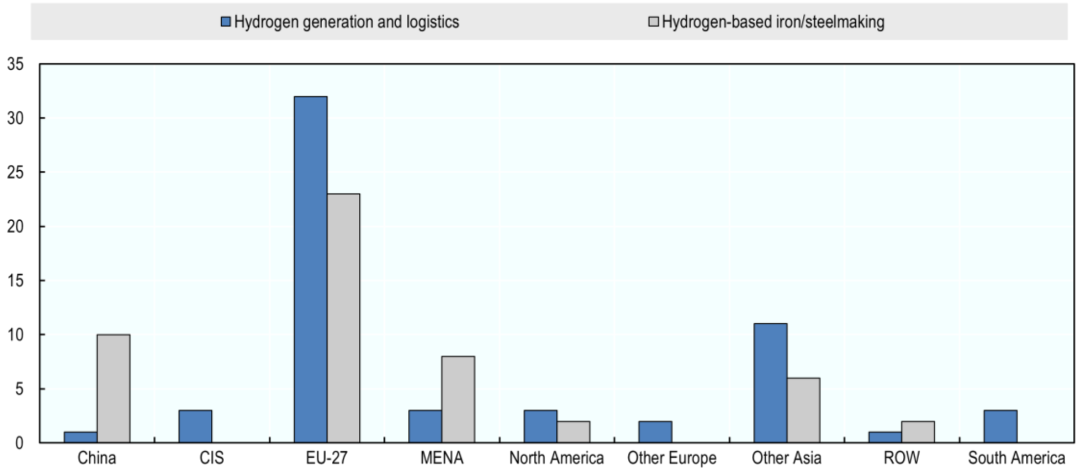
The analysis of steel company strategies shows that these companies recognise the potential of hydrogen for decarbonisation yet are facing several challenges slowing deployment. Most companies in the sample (78%) foresee to adopt hydrogen-based solutions as part of their decarbonisation strategies. However, the limited commercial maturity of hydrogen solutions combined with a series of interrelated challenges are hindering deployment. These range from i) technology scale up; ii) cost competitiveness of hydrogen solutions vis-a-vis existing fossil fuels inputs; iii) the difficulties in trading hydrogen internationally compared to other inputs, and; iv) a set of broader challenges that are affecting the steel sector.

The aim of this section is to provide a picture of how steel companies are approaching the use of hydrogen in their iron/steel production as part of their decarbonisation strategy. The analysis focuses on both global and major/emerging steel producers in each region, building on previous analysis done on companies' overall decarbonisation strategies (OECD, 2024[27]).

Deep dive into major steel producers' approach to hydrogen application

Figure 4.1 shows the broader landscape of global hydrogen-related projects across multiple steel companies, beyond our sample. Companies in the European Union (EU) display the highest number of projects announced or planned for hydrogen generation (32 projects) as well as for hydrogen-based iron and steelmaking (23 projects). Companies in China have so far announced 10 hydrogen-based iron and steelmaking projects, while companies in the MENA region are also active in this field. Companies in Asia (excluding China) are also engaged in projects focused on hydrogen generation and logistics. As shown in the Figure 4.1, steel companies are investing not only in hydrogen-based steel assets (grey bar) but also in hydrogen generation and logistics (blue bar), including hydrogen infrastructure e.g. pipelines, clean hydrogen generation jointly with energy utilities, etc. However, the ongoing excess capacity surge and lack of demand, has led to the postponement or cancellation of several announced hydrogen related projects, particularly in the EU.

Figure 4.1. Global hydrogen-related projects across the steel companies by 2023

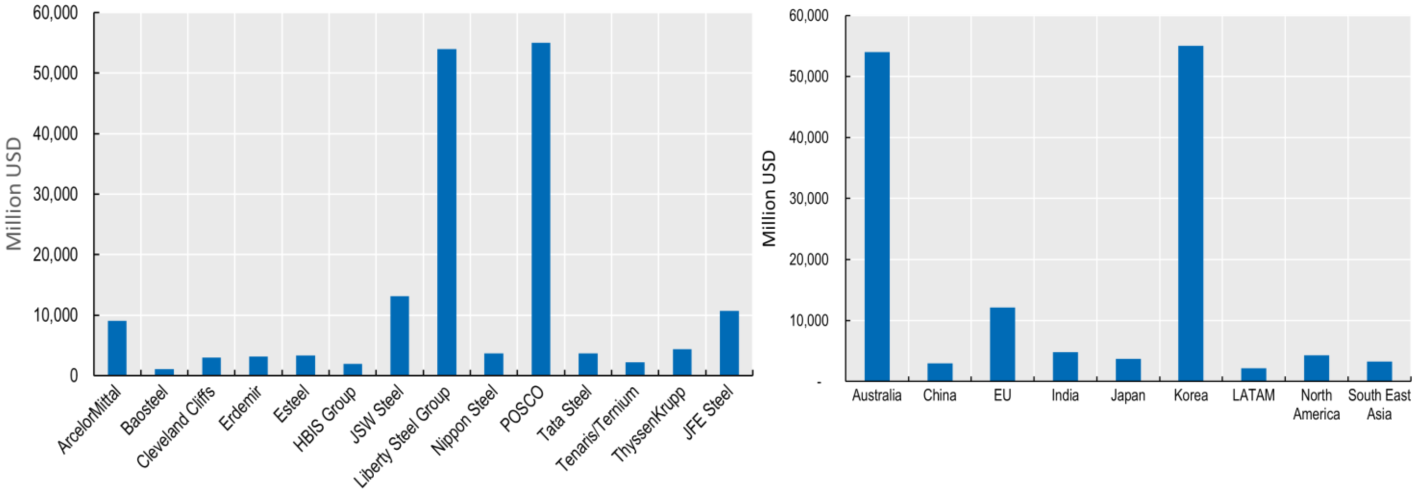


Source: (World Steel Dynamics, 2023[31])

Among the sample companies, 78% (25 out of 32) included hydrogen generation and/or hydrogen-based steel making projects in their decarbonisation strategies. Multinational companies such as ArcelorMittal and Tata steel, whose plants are located in several different regions, included hydrogen projects as part of their decarbonisation strategy.

As hydrogen-related projects in the steel industry gain momentum, many steel companies are announcing major investment plans to realise this hydrogen strategy (Figure 4.2). Among the sample companies, POSCO and Liberty Steel Group have set the highest hydrogen investment plan at USD 55 billion and USD 54 billion respectively, followed by JSW and ArcelorMittal at USD 13 billion and 9 billion respectively. POSCO's substantial investment plan is for the development of its H2-DRI and its commercialisation. The majority of Liberty Steel's investment regards a partnership between Australia and United Arab Emirates to trade high grade iron ore to produce green iron.

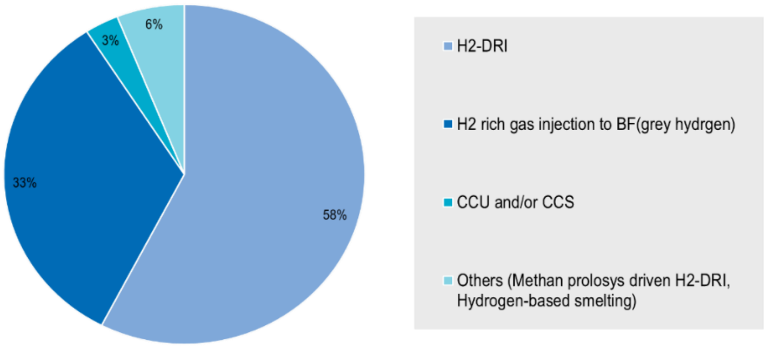
Figure 4.2. Projected hydrogen investment size by companies and regions, 2023



Note: Hydrogen investment includes hydrogen generation and logistics as well as hydrogen-based iron/steelmaking. The countries not shown in the figure have not indicated the amount of investment.
Source: (World Steel Dynamics, 2023[31])

The most frequently stated hydrogen applications in steel productions are H2-DRI, H2 rich gas injection to BF-BOF, CCUS applied blue hydrogen and other technologies such as methane-pyrolysis driven H2-DRI, hydrogen-based smelting (Figure 4.2). This may the result from the fact that H2-DRI can contribute to large CO2 emission reductions, while H2-rich gas injection requires only minor modifications to existing plants and can therefore be implemented at relatively lower cost and faster than other technologies (Mauret et al., 2023[32]).

Figure 4.3. Type of hydrogen-based steel projects selected by the sample companies by 2023



Source: OECD elaboration based on (World Steel Dynamics, 2023[31])

Challenges

Companies who are engaging with hydrogen-based iron and steelmaking solutions for their decarbonisation strategies face a set of interrelated challenges, which also depend, to some extent, on the jurisdictions they operate in. While the technology scale-up and the significant investment required to enable this decarbonisation are obvious challenges, other related challenges that companies are facing are also identified. These include: i) cost competitiveness of hydrogen solutions vis- à-vis existing fossil fuels inputs, which are in turn dependent on the cost of renewables and electrolysers as well as the large investment needs for their deployment; ii) the difficulties in trading hydrogen internationally compared to other inputs and; iii) a set of broader challenges that are affecting the steel industry and its efforts to upgrade its industrial base including ensuring a just transition for workers and communities.

