Scaling Up Hydrogen: The Case for Low-Carbon Steel

A BNEF and Climate Technology Coalition White Paper

January 11, 2024

Contents

Section 1. Background to this White Paper

This paper was commissioned as part of BloombergNEF's work as Research Partner for the *Bloomberg New Economy Climate Technology Coalition*. The Coalition was formed in 2022 by a global group of stakeholders that are well placed to provide insights on approaches to industrial decarbonization. It has set an agenda to identify and support the rapid scale-up of the next generation of climate-critical green technologies that will be instrumental in achieving the world's goals to avoid climate catastrophe. The planet simply cannot wait for polluting industries to slowly shift strategy and technologies.

This initiative seeks to inspire and lead by example. It will take getting into specifics to make any tangible progress and, to that end, the Coalition – composed of technology specialists, researchers, financiers, industrialists and public sector experts – is initially focused on tackling roadblocks to scaling up the clean hydrogen ecosystem, and further on decarbonizing 'hard-to-abate' sectors (industries where cleaner alternatives are currently lacking or prohibitively expensive) through initiatives on low-carbon ammonia, methanol and steel.

Coalition members have given insight into their own projects and efforts in these areas, some of which can be found in this BNEF-produced report. The Coalition finds it encouraging that BNEF's thorough analysis shows potential for decreasing green hydrogen costs, identifying pockets of demand, and increasing clean hydrogen and ammonia production capacity.

Steering committee:

Michael Bloomberg, Founder of Bloomberg LP and Bloomberg Philanthropies, and three-term Mayor of New York City

Mark Carney, UN Special Envoy on Climate Action and Finance and Chair of Brookfield Asset Management; Head of Transition Investing; Chairman of the Board, Bloomberg, Inc.

Natarajan Chandrasekaran, Chairman, Tata Sons

Bruce Flatt, Chief Executive Officer, Brookfield Asset Management

Dr. Andrew Forrest AO, Chairman, Fortescue

Sara Menker, Founder and Chief Executive Officer, Gro Intelligence

H.E. Khaldoon Khalifa Al Mubarak, Managing Director and Group Chief Executive Officer, Mubadala

Neil Shen, Founding and Managing Partner of HongShan (Sequoia China)

Lord Adair Turner, Chairman, Energy Transitions Commission

Lei Zhang, Founder and Chief Executive Officer, Envision

Section 2. The case for low-carbon steel

$96 per ton

BNEF-estimated carbon price required for green hydrogen-based steel to compete with the cheapest natural gas-based steel in 2030, assuming full carbon prices

$489 per ton

BNEF-estimated production cost of hydrogen-based steel in 2050, assuming delivered hydrogen cost of $1 per kilogram

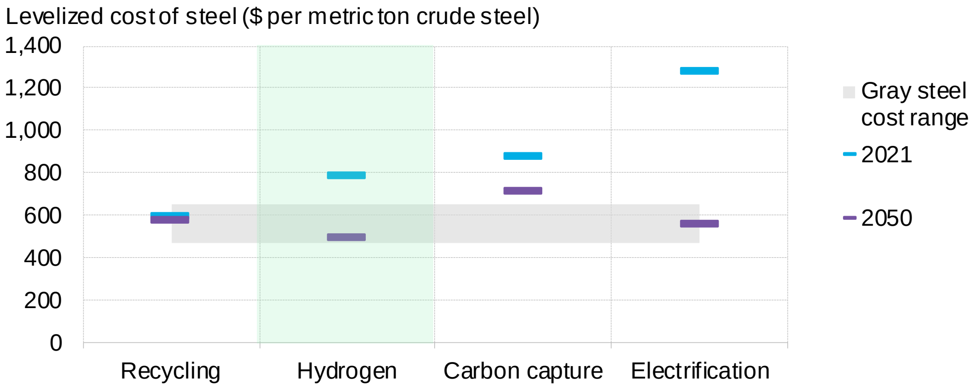
32

Number of offtake agreements or memorandums of understanding for hydrogen-based steel identified by BNEF, as of September 2023

The steel sector – which accounts for 7% of global carbon emissions – could be one of the largest sources of demand for low-carbon hydrogen. Steelmaking methods using hydrogen could decarbonize over 40% of global production by 2050. BNEF estimated this would require at least 150 million metric tons of hydrogen per year. The costs of hydrogen-based steel are already in a range acceptable to some buyers, while the policy frameworks and commercial justification for scaling low-carbon steel are starting to take shape. This BNEF/Climate Technology Coalition whitepaper provides an overview of hydrogen's role in steel decarbonization and outlines commercial and policy considerations that, if implemented, could bring forward the timeline for cost-competitive hydrogen-based steel.

- **Today's steel and iron market is worth $ 1.6 trillion, with most steel going to buildings, infrastructure, mechanical and electronic equipment, and the transport sector.** Steel products are mostly made and consumed locally, with only 22% traded internationally. The construction sector represents over half of global steel demand, and the length of its value chain increases the complexity of steel decarbonization.
- **The steel sector is the largest industrial consumer of coal, and hydrogen is the most critical technology to decarbonize production.** Hydrogen-based production methods account for 42% of global steel production in a net-zero-by-2050 scenario, according to BloombergNEF's New Energy Outlook (Figure 2). Hydrogen can replace coal and natural gas as both a primary fuel and reducing agent for high-quality iron ore in the direct reduction-electric arc furnace (DR-EAF) route.

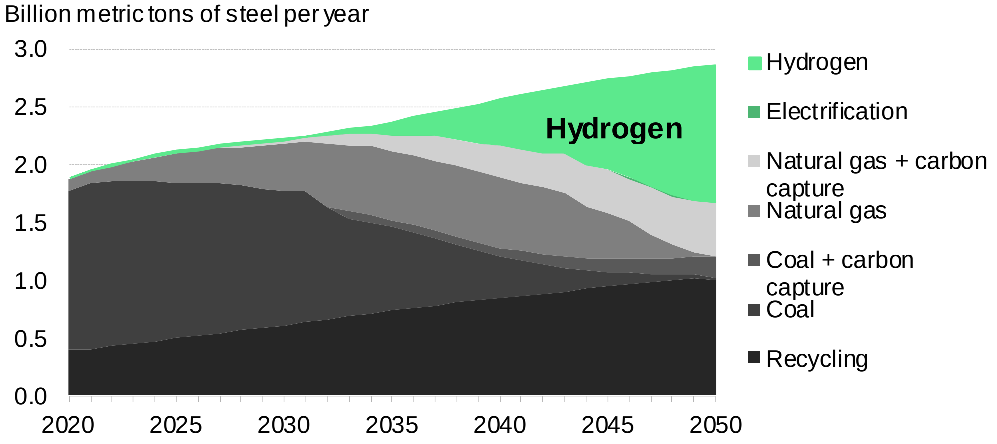
Figure 1: Average levelized cost of net-zero steel compared to business-as-usual, in 2021 and 2050



Source: BloombergNEF. Note: This cost analysis assumes a delivered green hydrogen cost of $1 per kilogram.

- **But hydrogen might not be the immediate option due to some short-term challenges.** The limited availability of high-quality iron ore grades means other routes that can use lower quality iron ores will be important. These include utilizing a fluidized bed to make the sponge iron and a melter to remove the gangue in preparation for steelmaking. The hydrogen-based steel process could be the cheapest option to produce net-zero steel in 2050. However, the use of 100% hydrogen in direct reduction furnaces has not yet been proven at commercial scale. Using green hydrogen in the direct reduced iron (DRI) process is still very expensive today – with at least a $150-$300 per ton premium over natural-gas-based steel (Figure 1).
- **The policies and commercial interest to expand the demand for low-carbon steel are already starting to take shape**. The US Federal Buy Clean Initiative should drive some government demand for green steel, and the European Union's carbon market creates a case for hydrogen-based steel to be cost-competitive by the early 2030s. Steelmakers are starting to set independent net-zero targets, which covered 38% of global crude steel capacity as of January 2023. Meanwhile, individual steel buyers have been signing green steel offtake agreements with producers since 2021 and BNEF now tracks 32 offtake agreements or memorandums of understanding for hydrogen-based green steel as of September 2023.

Figure 2: Pathway to net-zero emissions for global steel production in 2050, by process, in BNEF's Net Zero Scenario



Source: BloombergNEF. Note: This analysis does not consider blending hydrogen into blast furnaces, combinations of direction reduction furnaces with basic oxygen furnaces, or adding melters into the process.