Technology scale-up

Many companies have selected H2-DRI as the primary technology in their decarbonisation strategies (OECD, 2024[27]). However, H2-DRI remains at Technology Readiness Level (TRL) 6 and is dependent on the availability of high-quality iron ore as well as the price of electricity for the electrolysis of H2-DRI (IEA, 2024[14]). Another scale-up challenge concerns bottlenecks in DRI engineering and construction capacity, as currently only two technology providers exist accounting for about 97% of the market for gas-based DRI plants (Agora Industry and Wuppertal Institute, 2023[2]), which can be considered as a proxy for H2-DRI construction capacity (IEA, 2023[33]). Hydrogen rich gas injection technology is considered to be capable of reducing CO2 by 30% of BF-BOF without significant plant modifications, but has yet to be fully explored and is at TRL 7. However, some studies suggest that this pathway may not be compatible with net-zero target without CCUS (Bataille, Stiebert and Li, 2024[11]).

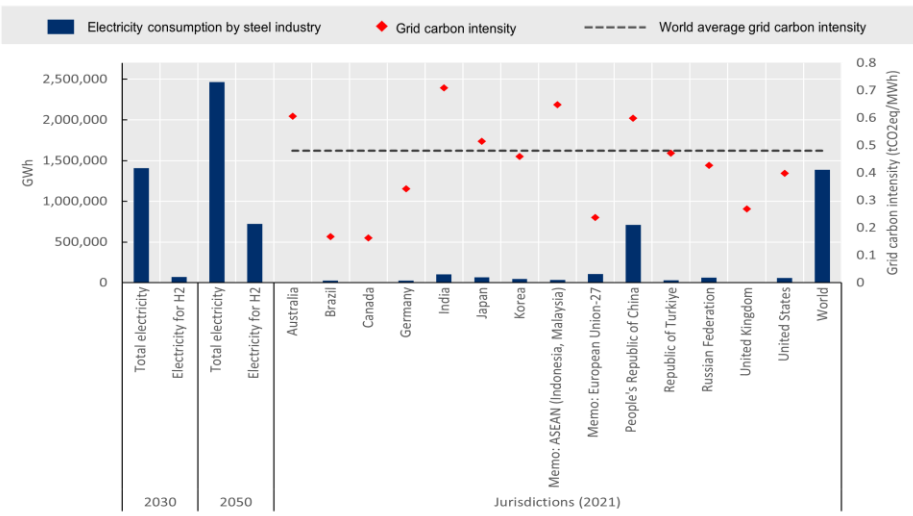
Hydrogen-based steelmaking requires additional infrastructure, e.g. for hydrogen storage, transport, renewable energy and grids to absorb the large amount of renewable energy for renewable hydrogen. In this sense, while many steel companies have announced ambitious hydrogen strategies and outlined hydrogen projects, the number of companies moving forward with hydrogen infrastructure development remains relatively small, as hydrogen infrastructure has certain characteristics of a public good, thus requiring public investment (Annex B). Many of hydrogen infrastructure projects are carried out in partnership with energy utilities and government (or public enterprises), and often these projects are located in a country where renewable energy sources are abundant.

Renewable-based electricity for hydrogen production and steelmaking

One of the requirements for expanding H2-DRI is the massive amount of electricity needed to produce hydrogen. The global electricity demand in the steel sector was 1232.7 Twh in 2019. For countries to reach their announced net zero targets for the steel industry, the steel industry electricity demand is expected to increase to 1407 TWh by 2030 and 2465 TWh by 2050 (IEA, 2023[34]; IEA, 2020[35]). This increase in electricity is primarily attributed to the expanded production of electrolysis production for green H2-DRI-EAFs and electric arc furnace operations.

The electricity for hydrogen produced by electrolysis can be sourced either, from the national grid and/or partially from the steel plant's own off grid electricity system. Sourcing from the national grid may pose challenges insofar as some grids remain largely reliant on carbon-intensive energy sources and as it could draw renewable capacity that could be directed towards decarbonising other sectors of the economy.

Figure 4.4. Electricity consumption in 2021 and 2030 & 2050 projections for the steel industry



Source: OECD elaboration based on (IEA, 2023[36]; IEA, 2020[35])

If the national grid does not supply renewable energy sources and a large portion of its energy mix comes from fossil-based sources, GHG emissions will be generated, which will result in high scope-2 emissions in the steel industry. To overcome this challenge, the steel industry is exploring the deployment of ad-hoc renewable energy infrastructure for hydrogen-based steelmaking with renewable energy operators. Through Power Purchase Agreements (PPAs) the steel industry could secure stable renewable energy supplies at a fixed price for a long period of time, and at the same time renewable energy operators will secure future revenues which will enable them to invest in green hydrogen infrastructure.

Investment costs

The use of carbon-free hydrogen as both a reducing agent and a fuel source will be the expected goal for steelmakers once a viable supply of clean hydrogen becomes available (von Schéele, 2023[37]). However, hydrogen-based steelmaking technology requires either plant replacement, new plant construction or auxiliary facilities which are capital intensive. Additional infrastructure for hydrogen facilities as well as renewable electricity, scaling up electrolysis, e.g. proton exchange membrane (PEM) electrolysis, etc., require large amounts of investment.

The steel industry is expected to need around USD 47 billion per year for the next 30 years to meet increasing demand and maintain existing facilities, even in the absence of major plant modification (Mission Possible Partnership, 2022[38]). Transitioning the worldwide steel plants to innovative technologies, such as H2-DRI will necessitate an additional annual investment of USD 8-11 billion (ibid). Hydrogen use in particular may potentially increase to 45-75 mt/y by 2050, from low carbon energy sources which will increase electricity demands for both the production of green hydrogen and to meet the needs of progressively electrified steel assets.

Certain assessments indicate that regarding overall investment across the steel value chain, power generation would represent the largest share of the necessary investment, followed by steelmaking capacity, bringing the total investment required for net-zero steel between USD 5.2 trillion and 6.1 trillion.

More specifically, when looking at the investment costs associated with hydrogen-based steelmaking solution, these investment costs vary depending on the chosen application. The capital expenditure (CAPEX) of industrial plants for gas injection in BF depends significantly on the origin of the injected gas, the scale of gas injection and the required gas pre-treatment stages, i.e. from cleaning to heating but, the total investment costs for a first implementation of injection of H2-rich gas in the BF shaft is estimated at €140 million (De Santis et al., 2021[39]).

The CAPEX for a hydrogen-based direct reduction iron (H2-DRI) plant, which includes the shaft furnace, electric arc furnace (EAF), and electrolyser units, is estimated to range from €470 to 574 per ton of crude steel, depending on the estimated cost of electrolysers (ibid), which implies a CAPEX increase of 20 to 30% compared to coal based BF-BOF if the upper estimate for electrolysers costs are taken into account.

However, the cost of H2-DRI challenge lies with Operating Costs (OPEX). OPEX will significantly depend on the future cost of low-carbon hydrogen. In the absence of effective solutions to address the OPEX cost gap, cost will persist as a primary challenge (ibid).

Trade

The majority of hydrogen that is currently used in steelmaking nowadays is generated and consumed domestically on-site (OECD, 2024[40]). It is anticipated that in the coming years hydrogen will be traded on a global scale as the availability of low-carbon hydrogen increases and the technologies that enable the uptake of low-carbon hydrogen achieve technological maturity, with no overlap between where hydrogen is produced and consumed. Despite this potential, hydrogen transport presents several challenges due to its physical properties. Hydrogen’s low volumetric energy density makes it inefficient and costly to transport it in its pure form. Specialised infrastructure may be needed to transform hydrogen into more transportable forms and avoid important energy losses. Building these infrastructures may result in increased capital expenditures.

As hydrogen-based steelmaking gradually switches to renewable-based hydrogen, comparative advantages in renewable-based electricity may lead to some relocation where renewables and hydrogen costs may be lower, giving rise to what some have referred to as a “renewables pull” effect (Samadi, Fischer and Lechtenböhmer, 2023[41]). Early signs of this trend can already be seen in recent project announcements by some steelmakers, where the cost advantage of renewable energy in certain regions drives investment and relocation decisions (ibid.).

For example, the energy-intensive iron ore reduction process may potentially shift to countries like Australia and those in the MENA region, which benefit from more favourable wind and solar conditions for renewable production. Compounded with the challenges in transporting hydrogen in its pure form, these countries could produce hydrogen derivatives, such as ammonia, hydrogen-based Direct Reduced Iron (DRI) or Hot Briquetted Iron (HBI), domestically and export it for further processing into steel (IEEFA, 2024[42]).

Another challenge that steel companies are facing in connection to trade in hydrogen is the lack of interoperability among different definitions of clean hydrogen. Some use terms like "clean hydrogen”, "low-carbon hydrogen," or "renewable hydrogen," while others adopt a color-coded system. Among these, "clean hydrogen" is the most widely used term, typically based on carbon intensity and system boundary criteria. Yet, even when countries set targets for "clean hydrogen," they often use different standards for carbon intensity and system boundaries, which risks further fragmentation, particularly as hydrogen is poised to become a globally traded commodity.