- To bring on early volumes of hydrogen-based steel and scale commercial demand, the Climate Technology Coalition **has identified potential commercial actions and policy interventions.**
- The potential **commercial actions** focus on, as appropriate, scaling the demand, financing and production of hydrogen-based steel, specifically:
  - **A ladder approach of focusing on the near-term motivated offtakers, while keeping an eye on the larger offtake market:** The near-term opportunities appear to depend on two dimensions – the buyer's willingness to procure green products, and their approach to any "green premium". Car or car part makers, home appliance manufacturers, and specialized building materials companies are three markets that have shown potential for near-term offtakes. The construction sector is a larger but longer-term demand market for

green steel. Manufacturers and project developers could collaborate with each other to increase efficiencies. Collaboration amongst construction sector buyers, at all times in accordance with antitrust laws, could be one way to show a strong demand signal and encourage greater levels of pricing transparency, as appropriate.

  - **Tap into new kinds of financing:** To de-risk the first few green steel projects, steelmakers could look to sign long-term energy supply contracts and long-term steel offtake agreements, ideally involving their suppliers and customers in project investment. Beyond direct project finance, offtakers could also fund green steel projects through pre-purchase funding, such as an advanced market commitment, a joint venture, or by taking an equity stake in the steel company. To make investing in green steel attractive to climate-conscious investors, established steelmakers could spin off a green steel subsidiary.
  - **Lower the cost of hydrogen-based steel as soon as possible**: Steelmakers could tap into low-cost 24/7 clean power to drive down the costs of hydrogen-based steel. This might mean some iron production relocates to places with cheap baseload clean power, such as hydro, nuclear or geothermal. Structuring multiple virtual clean power purchase agreements – a contract to pay for clean energy generation at a different location from the steel or iron plant, which can virtually replace the grid power the asset consumes in reality – could be another way to go in advanced markets such as the US. For steelmakers that struggle to bear the high costs of switching to clean hydrogen now, they could start with lower-cost gray hydrogen feedstock – made using fossil fuels – to test out the equipment.

- The **policy actions** focus on utilizing existing toolkits, while also building the ecosystem required to define and finance green steel. Specifically:
  - **Accelerate carbon pricing for the steel sector**: One of the best policy tools for industrial decarbonization is carbon pricing. It is technology neutral and drives the lowest-cost route to decarbonization. The EU Emissions Trading System, combined with the Carbon Border Adjustment Mechanism, could provide a blueprint for policymakers globally. To incentivize the switch to hydrogen-based steelmaking, BNEF estimates carbon prices would need to exceed $96 per ton. A phase-out period, where the amount of free allocations are reduced annually, is helpful for the transition, but should be short enough to encourage near-term action among steelmakers. To protect against falling carbon prices, governments could also develop carbon contracts for difference for the steel and hydrogen sectors.
  - **Streamline low-carbon steel standards:** There are many industry-led standards on low-carbon steel, but all come with different scopes and criteria. Policymakers could take the lead to streamline these standards, and to develop a robust standard that takes into account all emissions scopes including a declining emissions threshold in line with the net-zero target. Using an internationally recognized framework, such as the International Organization for Standardization (ISO), is recommended and has already been widely used in steel products.
  - **Government incentive programs to create green steel demand in construction**: Public procurement accounts for 25% of global steel demand, so could play an important role in kickstarting the green steel sector. Policymakers could set a strict enough emissions ceiling for steel that incentivizes investment in new plants, with the threshold decreasing every few years to encourage further carbon cuts.

- **Develop green building standards that include embodied emissions**: Some cities and federal governments have begun setting mandatory reporting of 'embodied emissions' for new builds – the CO_2 emitted during the manufacture of the building materials. Some are also setting carbon emission thresholds. These reporting mandates are useful to help socialize the concept of embodied emissions among the real estate sector, and to provide datapoints to policymakers as they begin setting emissions thresholds. Policymakers are setting easy-to-achieve limits to begin with, often in a tiered system, with the idea of tightening the thresholds every few years to encourage deeper decarbonization. Government carbon limits could align with new embodied carbon emission limits being developed by building standards organizations such as the Leadership in Energy and Environmental Design (LEED) and BREEAM.

Section 3. Overview of the steel sector

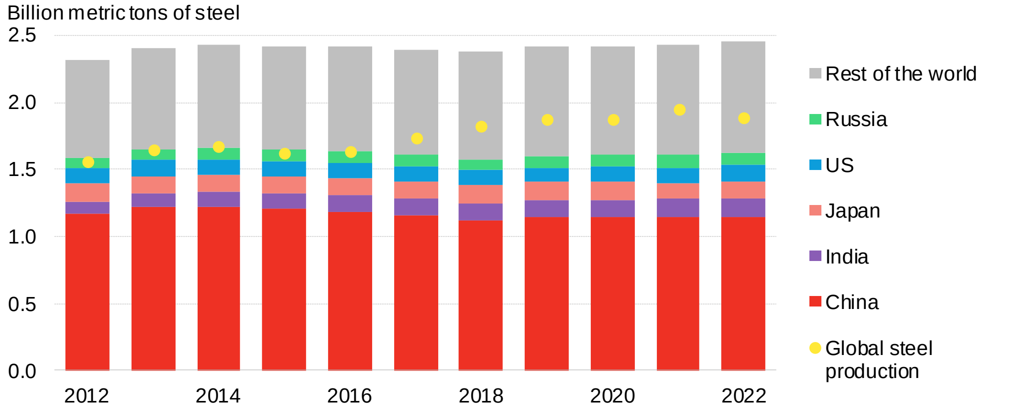
Steel is the third most used material in the world and the largest industrial consumer of coal. Today's steel and iron market is worth $1.6 trillion, with most demand coming from buildings, infrastructure, mechanical and electronic equipment, and the transport sector. Steel production is responsible for 7% of the world's CO_2 emissions and there is currently no commercial, cost competitive route for it to reach net-zero emissions.

3.1. Steel market overview

Over an 11-year average, 48% of steel production capacity was based in China

In 2022, global steel production capacity was 2.5 billion tons, according to the OECD, with actual production coming in at 1.8 billion tons – a 77% utilization factor. Overcapacity is a persistent feature of the steel sector, with utilization averaging 72% over the past 11 years. Government intervention in the sector is mostly responsible for this, particularly in China, where the bulk of production capacity – 48% on an 11-year average – is situated (Figure 3). Nations see steel production as a strategic necessity, often encouraging new plants to be built, while also subsidizing older assets that would otherwise close. Major steel producers also include India, Japan, the US, and Russia.

Figure 3: Global steel production capacity by market and output



Source: BloombergNEF, OECD.

Only 22% of crude steel is traded internationally

Most steel is consumed locally. Globally, the share of steel products traded internationally sat at 22% in 2022, with Europe being the largest net importer and the US a close second. In China, only 6% of the steel produced there was traded internationally last year. Some countries export much larger portions of their steel. Japan exports a net 30% of the steel it produces, while Ukraine has the largest share of its production sold internationally, at 65%.

The market for steel is highly segmented, with as many as 3,500 grades tailored to specific applications and differentiated by their elemental compositions. These can be grouped into four main categories: carbon, alloy, stainless and tool steel. Carbon steel is the simplest form, consisting largely of iron and carbon, with traces of other elements, and accounts for most steel production globally. Of the EU's crude steel output in 2021, some 77% was carbon steel.

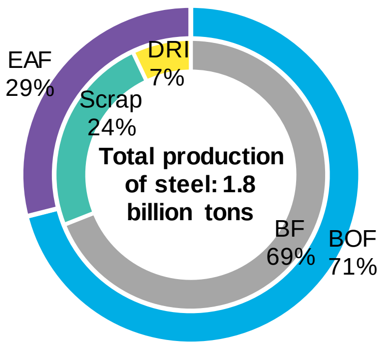
3.2. Steel production

Two production routes exist for crude steel: primary and secondary. Primary steel production is a two-step process, starting with the reduction of iron ore (the removal of oxygen). This is done via smelting in a blast furnace (BF) or by direct reduction (DR). The resulting iron is then fed into a basic oxygen furnace (BOF) or electric arc furnace (EAF) along with some scrap, and any additives needed to create the specific form of steel needed. Secondary steel production uses scrap as its majority feedstock and skips the BF or DR step. Recycled steel is formed in an EAF.

Iron can be produced on-site (via integrated mills) or imported (through non-integrated mills). Most steel is made in integrated mills, though direct reduced, or sponge, iron is widely traded.

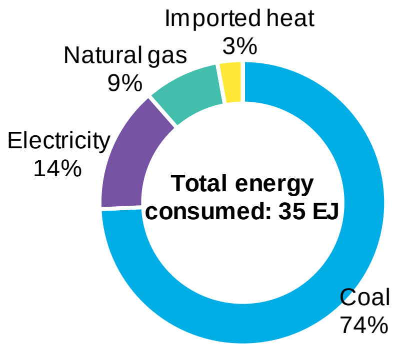
The BF-BOF route for making primary steel accounts for 71% global steel production (Figure 4). This relies on coke – coal, baked in the absence of air – as the fuel and reducing agent. No alternative fuels exist at scale that serve both purposes. Consequently, coal accounts for 74% of all energy demand in the steel industry (Figure 5).

Figure 4: Primary and secondary production of steel in 2022, by process



Source: BloombergNEF, World Steel Association, Bureau of International Recycling. Note: EAF refers to electric arc furnace; DRI is direct reduced iron; BF is blast furnace; BOF is basic oxygen furnace.

Figure 5: Energy consumed by the steel industry in 2022, by fuel type



Source: BloombergNEF, International Energy Agency. Note: EJ is exajoules.

3.3. Steel CO_2 emissions and the path to net zero

Steel is responsible for 7% of global, and almost 30% of industrial, CO2 emissions

The scale of production and heavy reliance on coal makes steel one of the largest single sources of carbon emissions. It is responsible for 7% of global and almost 30% of industrial emissions. The BF-BOF production route is the most energy and emissions intensive, consuming 21.4 gigajoules and 2.2 tons of CO_2 equivalent per ton of steel, according to the IEA (Figure 6). Switching to scrap-based EAF could cut emissions substantially, but is limited by the supply of scrap material available.

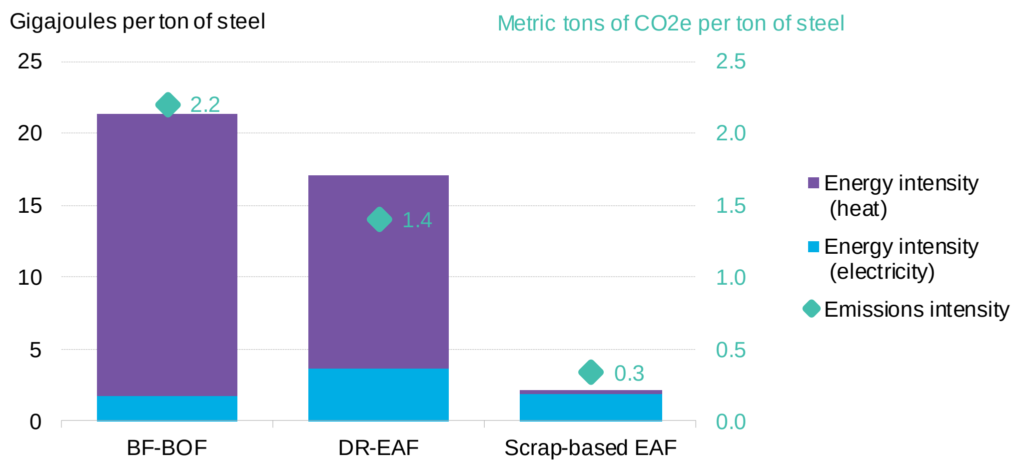
The DR-EAF route is a near-term, low-carbon alternative to BF-BOF-based primary steel production. This method is popular in the Middle East and North Africa region due to abundant natural gas reserves and a lack of quality coking coal[1]. India also uses this route, but it leans on gasified coal instead of natural gas.

There are a few potential routes to net-zero steel, at various stages of development:

- Using hydrogen, produced via renewables-powered electrolysis, as the fuel and reducing agent. When reduced by hydrogen, high-quality iron ore can be turned to steel in an EAF. Lower-quality iron ore can also be reduced with hydrogen but then an additional melting stage is required to remove the gangue and make it suitable to be added to a BOF or EAF.
- Scrap-EAF plants powered with renewable electricity.
- Equipping fossil-fuel burning steel plants with carbon capture.
- BF-BOF plants using biomass as a fuel and reducing agent.
- Direct electrification of ironmaking through technologies such as molten oxide electrolysis, or electrowinning, combined with an EAF or BOF.

Switching to scrap-based EAFs will cut emissions substantially, but is limited by the supply of scrap material available

Figure 6: Energy and emissions intensities of current steel production processes



Source: BloombergNEF; International Energy Agency, "Iron and Steel Technology Roadmap" (2019). Note: DR-EAF (direct reduction paired with an electric arc furnace) assumes natural gas as the fuel. The energy intensities are in final energy terms excluding the conversion losses in the energy transformation. BF-BOF is blast furnace paired with a basic oxygen furnace.

Some 38% of global crude steel capacity is currently covered by a corporate net-zero target

BNEF estimates that only 38% of global crude steel capacity is currently covered by a corporate net-zero target[2]. Corporate action is driven by a variety of factors, including both regulatory and market risks. Emissions trading schemes in the EU and China are set to penalize carbon-intensive steel products in the future, and customers are increasingly looking to cut 'Scope 3 emissions' – indirect emissions from their value chain – in a bid to reach their own net-zero goals. The CO_2 emitted during steel production can be a significant portion of the Scope 3 emissions for automotive companies and the construction and buildings sector.

What are Scope 1, 2 and 3 emissions?

Scope 1 emissions are direct emissions from assets owned or controlled by a company. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3

[1] See BNEF's *Decarbonizing Steel: Technologies and Costs* (web | terminal) *report* for more.

[2] See BNEF's *Decarbonizing Steel: Corporate Strategies* (web | terminal) for more.

emissions are all indirect emissions (not included in Scope 2) that occur in the value chain of the reporting company, both upstream and downstream.

3.4. Steel demand and value chain

Steel production is closely linked to industrialization – as nations become richer, they build more infrastructure and durable consumer goods. These industries make up most of the demand for steel (Table 1).

Table 1: End uses for steel

Sector		Share of steel use (%)
Buildings and infrastructure	Infrastructure (stations, underground structures, pipes, bridges, tunnels)	52
Mechanical and electronic equipment	Industrial mechanical equipment (cranes, etc.)	16
	Mechanical and electronic equipment	5
Transport	Automotive	12
	Others (ships, trains, etc.)	5
Metal products	Cans, fixtures, furniture, consumer goods etc.	10

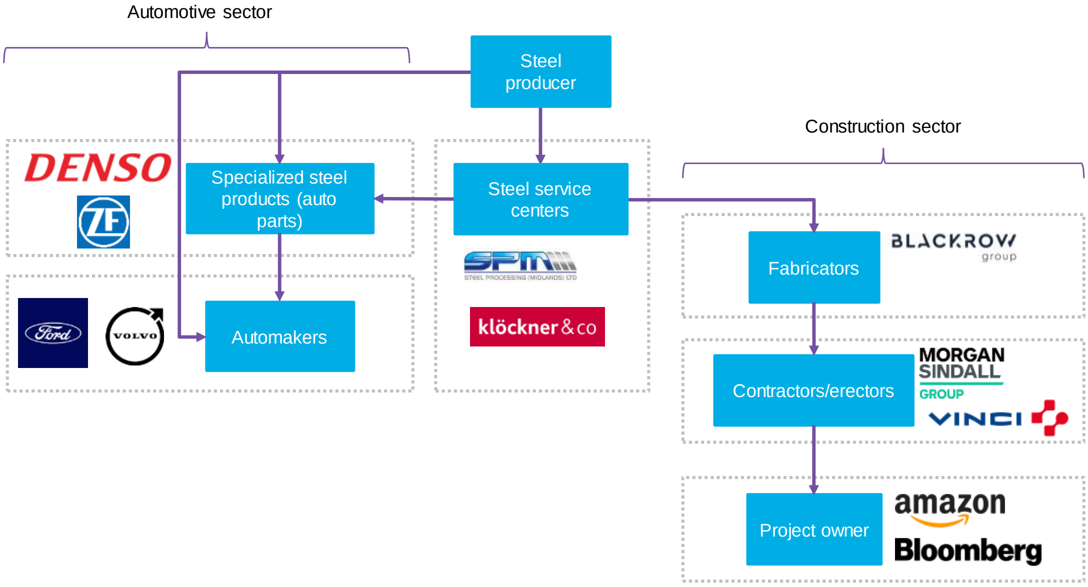
Source: BloombergNEF, World Steel Association 2023.