For instance, Australia, which is positioned to play a significant role in decarbonising the steel industry due to its abundant iron ore and renewable energy resources, has yet to establish a clear standard for clean hydrogen. This may be because its trading partners—such as Korea, China, and Japan—each have different criteria for what constitutes clean hydrogen, creating uncertainty for Australian exports of DRI (direct reduced iron) or HBI (hot briquetted iron). This fragmentation is especially problematic for the steel industry, which is already grappling with the challenge of developing a global standard for low-emission steel.

Conclusions

This section showed that steel companies understand the potential of hydrogen for decarbonisation yet are facing several challenges slowing deployment. Most companies in the sample (78%) foresee to adopt hydrogen-based solutions as part of their decarbonisation strategies. Steel companies are engaging in both hydrogen generation and logistics as well as in exploring the use of hydrogen in iron and steelmaking.

However, the limited commercial maturity of hydrogen solutions combined with a series of interrelated challenges are hindering deployment. These range from i) technology scale up; ii) cost competitiveness of hydrogen solutions vis-a-vis existing fossil fuels inputs; iii) the difficulties in trading hydrogen internationally compared to other inputs, and; iv) a set of broader challenges that are affecting the steel industry and its efforts to upgrade its industrial base including ensuring a just transition for workers and communities.

Companies’ investment in hydrogen-based solutions is so far limited, despite hydrogen been perceived as an important lever for decarbonisation. This is particularly the case of jurisdictions with significant market distortions, thus not constituting an immediate threat to the furthering of excess capacity. However, as new projects are announced and come online, it will be important to monitor whether companies initiating such projects are traditional recipients of market-distorting government support.

5 Assessing governments' hydrogen strategies and policies

To fully realise the potential of hydrogen as a driver for decarbonisation in the steel industry, technologies, business strategies, government policies and market systems must be in alignment. This section will discuss how national policy strategies respond to support the adoption of clean hydrogen and accelerate the shift toward a net zero future in the steel industry and what this means for the global level playing field.

The policy analysis is targeted at 18 different jurisdictions that covered regions including North and Latin America, the European Union, Other Europe, CIS, the Middle East and North Africa, and Asia Pacific and Southeast Asia. These regions were chosen to ensure a balanced representation of both OECD members and partner countries. The selection of these countries was based on the significant size and growth of their steelmaking capacity.

National hydrogen strategies and implications for the steel decarbonisation

The common feature across all selected 18 jurisdictions is that they have released national hydrogen strategies. These strategies are horizontal, addressing hydrogen application across multiple sectors rather than being specific to one sector. Several countries have set targets for hydrogen production and hydrogen price by 2030 and 2050, aiming to establish hydrogen as a key pillar of their decarbonisation strategies.

As for the implications of national hydrogen strategies for the steel sector, most of the selected jurisdiction, 17 out of 18, specifically mention the steel industry in their hydrogen strategies, reflecting their ambitions towards decarbonising the steel industry by using hydrogen in the production process.

Among them, 56% of selected countries have mentioned hydrogen-based steel technology in the national hydrogen strategy. These countries include Australia, Brazil, Canada, Germany, India, Indonesia, Japan, Korea, Malaysia, UAE, the UK, and the US. The remaining 44% of countries do not state the specific hydrogen-based steel technologies. Nevertheless, it is important to note that referencing the steel industry in the hydrogen strategies does not necessarily imply a detailed analysis or a clear roadmap particular to the steel industry. As such, there appears to be a gap in the level of detail and thoroughness of the strategic hydrogen approach to steel (Table 5.1).

Table 5.1. An overview of national hydrogen strategies

Region	Country	Hydrogen Strategy Announced	Hydrogen Strategy Updated	Steel included?	Target technology
Asia (Without China & India)	Korea	2019	-	Y	H2-DRI
	Japan	2017	2023	Y	H2 gas injection, H2-DRI
	Indonesia	2023	-	Y	CCUS
	Malaysia	2023	-	Y	CCUS
China	China	2021	-	Y	-
India	India	2023	-	Y	H2-DRI
CIS	Russia	2020	2023	Y	-
European Union	European Union	2020	-	Y	-
	Germany	2020	National Hydrogen Strategy Update (2023)	Y	H2-DRI
Other Europe	United Kingdom	2021	2023	Y	H2-DRI
	Turkey	2023	-	Y	-
Latin America	Brazil	2022	-	Y	H2-DRI
Middle East	Oman	2022	Oman Green Hydrogen Strategy (2024)	Y	-
	Saudia Arabia	2020	-	N	-
	UAE	2023	-	Y	H2-DRI
North America	United States	2023	-	Y	H2-DRI
	Canada	2020	2024	Y	-
Oceania	Australia	2019	2024	Y	H2-DRI

Source: OECD elaborations

Where most national hydrogen strategies mention the steel industry, they often lack two critical aspects: a clear prioritization of the steel sector and detailed plans for hydrogen's application within it. This is to some extent understandable given the wide range of sectors where hydrogen can be applied. However, considering that clean hydrogen would be initially available in limited quantities, governments may eventually need to prioritise certain industries for hydrogen applications, particularly in those industries where hydrogen has the greatest impact in lowering emissions such as steel.

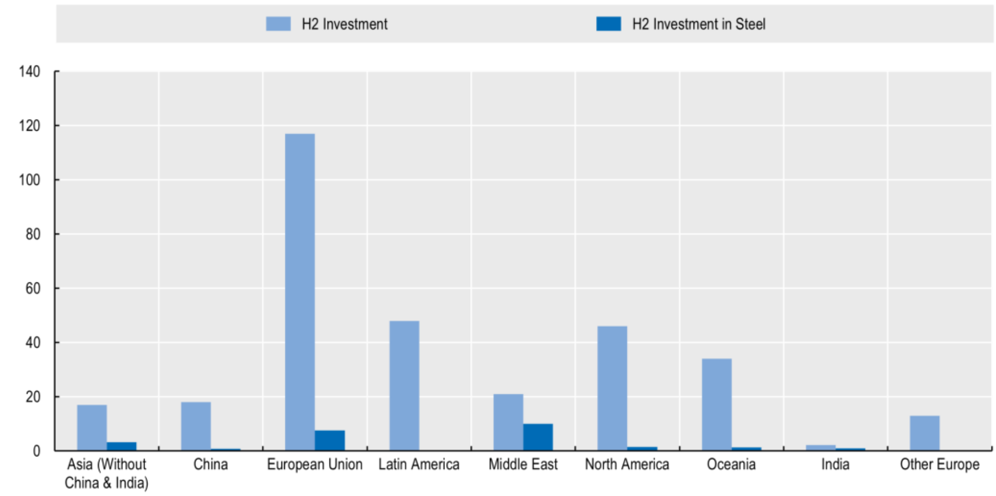
While prioritizing the steel industry is essential due to its high abatement potential, providing specific details on how hydrogen will be applied in this sector is equally important. A broad, cross-sectoral approach could unintentionally slow the adoption of innovative technologies and market development within individual industries. This risks delaying decarbonisation, as sector-specific solutions may lack the targeted support necessary for swift implementation. To address this, governments could consider not only to prioritise steel but also to develop steel-specific roadmaps for hydrogen applications.

Supply side incentives

Renewable and clean hydrogen remains more expensive than fossil-based hydrogen, making it less competitive in the market. To bridge this cost gap, many governments have announced investment plans to support hydrogen production. Several jurisdictions are prioritizing hydrogen development as part of their industrial strategies, with some specifically targeting its use in steelmaking. Figure 5.1 highlights the comparative investment levels across different regions in advancing hydrogen strategies for industrial development and the steel sector (Hydrogen Insights, 2023[43]). The European Union leads with a significant investment of 117 billion USD, followed by Latin America (48 billion USD), North

America (46 billion USD) and Oceania (34 billion USD) (Figure 5.1). Some regions, such as China, Middle East and Other Europe have also announced investments in hydrogen that are specific to the steel industry, although the size of these investments have not been specified.

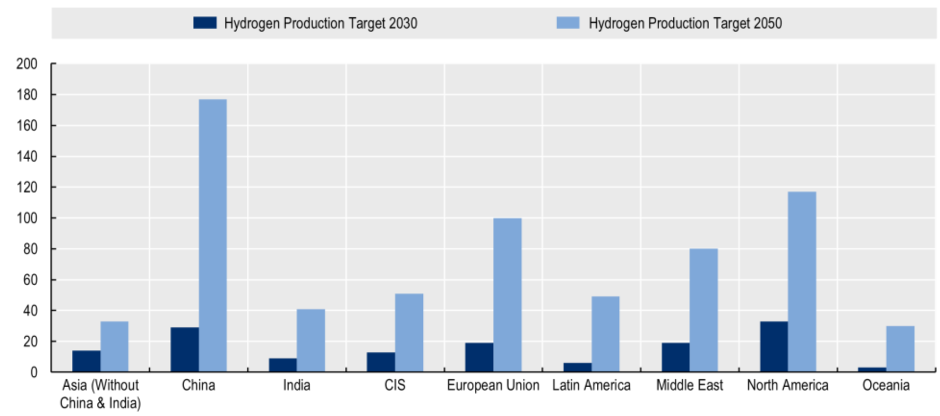
Figure 5.1. Hydrogen investment size by region



Source: (Hydrogen Insights, 2023[43])

In addition to directly investing in hydrogen generation, governments are using production and sometimes price targets to provide certainty on the future of this market and make hydrogen a cost competitive option for end users. Hydrogen production targets encourage hydrogen producers to scale up their technology readiness level as well as their capacity, encourage investors to invest in relevant technologies, and increase output to align with the set target. Setting targets signals future availability and market certainty, thereby stimulating demand. Clean hydrogen production targets are set for 2030 and 2050, where jurisdictions expect limited availability in 2030 and widespread diffusion in 2050. Production targets depend on the relative size of each economy, with the EU leading in setting a target of 100 mmt of hydrogen to be available by 2050 followed by the United States, India, and Australia (Figure 5.2).

Figure 5.2. Hydrogen production targets by region



Source: OECD elaborations based on national hydrogen strategies, (Hydrogen Council, 2023[44])

In addition to setting production targets, some countries are also setting price targets for 2030 and 2050 to provide certainty to off-takers over the long run and incentivise hydrogen adoption. Price targets for 2030 differ across countries, in line with different starting points, however they tend to converge to 1 USD per kg in the 2050, when widespread diffusion is expected. These price targets reflect the need to make hydrogen a cost competitive option for adopters.

The cost of renewable hydrogen is primarily determined by the cost of renewable electricity, the annual operating hours of the electrolyser, and the electrolyser system costs. Therefore, it will be imperative for governments to consider not only clean hydrogen applications to the steel industry, but also to oversee the upstream industries, such as at the intake of renewable electricity for the renewable hydrogen producers for steel production for seamless coordination within the steel value chain. If the government can ensure the cost competitiveness of renewable and low-emission hydrogen, it will give a clearer signal to the hydrogen producers and steel companies to switch their source from high emitting hydrogen to renewable and low-emission hydrogen.

Some jurisdictions such as the United States have gone further in stimulating hydrogen production as part of their national efforts to clean their economy. For instance, as part of the Inflation Reduction Act, the United States' government has set an important tax incentive scheme to ensure that hydrogen production costs and prices as a result become competitive with those of other fossil fuels.

Demand side incentives

Governments also consider stimulating hydrogen demand by facilitating links between hydrogen supplying companies and hydrogen demand companies to ensure a stable market for hydrogen. This can be done through instruments such as public-private and private-private partnership, as well as long-term contracts, e.g. Carbon Contracts for Difference (CCfD) as is the case of Germany (Box 5.1)

In addition, by linking producers with committed buyers, countries can reduce market uncertainty and accelerate the deployment of clean hydrogen. Some countries have come up with match-making linking hydrogen generators and hydrogen off-takers creating private-private and private-public partnership to accelerate the commercialisation of new technologies and create synergies across hydrogen producers across industries.

For example, the US Department of Energy has launched a platform, 'H2 Matchmaker' to facilitate partnerships and match hydrogen suppliers and customers to help create a market. This includes green hydrogen, green ammonia, renewable electrolysers, other industrial applications. In addition, Korea has introduced the matchmaking platform by connecting hydrogen conglomerate suppliers and SMEs to create an industrial demand ecosystem. For example, LG Chemical, a conglomerate that develops Alkaline electrolyser, has been matched with SMEs that need Alkaline electrolysers to produce electrodes, etc.

Box 5.1. Incentivising hydrogen production and consumption for industrial decarbonisation through CCFDs, the case of Germany

In March 2024, the German Federal Ministry for Economic Affairs and Climate Action (BMKW) launched the first bidding round of €4 billion for its estimated €50 billion scheme for so-called "Climate Protection Contracts" (Klimaschutzverträge), which work as Carbon Contracts for Difference ("CCfDs"). Carbon Contracts for Difference work as an upfront financing mechanism that guarantee a strike price for using a low carbon option, that makes it price competitive against a high carbon alternative. These contracts aim to accelerate the deployment and commercialisation of low carbon technologies at a quick pace so that in the medium term they can run without the need for government funding (BMWK, 2024[45]).

The German CCfDs will offer payments for 15 years to industrial players (such as steel and chemicals producers) to switch to using hydrogen, electrification, or other low-emissions methods of production. In cases where hydrogen is used, it must meet the strict criteria of the EU taxonomy. In particular, blue hydrogen can only be used if the production process is particularly low on emissions. Companies using green hydrogen – the cleanest form of hydrogen – are given more funding than companies using blue hydrogen. The scheme will also indirectly incentivise investment in the production of a green hydrogen infrastructure, such as hydrogen production plants and pipelines.

Under the scheme, winning bidders, selected on their promise to save the most carbon at the lowest price, would be guaranteed a strike price for using the lower-carbon option, in the form of a top-up payment from the government based on the prevailing cost of the higher-carbon option, including any existing carbon price under the EU Emissions Trading System (ETS). In essence, the end user would pay the same for the low-carbon and high-carbon option with this top-up subsidy. However, if the greener option becomes cheaper, the situation is reversed. If the manufacturing cost using low-carbon alternatives becomes cheaper than the existing fossil fuel-based alternative at a specific time, the symmetric nature of CCfDs would ensure repayment of the difference. This crossing point is expected to occur as EU ETS credits become more expensive over time and clean technologies (such as hydrogen) becomes cheaper as the market grows (Ason and Dal Poz, 2024[46]).

The German CCfDs include an early termination option after three years if low-carbon production becomes cheaper than the alternative. The early termination feature is important as governments experiment with CCfD-type instruments in different markets. One of the biggest challenges in creating a functioning market for clean hydrogen is how to incentivise demand, as early movers may be wary of committing to long-term contracts, knowing that the cost of low-carbon products (e.g. low-carbon hydrogen) will fall over time. The early termination feature attempts to address this delicate balance by offering long-term support contracts that are in place when prices are too high but can be terminated when the competitive market starts to drive prices down.

Before its launch, the funding programme underwent thorough revision to ensure its compliance with the European Commission Communication on Guidelines on State Aid for Climate Action, and its first bid was authorised by the EC's Decision of February 16, 2024 (European Commission, 2024[47]).

Trade policies

Trade-related hydrogen policies tend to be pronounced in countries like Australia, where renewable energy sources are abundant and therefore conducive to the clean hydrogen production, as well as iron ore reserves for the production of hydrogen derivatives such as DRI/HBI. Australia has set a clean hydrogen export target thereby sending a strong signal to the global hydrogen market. Not only Australian iron ore importing countries such as Japan and Korea, but also the EU and India have entered into hydrogen partnership with Australia. Furthermore, Australia plans to implement the Guarantee of Origin Scheme for hydrogen and steel in 2025, a certification framework that will support trade and the expansion of the hydrogen industry domestically and internationally. This will contribute to the harmonisation of what constitutes low emission hydrogen by meeting the requirements of the hydrogen import market.

Implications for the global level playing field

This section has illustrated the many ways by which governments can support the build-up of a hydrogen economy and incentivise the take up of hydrogen in downstream sectors. The envisioned measures tend to be horizontal in nature and are typically aimed at addressing the lack of clean energy infrastructures, which are fundamental to address the negative externality of climate change and transition to a clean economy. Moreover, once clean energy infrastructures are deployed, these measures are likely to be phased out, thus implying a temporary framework to reach the stated policy objectives.

The temporary nature of these measures is even more important when considering measures that are less horizontal such as the partial covering of additional costs associated with the adoption of hydrogen, as these aims at making hydrogen cost competitive with alternative fossil fuels options so that first movers are not at disadvantage when committing to transition to lower emissions production routes. Once price differentials are addressed, support should be removed to ensure a level playing field. The temporary and horizontal nature of government support measures for hydrogen production and consumption make these measures less distortive in comparison with other types of support to energy inputs, such as the provision of below market energy inputs to energy intensive industries such as steel.

The provision of below market energy inputs to steel firms impacts the level playing field as beneficiary companies enjoy higher profit margins and can sell steel products at lower prices as a significant part of their cost structure is absorbed by the government (OECD, 2023[48]). In addition to distorting the level playing field, these measures, in particular when applied to coal, oil and gas inputs, delays the transition as they mute price signals and the incentives to switch to low carbon production methods.

While temporary energy price relief measures can be justified on the ground that they aim to address the impact of temporary shocks that can significantly disrupt market functioning such as the support provided in response to the energy price shock caused by the Russian invasion of Ukraine, the systematic provision of below market energy inputs constitutes a major concern. For example, in non-OECD economies energy subsidies are often long-term and are part of broader industrial policies rather than short-term responses. In regions like the Middle East, North Africa, and Southeast Asia these subsidies keep energy prices artificially low on a permanent basis, giving energy-intensive industries, such as steel, an unfair competitive advantage by significantly reducing their production costs.

The provision of below market energy inputs may raise concerns also for the developments in hydrogen-based solutions in light of the correspondence between the geographical concentration of fossil fuel subsidies and the developments of gas-based DRI facilities in the MENA region (see section 0), although subsidies for natural gas appear to account for a smaller share compared to oil.

While the majority of DRI projects are built under the premises of using natural gas as transition fuel, it is key that support provided is conditional upon the adoption of green hydrogen at a certain stage to ensure that carbon is not locked in beyond what desirable, in line with the COP28 UAE consensus. The presence of fossil fuels subsidies in the MENA region may disincentivise such transition from gas to hydrogen, thus failing to address emission from the steel value chain in the long run.