Steel value chains are subject to the end use of the metal

The process for buying steel depends on the end use of the metal. In the automotive sector, the value chain is short, often with two to four participants. For passenger cars, automotive companies often buy steel for the vehicle body directly from the steelmakers but purchase more complex steel parts, such as the engine, from a third party. These relationships are governed by long-term contracts – typically seven years – that secure demand and reduce risk for both parties.

For steel procurement in the construction sector, there can be many more participants between the steelmaker and the end user. Here, steel is bought on the spot market up to three months in advance of the start of construction. Examples of both value chains are illustrated in Figure 7.

Figure 7: Steel value chain for automotive and construction sectors, and example companies at each stage



Source: BloombergNEF

Section 4. Hydrogen's role in steel decarbonization

Hydrogen-based DR-EAF accounts for 42% of global production by 2050 in BNEF's Net Zero Scenario. In direct reduction furnaces, hydrogen can replace coal or natural gas as both the primary fuel and reducing agent. If the iron ore is high quality, this DRI product can then be turned into steel in an EAF. If the iron ore is a lower quality, then the iron, once reduced by hydrogen, can be put in an electric melter that produces a pig iron that can be used to make steel in an EAF or BOF. The use of 100% hydrogen in any steelmaking process has yet to be proven at commercial scale. High costs and a lack of supporting infrastructure are the biggest challenges for this decarbonization route today.

4.1. How hydrogen is used in steel decarbonization

Hydrogen can be used to lower the carbon emissions of iron and steelmaking in a number of ways.

In Asia, the average steel plant is 10-13 years old, with operating lifetimes of 20-40 years

Hydrogen use in BF-BOF plants

In BF-BOF plants, emissions can be reduced by 20% through replacing pulverized coal with hydrogen to provide additional heat and reducing gases. It cannot be a full decarbonization solution for BF-BOFs due to the technical limitations on replacing the coal.

Using hydrogen in the BF-BOF production route, which accounts for 69% of steel production (Figure 4), is challenging. BF-BOF capacity is still growing, especially in China and India. The average plant in Asia Pacific is 10-13 years old, according to the International Energy Agency, with operating lifetimes of 20-40 years. These plants will either need to use carbon capture to decarbonize (plus direct air capture credits to sequester the remaining CO_2) or shut down and be rebuilt with DR-EAF furnaces.

Hydrogen use in DR-EAF plants

All steel CO_2 emissions can be eliminated by using green hydrogen in a DR and an EAF powered by renewables

In DR-based plants, hydrogen can play a larger role. It can replace coal and natural gas as both the primary fuel and reducing agent in the iron-making step. Combined with an EAF, close to 100% of steel CO_2 emissions can be reduced if the hydrogen is green and the EAF is powered by renewable energy. DR furnaces require ore with a minimum iron content of at least 65-66%, and preferably 67%. Lower iron content can lead to corrosion in the EAF and lower yields of steel.

Using 100% hydrogen in DR furnaces is still an early-stage technology. The Hybrit project, a joint venture formed by SSAB, LKAB and Vattenfall, utilizes 100% hydrogen to produce small batches of low-carbon steel. The first batch has been delivered to Volvo and other steel customers. A complete industrial-sized demonstration plant is expected to come online around 2025, producing 1.3 million tons of sponge iron by 2026, using 100% hydrogen in the DR furnace. The sponge iron will be fed into EAF powered by renewables to produce clean steel.

Similarly, the startup H2 Green Steel plans to begin production of hydrogen-based steel by 2026. Once it has been commissioned, it will be the largest producer of near-zero steel. Midrex, a North American equipment and technology provider, reports its Midrex NG can replace up to 30% of the natural gas used with hydrogen, whereas its Midrex Flex and Midrex H_2 plants are 100% hydrogen compatible.

Hydrogen applications for lower-quality iron ore

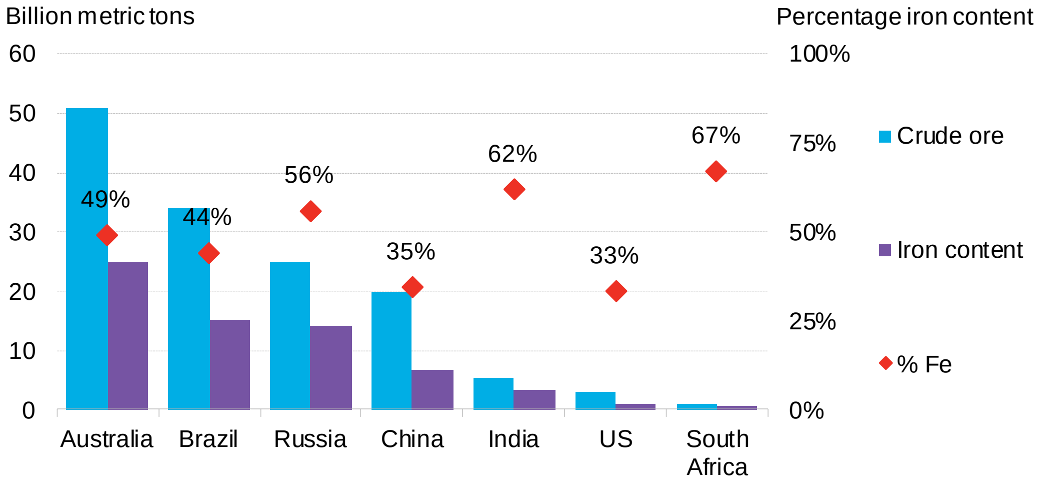
The majority of iron ore supply is not considered 'high quality', meaning it contains less than 65% iron content (Figure 8). This has the potential to limit the role of hydrogen in a net-zero steel sector, if the DR-EAF process described above is the only route pursued for hydrogen-based steel. However, this constraint can be overcome through various technology routes:

Low- and medium-grade iron ores can also be used to make hydrogen-based steel.

- Beneficiate the ore before processing. The iron content of low-grade ores can be raised by removing impurities prior to pelletizing. This is an added cost and creates waste but allows lower grade ores to be used in existing direct reduction shaft furnaces.
- Change the DR furnace type. Moving from shaft to circulating fluidized bed reactors removes the need for pellet plants that currently require natural gas. This could allow cheaper, abundant iron ore fines to be used, lowering costs. There is active research into deploying these types of furnaces.
- Add a melter (an electric smelting furnace) after the reduction stage. The melter continuously melts the direct reduced iron (sponge iron) and allows the gangue to be separated from the iron and removed as slag. The remaining pig iron is high purity and suitable for conversion to steel in an EAF or BOF.

All of these options for combining low-grade ore and hydrogen are in active development by miners and steelmakers. It does not appear that a lack of high-grade ores will hinder hydrogen-made steel in the long term.

Figure 8: Iron ore reserves and iron content, by country, 2021



Source: BloombergNEF, US Geological Survey. Note: Total iron (Fe) content is calculated by dividing crude ore by iron content.

The missing carbon problem

Elemental carbon is an important component of steel. In the iron-making process, small amounts of carbon are picked up from the coke (coal) used in smelting, changing the nature of the metal. Replacing coke or natural gas with pure hydrogen removes carbon from the iron-making process, requiring a new source of the additive.

The Hybrit project overcomes this by melting coal with the DRI in the EAF. The reintroduction of coal means steel production cannot be entirely decarbonized unless carbon is sourced from carbon-neutral or -negative sources, such as carefully managed biomass.

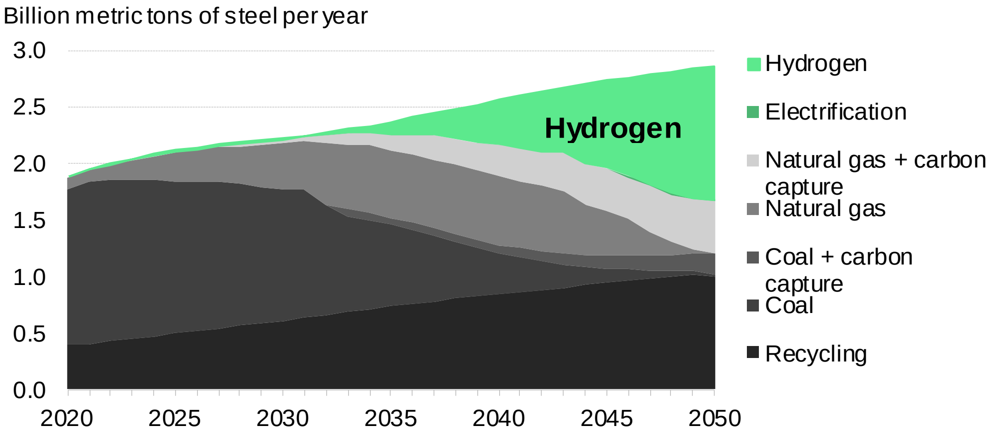
4.2. The size of hydrogen's role in net-zero steel production

BNEF's *New Energy Outlook: Industry* report outlines a scenario in which multiple routes can be used by 2050 to achieve net-zero steelmaking[3]. DR-EAF processes make up the bulk of new production in 2050, at which point they account for around 88% of primary and 57% of global steel production. Hydrogen-based DR-EAF comprises 42% of global production, amounting to about 150 million tons of hydrogen demand (Figure 9). Issues with high-quality ore availability could be overcome by changing the DR equipment to a fluidized bed and adding a melter before the EAF step.