While, as described in section 3, the buildout of DRI capacity in the MENA region seems to be based on the premises of comparative advantages in natural gas production, it is crucial that subsidies to natural gas are removed to avoid the displacement of low carbon efficient facilities that are trying to find their way in global steel markets and the furthering of excess capacity.

Conclusions

This section showed that the largest steelmaking jurisdictions have set national hydrogen strategies that cover the steel sector, however sector specific details are missing. Most of the selected jurisdictions have set out a national hydrogen strategy that includes the steel industry highlighting that hydrogen will play an important role in replacing fossil fuels. Nevertheless, mentioning of steel does not necessarily imply a detailed analysis or a clear roadmap for hydrogen application specific to the steel industry. As such, there appears to be a gap in the level of detail and thoroughness of the strategic hydrogen approach to steel. However, given expectations of limited hydrogen supply, governments may eventually need to be selective in identifying industries for hydrogen application, taking into consideration those industries where hydrogen is the only the alternative that can significantly contribute to lowering emissions such as steel.

National hydrogen strategies tend to cover the main challenges associated with hydrogen adoption albeit in a sector-agnostic approach. National hydrogen strategies tend to focus on building the supply and demand conditions ensuring a just transition for workers and communities in affected sectors, and on trade aspects including the for international cooperation, market access and a level playing field, while some countries also focus on their strategic positioning in hydrogen value chain.

Countries are adopting different strategies to build the supply conditions for hydrogen. These include allocating public money for investment in hydrogen infrastructure and in some cases, for hydrogen application in the steel sector, setting production as well as price targets, while also attempting to address cost differentials to ensure that hydrogen production costs and prices become competitive vis-à-vis those of other fuels.

Policies to incentivise hydrogen take up are geared towards ensuring the existence of a stable market for hydrogen. Governments also consider stimulating hydrogen demand by facilitating links between hydrogen supplying companies and hydrogen demand companies to ensure a stable market for hydrogen. The envisioned measures tend to be horizontal in nature and are typically aimed at addressing the lack of clean energy infrastructures, which are fundamental to address the negative externality of climate change and transition to a clean economy. Moreover, once clean energy infrastructures are deployed, these measures are likely to be phased out, thus implying a temporary framework to reach the stated policy objectives. This temporary nature aimed at bringing hydrogen to the market is key to avoid market distortions.

In sum, the temporary and horizontal nature of hydrogen related support measures is less likely to create market distortions to the level playing field compared to other forms of support, including for energy inputs.

6 Policy insights

Horizontal and temporary support for hydrogen deployment can help hydrogen uptake in steelmaking without necessarily leading to market distortions.

As the steel sector is plagued by the presence of massive distortions resulting from government support and leading to overcapacity and market frictions, policy makers need to find a way to support the advancement of low-carbon solution such as hydrogen-based steelmaking without further distorting the level playing field and aggravating the excess capacity situation. Policy measures that aim at addressing the price differential between hydrogen and fossil fuels-based production can be justified inasmuch as they remain anchored and time bound to that goal. In contrast, in jurisdictions where the presence of market distortion is significant, even such time-bound and horizontal support is likely to further distortions as it would put hydrogen-based production at cost parity with subsided production.

Support to facilitate the build-up of hydrogen-based steelmaking assets needs to always consider the implications for global steel excess capacity

While the adoption of hydrogen-based solutions responds to the policy-driven imperative of addressing the steel industry carbon footprint, it needs to follow market principles in both hydrogen and steel markets. Countries benefitting from national endowments of abundant solar and wind and, as a result, from comparative advantages in renewable energy and green hydrogen production, may consider developing a hydrogen-based steelmaking asset base. However, these comparative advantages need to be juxtaposed to the existing and future market conditions for steel. With global demand for steel expected to be subdued in the long-run, these capacity additions need to be accompanied by closures of high-emitting assets in relevant jurisdictions to prevent the exacerbation of excess capacity. At the same time, countries that are considering upgrading their fleet with hydrogen-based steelmaking solutions need to consider phasing out the corresponding existing emission intensive assets.

Government could consider developing a steel industry specific roadmap for hydrogen application to accelerate decarbonisation

Given the overarching direction of the hydrogen economy from the national hydrogen strategy that the selected jurisdictions have announced, governments could consider developing a detailed sector specific roadmap for the steel industry that outlines targets and support mechanisms for transitioning to hydrogen economy for the steel industry. Such roadmaps could provide detailed guidance on decarbonisation pathways using hydrogen, technological investments, and regulatory frameworks, ensuring that industries and have a clear direction for aligning with national hydrogen economy plan as well as climate goals. Financial incentives for renewable and clean hydrogen application into the steelmaking process and capacity-building for workers could be incorporated into the roadmap to accelerate the diffusion and scale up the hydrogen use in the steel industry.

Moreover, this steel industry specific roadmap for hydrogen adoption needs to include social-economic aspect. Establishing and integrating long-term just transition roadmap in hydrogen strategy specific to the steel industry will ensure a smooth green transition. This can be done by creating or improving steel industry workforce data, developing training programmes tailored to the national context, involving civil society and work union stakeholders in the decision-making process. Such roadmap would complement existing steel decarbonisation roadmaps where the heterogeneity of decarbonisation pathways is well acknowledged, and hydrogen-based steelmaking is part of a broader technological portfolio that includes other low-carbon technologies.

Prioritise industries that don't have an alternative to hydrogen to significantly reduce carbon emissions

Hydrogen can contribute to any industry's decarbonisation. However, as renewables and clean hydrogen generation are still in the nascent stage that needs to scale up, there will not be sufficient hydrogen to feed all industries in the short term. Choosing the right industries for hydrogen application is crucial as it maximises the impact of hydrogen in reducing emissions, enhancing energy efficiency and cost efficiency. As the steel industry is one of the hard-to-abate sectors, hydrogen is a key solution to decarbonise. Therefore, policymakers could consider prioritising the industries that offers the best environmental and economic benefits, accelerating the transition to the net-zero economy.

Close coordination of the entire steel value chains is a key enabler for hydrogen application to decarbonise the steel industry

Interoperability across the value chain, particularly between hydrogen producers (upstream) and the steel industry is crucial for hydrogen adoption and a rapid transition. Several jurisdictions have introduced a standard for renewable and clean hydrogen. By having cohesive interoperability hydrogen industry and steel industry, hydrogen generators can optimise production capacity, infrastructure development while steel companies can plan their uptake based on reliable hydrogen supply.

Coordination between government and companies is essential in accelerating hydrogen production and uptake in the steel industry. As hydrogen applications in the steel industry requires substantial capital and resources, in particular for what concerns the associated hydrogen infrastructure, governments may need to step in as steel companies may not have sufficient resources or capabilities to tackle the complexity of hydrogen value chains. Also, government's role as a match-making platform to connect hydrogen generators and consumers will be important, signalling commitment and building confidence for hydrogen and steel producers to rapidly advance towards hydrogen-based steelmaking production.

Enhancing international cooperation

The steel industry is one of the industries that could be affected by the renewable pull effect indicating which could lead to relocation internationally. Steel is already highly traded commodity. However, when renewable and clean hydrogen is applied to the steel production, this will enhance the trade dynamics significantly. Therefore, international collaboration can pool resources to accelerate the development of necessary technologies, reduce costs, and create global supply chains that ensure a seamless hydrogen supply. In addition, international cooperation can support interoperable standards and policies that facilitate cross-border trade in DRI/HBI which is crucial to achieving the global net-zero goal while ensuring a level-playing field.

References

Agora (2021), *Making renewable hydrogen cost-competitive: Policy instruments for supporting green H_2*, https://static.agora-energiewende.de/fileadmin/Projekte/2020/2020_11_EU_H2-Instruments/A-EW_223_H2-Instruments_WEB.pdf (accessed on 14 October 2024). [70]

Agora (n.d.), *15 Insights on the Global Steel Transformation*, https://www.agora-industry.org/fileadmin/Projekte/2021/2021-06_IND_INT_GlobalSteel/A-EW_298_GlobalSteel_Insights_WEB.pdf. [75]

Agora Industry and Wuppertal Institute (2023), *15 Insights on*, https://www.agora-industry.org/fileadmin/Projekte/2021/2021-06_IND_INT_GlobalSteel/A-EW_298_GlobalSteel_Insights_WEB.pdf. [2]

Ason, A. and J. Dal Poz (2024), *Contracts for Difference: the Instrument of Choice for the Energy Transition*. [46]

Australian Government (2022), *Australia's Guarantee of Origin scheme Policy position paper*, Department of Climate Change, Energy, the Environment and Water. [52]

Bataille, C., S. Stiebert and F. Li (2024), *Facility level global net-zero pathways under varying trade and geopolitical scenarios: Final Technical & Policy Report for the Net-zero*, https://netzeroindustry.org/wp-content/uploads/pdf/net_zero_steel_report_ii.pdf. [11]

Bellona (2021a), *Hydrogen in steel production: what is happening in Europe – part one*, https://bellona.org/news/eu/2021-03-hydrogen-in-steel-production-what-is-happening-in-europe-part-one. [4]

Bellona (2021b), *Hydrogen in steel production: what is happening in Europe – part two*, https://bellona.org/news/eu/2021-05-hydrogen-in-steel-production-what-is-happening-in-europe-part-two. [5]

Benavides, K. et al. (2024), "Mitigating emissions in the global steel industry: Representing CCS and hydrogen technologies in integrated assessment modeling", *International Journal of Greenhouse Gas Control*, https://doi.org/10.1016/j.ijggc.2023.103963. [49]

Bhaskar, A., M. Assadi and H. Somehsaraei (2020), "Decarbonization of the Iron and Steel Industry with Direct Reduction of Iron Ore with Green Hydrogen", *Energies*, https://doi.org/10.3390/en13030758. [81]

BloombergNEF (2024), *New energy outlook*, https://about.bnef.com/new-energy-outlook/. [12]

BMWK (2024), *Carbon Contracts for Difference*. [45]

CertifHy (2021), *CertifHy*, https://www.certifhy.eu/wp-content/uploads/2021/10/CertifHy_folder__leaflets.pdf (accessed on 14 October 2024). [51]

Climate Club (Forthcoming), *The Carbon Capacity Nexus: A framework for supply side industrial emission reduction pledges*. [60]

Cordonnier, J. and D. Saygin (2022), "Green hydrogen opportunities for emerging and developing economies: Identifying success factors for market development and building enabling conditions", *OECD Environment Working Papers*, No. 205, OECD Publishing, Paris, https://doi.org/10.1787/53ad9f22-en. [23]

CRU (2024), *Steel Long Term Market Outlook*, https://www.crugroup.com/en/communities/thought-leadership/2024/decarbonisation-will-reshape-global-steel-trade-flow/. [8]

DCCEEW (2024), *National Hydrogen Strategy 2024*, https://www.dcceew.gov.au/sites/default/files/documents/national-hydrogen-strategy-2024.pdf (accessed on 14 October 2024). [50]

De Santis, M. et al. (2021), *INVESTMENT NEEDS*, Green Steel for Europe Consortium. [39]

Devlin, A. et al. (2023), "Global green hydrogen-based steel opportunities surrounding high quality renewable energy and iron ore deposits", *Nature Communications*, https://doi.org/10.1038/s41467-023-38123-2. [22]

Eliason, J. (2024), *Clean Hydrogen Tax Credits: Treasury Department and IRS Propose Regulations on Production and Investment Tax Credits Under the Inflation Reduction Act*, https://www.orrick.com/en/Insights/2024/01/Treasury-and-IRS-Propose-Regulations-on-Clean-Hydrogen-Tax-Credits-Under-the-Inflation-Reduction-Act. [74]

EPRS (2020), *The potential of hydrogen for decarbonising steel production*, https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/641552/EPRS_BRI(2020)641552_EN.pdf. [63]

European Commission (2024), *Commission approves €4 billion German State aid scheme partially funded under Recovery and Resilience Facility to help industries decarbonise production processes*, https://ec.europa.eu/commission/presscorner/detail/en/ip_24_845. [47]

Fan, Z. and S. Friedmann (2021), "Low-carbon production of iron and steel: Technology options, economic assessment, and policy", *Joule*, Vol. 5/4, pp. 829-862, https://doi.org/10.1016/j.joule.2021.02.018. [61]

GFSEC (2024), *Impact of global excess capacity on the health of GFSEC industries*, https://www.steelforum.org/gfsec-impacts-of-global-excess-capacity.pdf. [25]

GFSEC/OECD (2022), *Assessing steel decarbonisation progress in the context of excess capacity: a steel indicator decarbonisation dashboard*, https://www.steelforum.org/steel-indicator-decarbonisation-dashboard.pdf. [26]

Global Energy Monitor (2024), *Pedal to the Metal 2024: Building momentum for iron and steel decarbonization*, https://globalenergymonitor.org/wp-content/uploads/2024/07/GEM-Pedal-to-the-Metal-2024-steel-iron-report.pdf. [56]

Green Hydrogen Catapult (2024), *Green Iron Corridors: Transforming Steel Supply Chains for a* [64]

Sustainable Future doi, https://greenh2catapult.com/wp-content/uploads/2024/09/green_iron_corridors_steel_supply_chain_report.pdf.

Hasanbeigi, A. et al. (2024), *Green Steel Economics*, https://www.globalefficiencyintel.com/green-steel-economics. [20]

Hydrogen Council (2024), *Hydrogen Insights 2024*, https://hydrogencouncil.com/wp-content/uploads/2024/09/Hydrogen-Insights-2024.pdf. [65]

Hydrogen Council (2023), *Hydrogen Insights 2023*, https://hydrogencouncil.com/wp-content/uploads/2023/05/Hydrogen-Insights-2023.pdf (accessed on 14 October 2024). [44]

Hydrogen Council (2020), *Path to hydrogen competitiveness: a cost perspective*, https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf. [68]

Hydrogen Insights (2023), “Hydrogen Insights 2023 An update on the state of the global hydrogen economy, with a deep dive into North America”, http://www.hydrogencouncil.com (accessed on 7 October 2024). [43]

IEA (2024), *Global Hydrogen Review 2024*, IEA, https://www.iea.org/reports/global-hydrogen-review-2024. [14]

IEA (2023), *ETP Clean Energy Technology Guide*. [33]

IEA (2023), *Extended World Energy Statistics and Balances*, https://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en (accessed on 14 October 2024). [36]

IEA (2023), *Global Hydrogen Review 2023*, https://iea.blob.core.windows.net/assets/ecdfc3bb-d212-4a4c-9ff7-6ce5b1e19cef/GlobalHydrogenReview2023.pdf. [34]

IEA (2023), *Global Hydrogen Review 2023*, http://www.iea.org. [77]

IEA (2023), *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach*, https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach. [57]

IEA (2021), *Net Zero by 2050: A Roadmap for the Global Energy Sector*, https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf. [7]

IEA (2021), *Recommendations of the global commission on people-centered clean energy transitions*, https://iea.blob.core.windows.net/assets/07406f49-ebdb-4955-9823-69c52cce04dc/Recommendationsoftheglobalcommissiononpeople-centredcleanenergytransitions.pdf (accessed on 27 October 2024). [76]

IEA (2020), *Energy Technology Perspectives 2020 - Special Report on Clean Energy Innovation*, OECD Publishing, Paris, https://doi.org/10.1787/ab43a9a5-en. [10]

IEA (2020), *Iron and Steel Technology Roadmap*, https://www.iea.org/reports/iron-and-steel-technology-roadmap (accessed on 19 January 2024). [35]

IEEFA (2024), *Hydrogen unleashed: Opportunities and challenges in the evolving H2-DRI-EAF pathway beyond 2024*, https://ieefa.org/resources/hydrogen-unleashed-opportunities-and- [42]

challenges-evolving-h2-dri-eaf-pathway-beyond-2024.

IEEFA (2022), *Iron Ore Quality a Potential Headwind to Green Steelmaking: Technology and Mining Options Are Available to Hit Net-Zero Steel Targets*, https://ieefa.org/resources/iron-ore-quality-potential-headwind-green-steelmaking-technology-and-mining-options-are. [67]

IRENA (2024), *Global trade in green hydrogen derivatives: Trends in regulation, standardisation and certification*,, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Oct/IRENA_Green_hydrogen_derivatives_trade_2024.pdf. [79]

Lee, M. and D. Saygin (2023), "Financing cost impacts on cost competitiveness of green hydrogen in emerging and developing economies", *OECD Environment Working Papers*, No. 227, OECD Publishing, Paris, https://doi.org/10.1787/15b16fc3-en. [66]

Macquarie, R. et al. (2023), *Just and robust transitions to net zero A framework to guide national policy*, University College London, Grantham Research Institute on Climate Change and the Environment, ClimLaw: Graz, Centre for Climate Law and Sustainability Studies, Center for International Climate Research. [69]

Mauret, F. et al. (2023), "Impact of Hydrogenous Gas Injection on the Blast Furnace Process: A Numerical Investigation", *Metallurgical and Materials Transactions B*, Vol. 54/4, pp. 2137-2158, https://doi.org/10.1007/s11663-023-02822-4. [32]

Mercier, F. and L. Giua (2023), "Subsidies to the steel industry: Insights from the OECD data collection", *OECD Science, Technology and Industry Policy Papers*, No. 147, OECD Publishing, Paris, https://doi.org/10.1787/06e7c89b-en. [80]

Mission Possible Partnership (2022), *Making Net-Zero Steel possible*, https://3stepsolutions.s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-Net-Zero-Steel-possible-steel.pdf. [6]

Mission Possible Partnership (2022), *Making Net-Zero Steel Possible*, https://missionpossiblepartnership.org/wp-content/uploads/2022/09/Making-Net-Zero-Steel-possible.pdf. [38]

Nduagu, E. et al. (2022), "Comparative life cycle assessment of natural gas and coal-based directly reduced iron (DRI) production: A case study for India", *Journal of Cleaner Production*, https://doi.org/10.1016/j.jclepro.2022.131196. [82]