Other technologies can play a role too. EAF plants powered with renewable electricity and using high proportions of scrap as feedstock meet 35% of steel demand by 2050 under BNEF's scenario, while BF-BOF plants equipped with carbon capture account for the rest of production.

Use of 100% hydrogen in DR furnaces has yet to be proven at large commercial scale

Figure 9: Pathway to net-zero emissions for global steel production in 2050, by process, in BNEF's Net Zero Scenario



Source: BloombergNEF. Note: This analysis does not consider blending hydrogen into blast furnaces, combinations of direct reduction furnaces with basic oxygen furnaces, or adding melters into the process.

[3] See BNEF's *New Energy Outlook: Industry* (web | terminal) for more.

4.3. The cost of low-carbon hydrogen-based steel

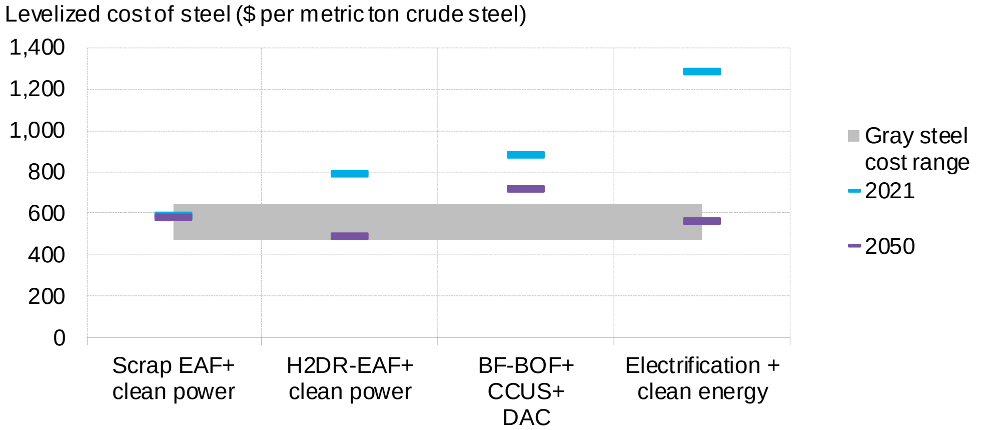
High costs are the biggest challenge for hydrogen-based steelmaking today. Making steel in a DR-EAF process in Europe with green hydrogen is 20-60% more expensive than conventional steel made with natural gas[4]. This premium is mainly driven by the cost of green hydrogen. BNEF estimates that green hydrogen production costs are $4-12 per kilogram today[5], assuming electrolyzers are running on intermittent wind or solar. However, steel producers require a constant supply of hydrogen, raising the cost of production. The amount of land and whether there is sufficient hydrogen transport and storage infrastructure near steel plants could also constrain green hydrogen supply.

It is expected that the cost of green hydrogen and clean electricity will fall significantly over time. With a delivered green hydrogen cost of $1 per kg (Figure 10), hydrogen-based steel costs $489 per ton – competitive with unabated production. BNEF anticipates many countries will be able to produce green hydrogen at these costs by 2050.

DR-EAF using green hydrogen in Europe is 20-60% more expensive than conventional steel

BNEF has not modeled the costs of the other hydrogen-based routes that can use lower quality ores. However, their costs will be similar or higher than hydrogen-based DR-EAF. While they can use cheaper iron ore grades, there is the additional melter capital expenditure and significantly more clean energy required than for gray steelmaking.

Figure 10: Average levelized cost of net-zero steel compared to business-as-usual, in 2021 and 2050



Source: BloombergNEF. Note: This cost analysis assumes a delivered green hydrogen cost of $1 per kilogram. EAF refers to electric arc furnaces; H2DR is hydrogen-based direct reduction; BF-BOF is blast furnace paired with a basic oxygen furnace. CCUS refers to carbon capture, utilization and storage. DAC stands for direct air capture.

4 Using green hydrogen production costs for Germany.

5 See BNEF"s *2023 Hydrogen Levelized Cost Update: Green Beats Gray* (web | terminal) for more.

Section 5. State of the low-carbon steel market

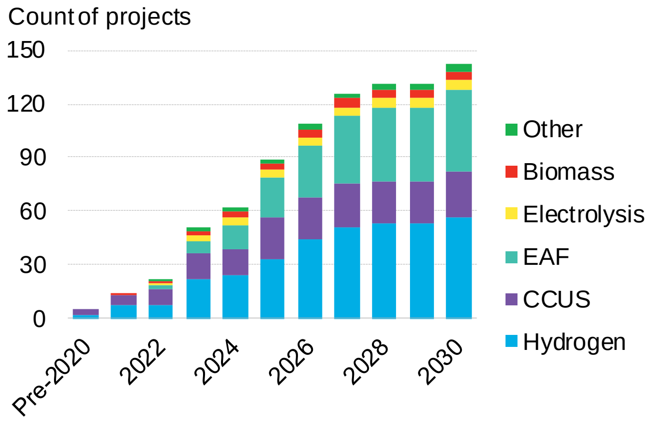
Low-carbon hydrogen is recognized as a key route to decarbonizing steel production, particularly in Europe, where carbon markets and subsidies are pushing steelmakers to turn to hydrogen. In the US, the federal government's green procurement initiatives will be an important driver of green steel demand. There is already clear demand for green steel, but financing the first low-carbon steel plants could be a slow process.

5.1. Hydrogen is not the only solution

While hydrogen is a crucial decarbonization technology for the long term, for some producers, it will not be their immediate solution to reducing emissions.

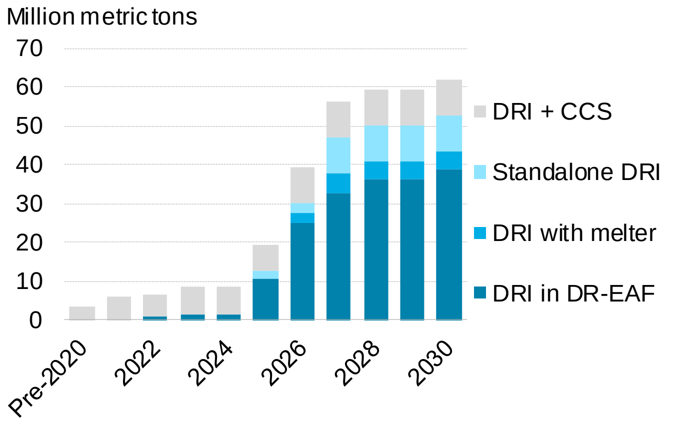
Of the announced low-carbon steel projects tracked by BNEF, 40%, or 57 projects, will use hydrogen by 2030. Scrap-EAF production accounts for 32% of projects and another 18% will utilize carbon capture (Figure 11). Direct reduced ironmaking (DRI), the main technology where hydrogen is used as both fuel and reducing agent, is expected to make up 62 million tons of steel capacity by 2030 (Figure 12).

Figure 11: Steel decarbonization project count by technology (cumulative)



Source: BloombergNEF. Note: CCUS is carbon capture utilization and storage. EAF is electric arc furnace. Data is accurate as of November 2023.

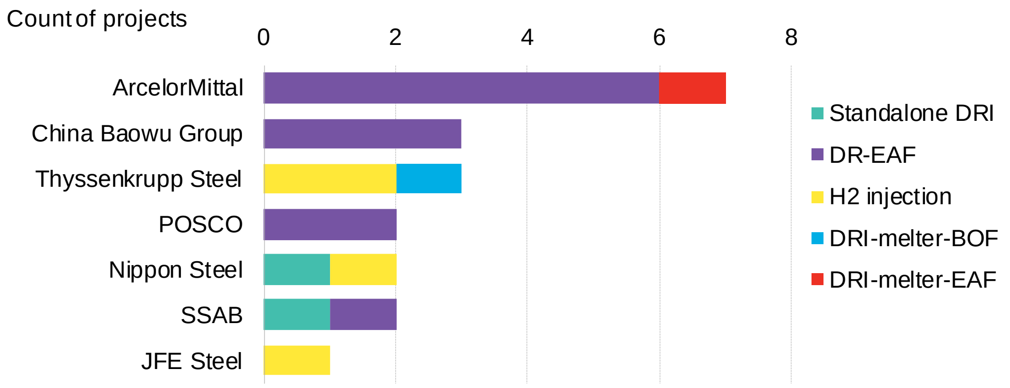
Figure 12: Total DRI capacity of hydrogen-based steelmaking, by type (cumulative)



Source: Public announcements, BloombergNEF. Note: DRI + CCS (direct reduced iron plus carbon capture and storage) indicates the use of gray hydrogen. DR-EAF is direct reduction paired with an electric arc furnace. Data is accurate as of November 2023.

Although hydrogen is not the immediate or only solution for steel decarbonization, most of the major steelmakers in the world have to some extent explored the possibility of hydrogen-based steelmaking. This includes not just DRI but a lot of other technologies. For example, Japanese steelmakers such as Nippon Steel and JFE are looking at blending hydrogen into blast furnaces for partial emissions reductions. Meanwhile, Thyssenkrupp is exploring combining the DRI process with BOFs. There are also examples of steelmakers building melters to be able to use hydrogen with lower-quality iron ores (Figure 13).

Figure 13: Low-carbon steel project count of select steelmakers, by hydrogen steelmaking technology routes (as of October 2023)



Source: Public announcements, BloombergNEF. Note: Only projects that are beyond pilot stage or have an announced timeline and detailed specifications are counted. DRI refers to direct reduced iron. DR-EAF is direct reduction paired with an electric arc furnace. BOF is a basic oxygen furnace. EAF is an electric arc furnace.

5.2. There are only a few policies for low-carbon steel

Few climate policies directly target the steel sector. The mechanisms in place to penalize emitters, such as carbon prices, are ineffective because many carbon pricing mechanisms give exemptions or 'free allocations' to the steel sector, while policies intended to spur demand or subsidize a transition are piecemeal. The most robust policy in place is aimed at green steel's enabling technologies: hydrogen, carbon capture and clean power. But without a clear demand push, these new markets will quickly become oversupplied.

Table 2: California's global warming potential (GWP) limits for unfabricated product

Steel product	Emissions intensity (metric tons of CO_2e per ton of steel)
Hot rolled structural	1.01
Hollow structural	1.71
Plate	1.49
Concrete reinforcing	0.89

Source: BloombergNEF, California's Department of General Services.

Green public procurement programs

Green or sustainable public procurement (GPP) programs are initiatives by government bodies to reduce the carbon emissions associated with their activities, and to support the development of companies developing sustainable goods and services. They can be applied to the purchase of a range of services and goods, including electricity, cleaning services and public space maintenance.

The US state of California is the only jurisdiction with an active, mandatory GPP that considers steel emissions. The federal government announced the Federal Buy Clean Initiative last year, which, like California, will set carbon emission thresholds for construction materials such as steel and concrete. BNEF calculates that this initiative could lead to up to 10 million tons of low-carbon steel procurement[6].

To be effective, a GPP must be sufficiently clear as to what constitutes a green, or sustainable, product or service. These criteria must be stringent enough to drive deep decarbonization over time. Both the California and US GPP set global warming potential[7] (GWP) limits on steel, as the

6 This estimate is based on 2021 data for apparent steel use in the US, construction demand for US steel and construction spending in the US. It assumes that dollars spent is proportional to steel input used.

7 This is a measure of how much CO_2 one metric ton of a product (in this case steel) is responsible for.

measure of what qualifies as low carbon. However, these thresholds are not low enough to encourage the investment needed in new green steel plants. As they currently stand, the GWPs for steel are set above the average EAF emissions intensity (Table 2), which accounts for 70% of US steel production. This means the GPPs only penalize steel imports or steel produced by the very few non-scrap EAF, or non-EAF, plants in the US. However, California, will revise its GWP targets downward every three years, based on industry improvements and similar revisions are planned for the Federal Buy Clean Initiative.

The US state of California is the only jurisdiction with an active, mandatory GPP that considers steel emissions

Programs like the International Deep Decarbonization Initiative (IDDI) seek to expand the use of GPPs, with nine countries committed and aiming to declare pledges by the end of 2023. The IDDI is a coalition of public and private institutions, coordinated by the United Nations Industrial Development Organization (UNIDO). Its activities include the standardization of carbon accounting methods and the design of industry guidelines. Approximately 9% of global steel demand is covered by the IDDI's participating countries.

Building life-cycle assessment measurements and mandates

Another type of policy, although slightly less directly related to steel, is government regulation targeting the embodied carbon of new buildings. Cities including London, Toronto, and Copenhagen have begun mandating the reporting of new-build embodied carbon emissions (including the carbon footprint of construction materials), with Toronto and Copenhagen taking additional steps that might benefit steel producers (Table 3).

Table 3: Examples of embodied building emissions policies in selected cities and countries

City	Policy type	Implementation year	Application	Emission threshold
London	Reporting mandate	2020	All strategic planning applications	None
Toronto	Reporting mandate with an incentive scheme that offers payment rebates to buildings that hit certain carbon thresholds	2010 but the new embodied emissions thresholds were only implemented in 2023.	All new buildings on mandatory reporting. Incentives given to those that comply with voluntary emission reduction.	250-350kg of CO_2e per m^2 for upfront embodied carbon
Seattle	Incentive scheme that allows buildings that meet certain sustainability criteria to shortcut the permitting queue	2013	All new buildings	None
Denmark	Reporting mandate and lifecycle emission mandate	2023	All new buildings	12kg of CO_2e per m^2 per year for lifecycle emission in 2023, decreasing to 7.5kg of CO_2e per m^2 per year
France	Reporting mandate and threshold mandate for construction-related and material production emissions	2022	Single-family homes and apartment buildings	640-740kg of CO_2e per m^2 between 2022 and 2024, decreasing to 415 -490kg of CO_2e per m^2 after 2031.

Source: BloombergNEF

Even without a carbon emissions target, mandating the reporting of embodied emissions is valuable. The widescale reporting of the full lifecycle emissions of a building, through environmental product declarations (EPDs), will enable policymakers to better understand how to set effective emissions targets, and will help climate-conscious real-estate investors.

Five EU countries have introduced regulations on life cycle carbon assessment for buildings

This is not just happening at the city level. Five EU countries – Denmark, Finland, France, the Netherlands and Sweden – have introduced regulations on life cycle carbon assessment (LCA) on buildings, addressing both embodied and operational emissions.

The Danish government began a testing phase for life-cycle building emission reporting mandates in 2020. Starting from 2023, Denmark requires all new buildings to document their environmental impact over a lifespan of 50 years through LCA calculations, and those above 1,000 square meters must comply with a lifecycle amortized carbon emission threshold of 12 kg of CO_2e per m^2 per year or lower. The threshold will be lowered every two years.

France has also set emission limits on building materials. In 2022, new regulations under the RE2020 law mandated emission reductions in building construction materials by at least 30%, and up to 40%, by 2030 compared to 2013 levels. The construction-related emissions have a threshold of 640 kg of CO_2e per m^2 for single family homes and 740 kg of CO_2e per m^2 for apartment buildings, between 2022 and 2024. This limit will be lowered over time, to 415-490 kg of CO_2e per m^2 after 2031.