OECD (2024), *Addressing steel decarbonisation challenges for industry and policy*, OECD Publishing, Paris, https://doi.org/10.1787/e6cb2f3c-en. [27]

OECD (2024), "Green industrial policies for the net-zero transition", *OECD Net Zero+ Policy Papers*, No. 2, OECD Publishing, Paris, https://doi.org/10.1787/ccc326d3-en. [30]

OECD (2024), *In-Session Workshop on Trade and Green Hydrogen*, https://one.oecd.org/document/COM/TAD/ENV/JWPTE(2024)4/FINAL/en/pdf (accessed on 14 October 2024). [40]

OECD (2024), *Latest developments in steelmaking capacity and outlook until 2026*. [24]

OECD (2024), *Latest developments in steelmaking capacity and outlook until 2026*, https://one.oecd.org/document/DSTI/SC(2024)3/FINAL/en/pdf. [28]

OECD (2024), *Steel Scrap and the Circular Economy*, OECD publishing. [54]

OECD (2023), "Measuring distortions in international markets: Below-market energy inputs", *OECD Trade Policy Papers*, No. 268, OECD Publishing, Paris, https://doi.org/10.1787/b26140ff-en. [48]

OECD (2023), *OECD work in support of industrial decarbonisation*, OECD Publishing, Paris, https://doi.org/10.1787/cd589e4f-en. [1]

OECD (2023), *OECD Work in support of Industrial decarbonisation*, https://issuu.com/oecd.publishing/docs/oecd_industrial_decarbonisation_2023. [72]

OECD (2023), *Regional Industrial Transitions to Climate Neutrality*, OECD Publishing. [71]

OECD (2023), *The Heterogeneity of Steel Decarbonisation Pathways*, OECD Publishing, Paris, https://doi.org/10.1787/fab00709-en. [59]

OECD (2023), *The Heterogeneity of Steel Decarbonisation Pathways*, OECD publishing, https://doi.org/10.1787/fab00709-en. [83]

OECD (2022), *Assessing Steel Decarbonisation Progress - Ready for the decade of delivery?*, https://www.oecd.org/industry/ind/assessing-steel-decarbonisation-progress.pdf (accessed on 4 January 2023). [53]

OECD (2022), "Framework for industry's net-zero transition: Developing financing solutions in emerging and developing economies", *OECD Environment Policy Papers*, No. 32, OECD Publishing, Paris, https://doi.org/10.1787/0c5e2bac-en. [58]

OECD/The World Bank (2024), *Scaling Hydrogen Financing for Development*, OECD Publishing, Paris, https://doi.org/10.1787/0287b22e-en. [21]

OECD/The World Bank (2024), *Scaling Hydrogen Financing for Development*, OECD Publishing, https://doi.org/10.1787/0287b22e-en. [17]

RMI (2022), *Steel yourself: Implications of Peak Demand in the Energy Transition*, https://rmi.org/insight/steel-yourself/. [18]

Samadi, S., A. Fischer and S. Lechtenböhmer (2023), "The renewables pull effect: How regional differences in renewable energy costs could influence where industrial production is located in the future", *Energy Research & Social Science*, Vol. 104, p. 103257, https://doi.org/10.1016/j.erss.2023.103257. [41]

Shahabuddin, M., G. Brooks and M. Rhamdhani (2023), "Decarbonisation and hydrogen integration of steel industries: Recent development, challenges and technoeconomic analysis", *Journal of Cleaner Production*, https://doi.org/10.1016/j.jclepro.2023.136391. [3]

Stegra (2024), *H2 Green Steel raises more than €4 billion in debt financing for the world's first large-scale green steel plant*, https://stegra.com/news-and-stories/h2-green-steel-raises-more-than-4-billion-in-debt-financing-for-the-worlds-first-large-scale-green-steel-plant. [78]

Steward, E. et al. (2023), *The role of hydrogen in decarbonising the steel industry: upstream and downstream in the UK and Ontario*, https://strathprints.strath.ac.uk/85755/1/Steward_etal_IGEC2023_The_role_of_hydrogen_in_the_decarbonisation_of_the_steel_industry.pdf. [29]

Terlouw, T., L. Rosa and C. Bauer (2023), "Global land and water limits to electrolytic hydrogen production using wind and solar resources", *Nature Communications*, https://doi.org/10.1038/s41467-023-41107-x. [16]

Transition Asia (2024), *Will China win the green steel race? H2-DRI-EAF market and policy development to 2030*, https://transitionasia.org/wp-content/uploads/2024/10/EN_Will_China_Win_the_Green_Steel_Race_241010.pdf. [15]

US Department of Energy (2022), *Financial Incentives for Hydrogen and Fuel Cell Projects*, https://www.energy.gov/eere/fuelcells/financial-incentives-hydrogen-and-fuel-cell-projects. [73]

Vogl, V., M. Åhman and L. Nilsson (2018), "Assessment of hydrogen direct reduction for fossil-free steelmaking", *Journal of Cleaner Production*, Vol. 203, pp. 736-745, https://doi.org/10.1016/j.jclepro.2018.08.279. [62]

von Schéele, J. (2023), "Pathways towards full use of hydrogen as reductant and fuel", *Matériaux & Techniques*, Vol. 111/4, p. 405, https://doi.org/10.1051/mattech/2023030. [37]

Watari, T. and B. McLellan (2024), "Global demand for green hydrogen-based steel: Insights from 28 scenarios", *International Journal of Hydrogen Energy*, https://doi.org/10.1016/j.ijhydene.2024.06.423. [13]

World Steel Dynamics (2024), *Glass half full or half empty? Steel industry decarbonisation by 2040*. [9]

World Steel Dynamics (2023), *Global Steel Information System*. [31]

WSD (2024), *2030 to 2040: Progress, still a long way to go*. [55]

Wurbs, S. et al. (2024), *"How Important Will Hydrogen be in the Energy System of the Future?" (In a Nutshell!)*, https://doi/org/10.48669/esys_2024-7. [19]

Annex A. The heterogeneity of hydrogen production pathways

Hydrogen can be produced in multiple ways, which are usually classified by colours. Grey and brown hydrogen are the main fossil-fuels based production pathways (natural gas and coal), representing over 80% of the global supply in 2022. Blue hydrogen refers to fossil fuel-based production equipped with CCS to capture carbon emissions. Green hydrogen is produced using electrolysis of water and renewable electricity (wind or solar power).

Green and blue hydrogen only accounts for less than 1% of the total production. Other forms of hydrogen include red hydrogen, yellow hydrogen, and turquoise hydrogen, respectively produced using nuclear power, grid electricity, and methane pyrolysis.

Both pink (nuclear power based) and green hydrogen (renewable energy-based) allow to produce hydrogen close to near-zero carbon emissions, while the carbon intensity of brown hydrogen (coal-based) has higher emission intensity.

Further analysis of the clean energy resources required to produce the green hydrogen needed for steel decarbonisation may be necessary. When accounting for the capital investment and clean energy required to produce green hydrogen, other production routes, such as scrap-based EAF production, may better support decarbonisation efforts in many instances.

Table A.1. Overview of hydrogen classification: fuel type, production share, carbon emissions, costs

Type of hydrogen	Type of fuel (process)	2023 share of total production	Amount of carbon generated for 1 kg of hydrogen	Production costs
Brown	Coal (gasification)	21%	22-26 kgCO2eq	€1.5-3/kgH2
Grey	Natural gas (steam reforming)	62%	9.5-13.5 kgCO2eq	€1-2.6/kgH2
Blue	Coal + Natural gas (CCS)	0.6%	1.5-6.3 kgCO2eq	€1.5-3.2/kgH2
Turquoise	Natural gas (methane pyrolysis)	N.A.	2-16 kgCO2eq	€1.5-4.9/kgH2
Red/Pink	Nuclear power (thermolysis/electrolysis)	N.A.	0.1-0.3 kgCO2eq	€3.3-6.8/kgH2
Yellow	Mains power (electrolysis)	N.A.	2.5-36 kgCO2eq	N.A.
Green	Renewable energy (electrolysis)	0.1%	0 kgCO2eq	€3.1-9/kgH2

Note: Upstream and downstream greenhouse gas emissions for individual processes are not included due to the high level of uncertainty about the figures. Hydrogen can also be produced with biomass-based processes, such as biomass gasification or fermentation, but these processes currently do not have an agreed upon “colour”.
Source: Authors’ compilation based on (Benavides et al., 2024[49]); (Wurbs et al., 2024[19]); (IEA, 2024[14]).

Annex B. Selection of steel companies by region

The sample of companies selected represents 40% of global crude steel production and around a third of global steelmaking capacity, as well as emerging steel producers that have recently shown strong capacity growth as in the case of Southeast Asia (Table B.1). This analysis builds on previous work on decarbonisation strategies of major steel producers, and, as such, does not cover new steelmaking producers that are entering steel markets via hydrogen-based steelmaking (OECD, 2024[27]) .