Grants and subsidies

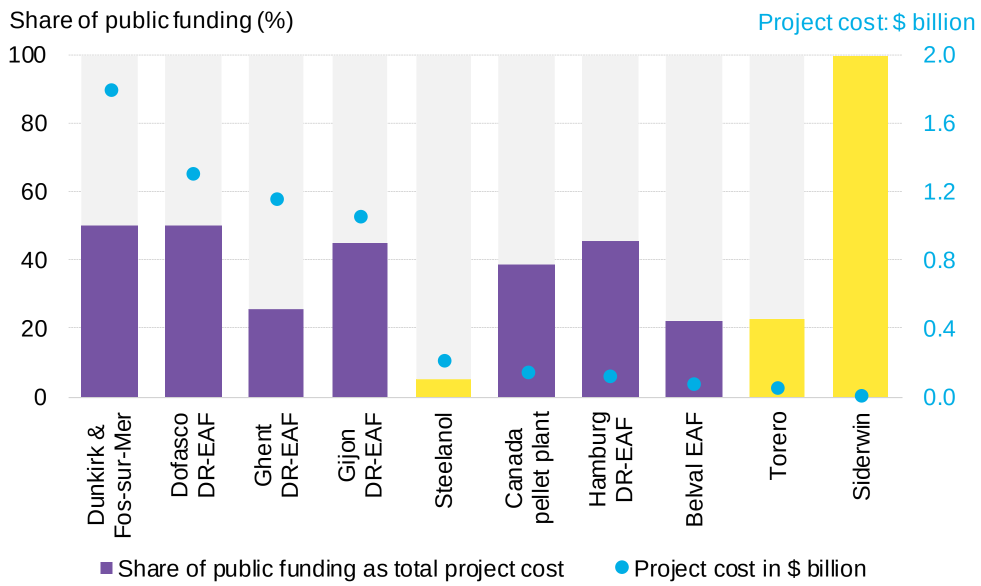
ArcelorMittal has disclosed receiving $1.2 billion from European governments for decarbonization projects

Government support has also taken the form of public financing, delivered through grants for low-carbon steel projects, or indirect subsidies for adjacent technologies. For most steelmakers, substantial emission reductions in the near or long term are a costly endeavor that risks higher levels of indebtedness, even for major manufactures[8]. ArcelorMittal has disclosed receiving $1.2 billion from European governments for decarbonization projects (Figure 14). Similarly, both Salzgitter AG and Thyssenkrupp have received support from the German government for the development of hydrogen-based steel plants. This kind of direct support from governments is partially aimed at decarbonization and partially at ensuring these large industrial employers remain in the region.

Low-carbon steelmaking also benefits from policies supporting the technologies required to create it. In the US, the Inflation Reduction Act (IRA) will make low-carbon steel production cheaper by subsidizing hydrogen production. Similarly, support for renewables has helped lower the cost of steel production utilizing EAFs.

[8] See BNEF's *Public Funding Will Be Test of Low-Carbon Steel's Mettle* (web | terminal) for more.

Figure 14: ArcelorMittal's steel projects with disclosed government support



Source: Company filings, BloombergNEF. Note: ***Purple*** *refers to direct grants from local governments.* ***Yellow*** *refers to EU-level grants. BNEF estimates these to be around 50% of project cost. The Steelanol and Torero projects also received €75 million in loans from the European Investment bank. Disclosure is updated as of July 2023. DR-EAF refers to direct reduction-electric arc furnace.*

Carbon markets

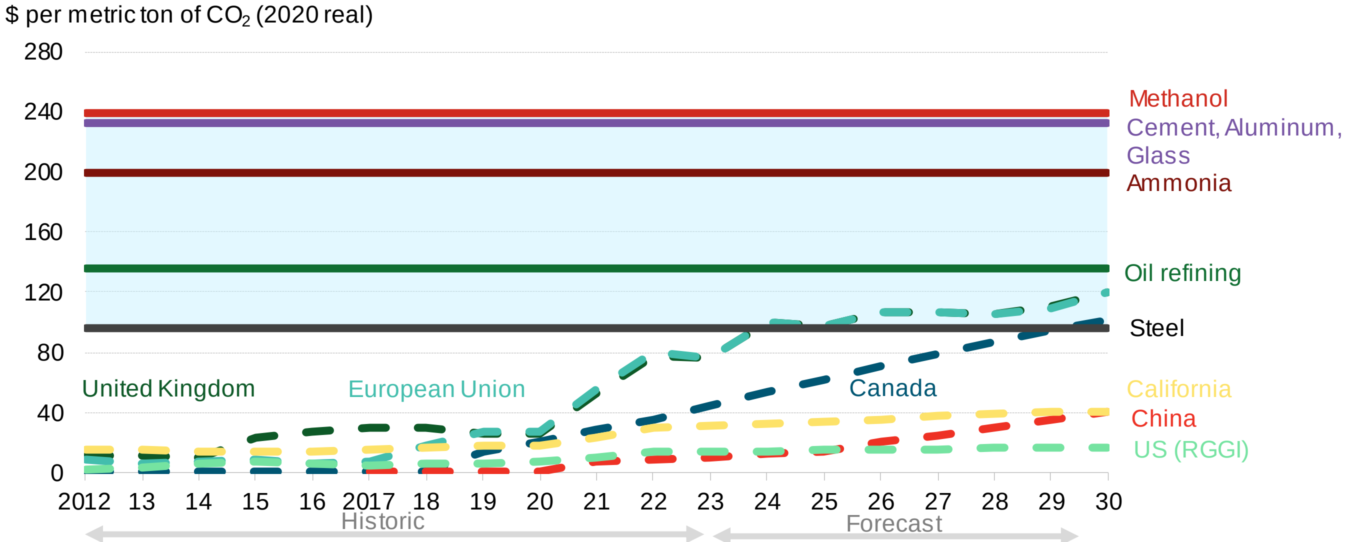
By 2030, DR plants using 100% green hydrogen at $2 per kg can be competitive with fossil fuels

The main policies under consideration that could change steel production pathways are emissions trading schemes, most notably that of the EU. By 2030, BNEF estimates that DR plants using 100% green hydrogen at $2 per kg can be competitive with DR plants using the cheapest fossil fuel at $96 per ton of CO_2, ie, if the EU's full carbon price is applied (Figure 15). The steel sector gets free allowances in the bloc today (as do all industrial emitters), allowing them to mostly avoid the carbon price. This is set to change soon, as the EU is phasing out free allocations for steel producers from 2026 to 2034.

Steel in Europe is therefore uniquely positioned to be an early adopter of hydrogen. With the addition of a carbon border adjustment mechanism (CBAM), which subjects imported steel to similar carbon prices, the EU provides local steelmakers protection from foreign competitors in markets without carbon pricing. This also serves to keep industrial production within Europe.

Canada's carbon price also covers industrial emitters, but uses a slightly different method, where emitters are only charged for their emissions above a set baseline. These baselines are being reduced over time, but remain generous to steel producers, limiting their financial penalty. China is still discussing bringing steel into its national carbon market, which currently only covers power, but the industry expects this to happen by 2025. Steel is already included in several of the country's regional carbon market pilots.

Figure 15: Carbon price forecast and carbon prices required for green hydrogen-based industrial products to be competitive with fossil fuel-based ones, assuming 100% hydrogen blend and $2 per kilogram hydrogen cost in 2030



Source: BloombergNEF. Notes: RGGI is the Regional Greenhouse Gas Initiative, a regional cap-and-invest carbon market covering the power sector across certain northeast US states.

5.3. Steel suppliers and buyers are acting to commercialize clean steel

Steelmakers are setting individual net-zero targets, but not as ambitiously as other sectors

SSAB, a Swedish steel producer, has set the most ambitions targets, aiming to be net zero by 2030

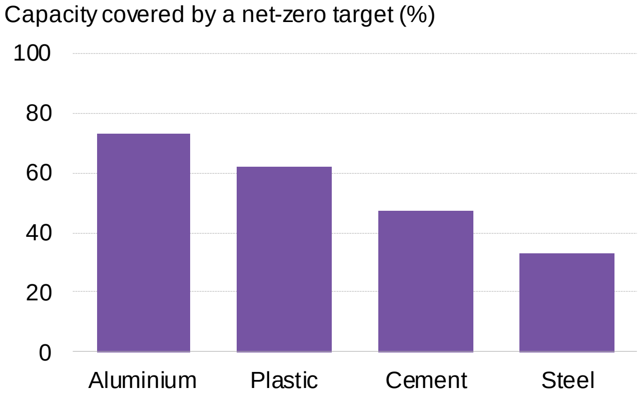
Even in the absence of mandates forcing steel decarbonization, 38% of global tracked crude steel capacity is covered by a 2050 corporate net-zero target. Among hard-to-abate sectors, steel has the least capacity covered, despite having a significant number of decarbonization pilots (Figure 16)[9].

The Asia Pacific region has the largest absolute quantity of steel production covered by net-zero targets. However, Europe leads in terms of percentage of capacity covered, at 82% (Figure 17). European producers have a greater incentive to produce green products, given the pressure from consumers and the future phase-out of free emissions allowances for steel companies in the EU ETS. SSAB, a Swedish steel producer has set the most ambitious targets aiming to be net zero by 2030[10].