Table B.1. Selection of companies by region

Region	Company				
Africa	Arcelor Mittal	Ezz			
Asia (Japan & Korea)	JFE Steel Corporation	Nippon	POSCO		
China	Ansteel	Baowu	HBIS	Jianlong	Shagang
India	JSW	Tata Steel	Sail		
South East Asia	Esteel	Krakatau Steel	Gunung Rajapaksi		
Oceania	Bluescope	Liberty Steel			
CIS	NLMK	MMK			
EU	ArcelorMittal	Tata Steel	Thyssenkrupp		
Other Europe	Erdemir Group	Tata Steel			
Middle East	Emirates Steel	IMIDRO	Saudi Iron & Steel		
Latin America	Techint				
North America	Nucor	U.S. Steel			

Annex C. Steel companies' investments in hydrogen infrastructure

Table C.1. Companies investment in hydrogen infrastructure

Company	Original plant location	Which infrastructure?	Project Location	Note
Arcelor Mittal	Spain	Construction of renewable hydrogen production & transmission infrastructure	Spain	2030 target: 9.5 GW of Solar PV 7.4 GW of electrolysers
CELSA GROUP	Spain	Hydrogen network infrastructure for the energy transition through renewable hydrogen	Spain	The total investment 3.23 billion EUR (USD 3.66 billion)
Liberty	UK	A green iron production facility, related port infrastructure and conveyor system	UAE	Green iron MOU: importing high-quality magnetite ore from Australia.
POSCO	Korea	Building a wide range of hydrogen infrastructure, e.g. hydrogen production and storage by 2030	Korea	USD 38 billion private investment for Korean hydrogen economy (KRW 43 trillion)
POSCO	Korea	Development for green hydrogen production and related infrastructure	Middle East, Australia and Latin America	
POSCO	Korea	CCS infrastructure facility, CO2 injection and storage for blue hydrogen	Malaysia	
Rio Tinto	Australia	Construction of two 100MW solar power facilities and 200MWh of on-grid battery storage and associated transmission infrastructure	Australia (Pilbara)	USD 600 million
Tenaris	Italy	Building safe pipeline infrastructure for hydrogen transportation to convert the existing Norwegian pipeline infrastructure of 8800km-subsea network to a hydrogen network	Norway	Partnership: Nel, Norwegian University of Science the Technology

Source: World Steel Dynamics (2023)

Annex D. An overview of clean hydrogen definitions across jurisdictions

Table D.1. Clean hydrogen definitions

Region	Countries	Hydrogen terms in Nat.l strategy	Definition of Clean Hydrogen	Reference Value (KgCO2e/kgH)
Asia (Without China & India)	Korea	Low-carbon hydrogen	Hydrogen certified under Article 25-2, which falls under any of the following: a. Zero carbon hydrogen, low carbon hydrogen, and a low carbon hydrogen compound	< 4
	Japan	Low-carbon hydrogen	Hydrogen produced from a variety of raw materials using different processes, including natural gas and lignite reformation, water electrolysis using electricity produced from renewable energy sources or fossil fuels, and a combination of these processes with CCUS/Carbon Recycling technologies	3.4
	Indonesia	Low-carbon Hydrogen	N/A	N/A
	Malaysia	Hydrogen	N/A	N/A
China	China	Clean Hydrogen	Hydrogen produced form raw materials that are derived from renewable energy sources	4.9
India	India	Green Hydrogen	”Green Hydrogen” shall mean hydrogen produced using renewable energy, including but not limited to, production through electrolysis or conversion of biomass.	2
CIS	Russia	N/A	N/A	N/A
European Union	European Union	Low-carbon Hydrogen, Renewable Hydrogen	Hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. Low-carbon hydrogen is defined as a fuel generating 70% GHG emissions saving compared to fossil-based.	3.4
Other Europe	United Kingdom	Low-carbon Hydrogen	Hydrogen produced from several pathways such as electrolysis, fossil fuel reformation with CCS, Biogenic feedstocks inputs with CCS, and biomethane	2.4
Latin America	Brazil	Low-carbon Hydrogen	Hydrogen produced from fuel or industrial input collected as natural hydrogen or obtained from renewable sources, including hydrogen produced from biomass, ethanol and other biofuels, as well as electrolytic hydrogen, produced by electrolysis of water, using renewable energies such as solar, wind, hydraulic, biomass, ethanol, biogas, biomethane, landfill gas, geothermal and others to be defined by the public authorities	7
Middle East	Oman	Green Hydrogen	N/A	N/A
	UAE	Low-carbon Hydrogen	N/A	N/A
	Saudi Arabia	Clean Hydrogen	N/A	N/A
North America	United States	Clean Hydrogen	Hydrogen produced through water-splitting using renewable or nuclear power, from fossil fuels with carbon capture and storage, and biomass or waste feedstocks	< 4
	Canada	Clean Hydrogen	Hydrogen produced form electrolysis or from natural gas with emission abated with CCUS.	< 4
Oceania	Australia	Clean Hydrogen	Clean hydrogen is produced using renewable energy or using fossil fuels with substantial carbon capture and storage	N/A

Source: National Hydrogen Strategy, Countries' policy briefs

Annex E. Facilitating global hydrogen production and trade, the case of Australia

Australia is rapidly shaping international trade for the global hydrogen market. Australia's strong potential in renewable energy sources, political and economic stability that offers low risk to investors, skilled workforce and readiness to supply global hydrogen has positioned itself as a hydrogen hub and attracts many industry players both domestically and internationally. Australia has released the updated National Hydrogen Strategy 2024, highlighting its role as a trailblazer in the production and export of Australian hydrogen. The strategy introduces two public financing mechanisms: **Hydrogen Production Tax Incentives (HPTI)** and **Hydrogen Headstart Program**. The HPTI aims to accelerate the deployment of renewable hydrogen production in Australia by guaranteeing USD2/kg of eligible hydrogen through Australia's tax system (DCCEEW, 2024[50]). The Headstart Program which the Australian Government announced its total ASD USD4 billion, will provide public funding to large-scale renewable hydrogen projects in Australia for maximum 10 years, which can help bridge the gap between the production costs and sale price of renewable hydrogen and/or derivatives. Australian-based hydrogen projects powered by 100% renewable energy can apply for the program (ibid).

In addition, the strategy outlines and sets the 2030 hydrogen export target of 0.2 million tonnes and a stretch potential of 1.2 million tonnes of hydrogen per year by 2030 and identifies its trade partners seeking to strengthen their partnership (DCCEEW, 2024[50]). The Australian government envisages the development of regional hydrogen hubs in Australia, where producers, users and exporters of hydrogen collaborate to share infrastructure and expertise. The objective is to reduce the cost of production, encourage innovation, and improve skills and training efforts. These hubs are expected to be located in each state. Australia's strong commitment to domestic hydrogen development as well as active initiatives to become a hydrogen hub, along with its abundant renewable energy sources and iron ore, have already signalled many international partnerships.

Table E.1. International Partnership Examples

Name of partnership	Partner country	Starting Year	Investment (million USD)	Target area
H2 Global Window	Germany	2024	444	Green hydrogen
Hydrogen Innovation and Technology Incubator (HyGATE)	Germany	2021	87	Green hydrogen
Australia-Korea Low and Zero Emissions Technology Partnership	Korea	2021	67	Clean hydrogen, ammonia, low emissions steel, iron ore and CCUS
Australia-Japan Partnership on Decarbonisation through Technology	Japan	2021	100	Clean hydrogen, low emissions steel and iron ore and CCUS
Australia-United Kingdom Clean Technology Partnership	UK	2021	371	Clean hydrogen, CCUS, SMR, green steel

Source: 2024 Australian National Hydrogen Strategy

Guarantee of Origin (GO) Scheme

With great potential to become a global hydrogen hub, and as the world's largest producer and exporter of iron ore, Australia plays an important role in decarbonising the global steel industry. The Australian government has announced its plan to implement the Guarantee of Origin (GO) scheme for hydrogen and further plans to include green metals, including iron, steel and aluminium, in 2025. The GO scheme operates as a lifecycle tracking system in general, but it is seen as a measure that can further contribute to industries like steel (CertifHy, 2021[51]). The GO scheme is a certification system that provides a transparent, verified source of energy or a product and information on production and life-cycle emissions. Several jurisdictions have implemented similar schemes as, such as the EU as part of the Renewable Energy Directive (RED).

Similar to, but distinct from the EU GO scheme, the Australian GO scheme has unique features: it would have no emission intensity requirements and would not categorise the emissions intensity through definitions such as 'green' or 'low-emissions' at an early stage. This would enable the GO scheme to satisfy the low-emissions products requirements of numerous domestic and international markets. Its system boundary will cover the well-to-user, i.e. emissions associated with the supply of raw materials, production transport and storage to the point of consumption or international departure (Australian Government, 2022[52]). Although the emission intensity and the system boundaries vary slightly from jurisdiction to jurisdiction, the GO scheme will be essential to meet the emissions intensity thresholds required by international hydrogen market. This is particularly pertinent to growing demand for clean/renewable hydrogen, as seen in the European Commission's delegated regulation and the US Inflation Reduction Act's emissions-based thresholds. Australia's key trading partners, i.e. Japan and Korea, are also developing certification systems. The GO scheme has a significant potential as a harmonised global certification for hydrogen across borders enhancing global interoperability in the global hydrogen market.

Endnotes

[i] DRI projects related to companies engaging solely in green iron production could feed existing EAFs or lead to further EAF additions, therefore their impact on steelmaking capacity needs to be assessed on a case by case basis