9 See BNEF's *New Energy Outlook Industry* (web | terminal) for more.

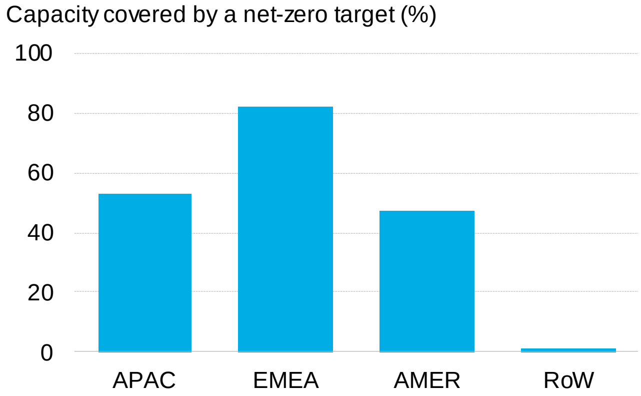
10 See BNEF's *Decarbonizing Steel: Corporate Strategies* (web | terminal) for more.

Figure 16: Tracked capacity covered by a corporate net-zero target, by material (January 2023)



Source: BloombergNEF. Note: Plastic includes polyolefins and polyethylene terephthalate (PET).

Figure 17: Tracked crude steel capacity covered by a net-zero target, by region (January 2023)



Source: World Steel Association, BloombergNEF. Note: RoW refers to the rest of the world and includes Russia and other smaller capacities uncategorized by region.

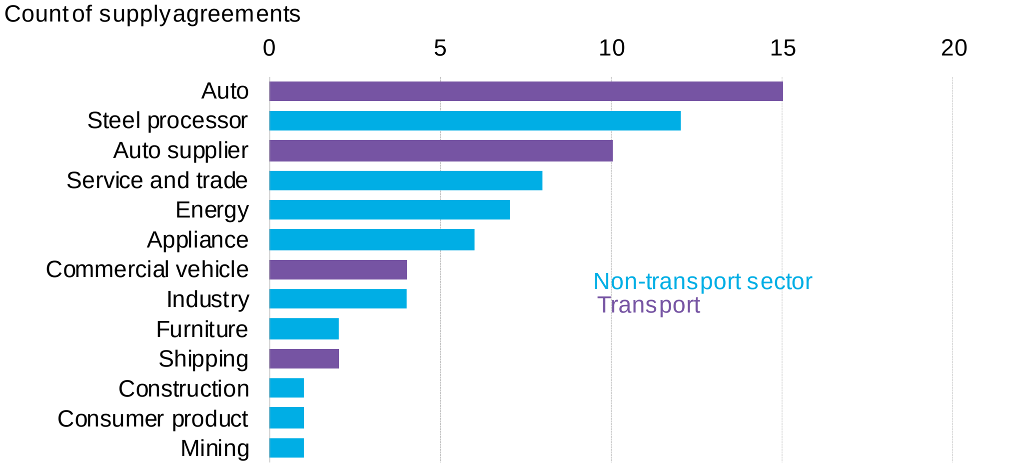
Steel consumers have shown a growing interest in low-carbon steel

As of October 2023, BNEF tracked a total of 73 supply agreements for low-carbon and clean steel products. The transport sector accounted for 42% of all agreements, with automakers and part suppliers signing 25 agreements combined (Figure 18).

So far, 32 supply agreements or memorandums of understanding have been signed for the offtake of hydrogen-based steel. Of these agreements, 23 were signed by H2 Green Steel (H2GS), five by German steelmaker Salzgitter, and the rest by ThyssenKrupp, Tata Steel and Baowu. Figure 19 shows offtakers that have signed either term sheets or binding offtake agreements for hydrogen-based green steel so far.

Companies in the automotive supply chain are the biggest group of offtakers for hydrogen-based steel. The automotive sector has a short supply chain and more importantly steel is only a small part of the final product's price tag (which affects the size of any potential "green premium"). The second-largest group of offtakers are steel processors or traders, which include specialized steel product manufacturers such as Marcegaglia and Bilstein Group, and service centers such as SPM and BE Group.

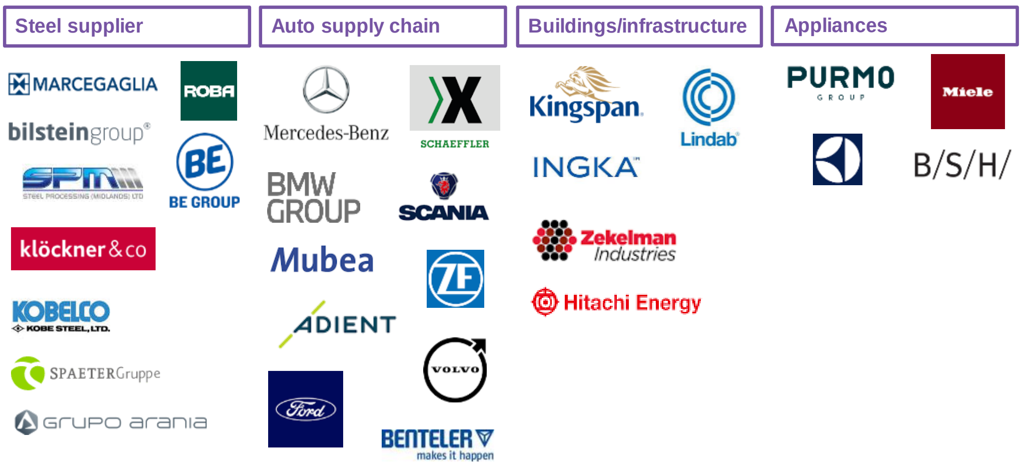
Figure 18: Count of supply agreements for low-carbon steel



Source: BloombergNEF. Note: As of October 2023.

While the buildings and construction sectors may face greater cost-related challenges, some building material companies have shown an interest in offtaking hydrogen-based green steel. Organizations like the Sustainable Steel Buyers Platform, which includes real estate development firm Trammell Crow in its membership, is aiming to stimulate demand from the private sector. In this case, the founding members are aiming to collectively procure two million tons of green steel in North America.

Figure 19: Offtakers of hydrogen-based green steel



Source: BloombergNEF. Note: As of September 2023.

Section 6. Commercial actions

Low-carbon steel, such as hydrogen-based steel, could be competitive in the early 2030s in the EU due to the phase-out of free allocation under the EU ETS, and in the US due to tax credits from the Inflation Reduction Act. In the meantime, there is a great deal that corporates can do to accelerate the adoption of clean steel, even in the absence of these strong policy incentives. Specifically, companies can consider:

Low-carbon steel, such as hydrogen-based steel, could be competitive in the early 2030s in the EU

- Securing near-term offtakes signed by the automotive and appliance sectors while working towards long-term offtakes from the construction sector
- De-risking the projects to enable financing
- Spinning-off subsidiaries to attract new investors
- Procuring cheap 24/7 clean power where possible
- Using all feedstock routes to accelerate the technology testing for the hydrogen-based DR process

6.1. Define the early adopters of low-carbon steel

There is already demand for low-carbon steel, as demonstrated by the nearly 50 green steel supply agreements BNEF has tracked (Figure 18). These early adopters tend to have a few things in common: supportive policies in their key markets, Scope 3 net-zero targets, and fewer challenges with potential cost-implications of green steel. While they may not constitute a significant amount of global steel demand, these buyers are important first 'rungs of the ladder'. Low-carbon steel producers can target these types of buyers – typically in the automotive or appliance sectors – while also pursuing the construction value chain, which comprises the majority of the steel market.

Target early-stage offtakers with green ambitions

It would be helpful to develop a framework approach that individual steel producers could use to determine which customers are most likely to be early adopters for the nascent sector.

Context

In general, a company's likelihood to offtake green products might depend on two dimensions – a business case for green products, and its approach to any potential "green premium".

A business case can come from any one of three drivers:

- **Current or expected future policy**. Companies in Europe or the UK have demonstrated more willingness to decarbonize due to regulations on carbon emissions and an expectation that these will become more aggressive over time. Companies are starting to normalize and factor carbon regulations into their business planning.
- **Customer demand**. Companies that are closer to consumers, such as automakers, are facing greater demand for sustainability from their buyers. They're in turn creating demand for suppliers to produce lower-carbon steel and are willing to sign an offtake agreement to get it.
- **Internal Scope 3 target**. Driven by image concerns and investor pressure, some companies have set up ambitious Scope 3 targets that cover the decarbonization of their supply chain.

For companies with a high proportion of steel use in their products, the adoption of low-carbon steel could significantly reduce Scope 3 emissions.

Car companies and auto parts manufacturers are the most active group of low-carbon steel buyers

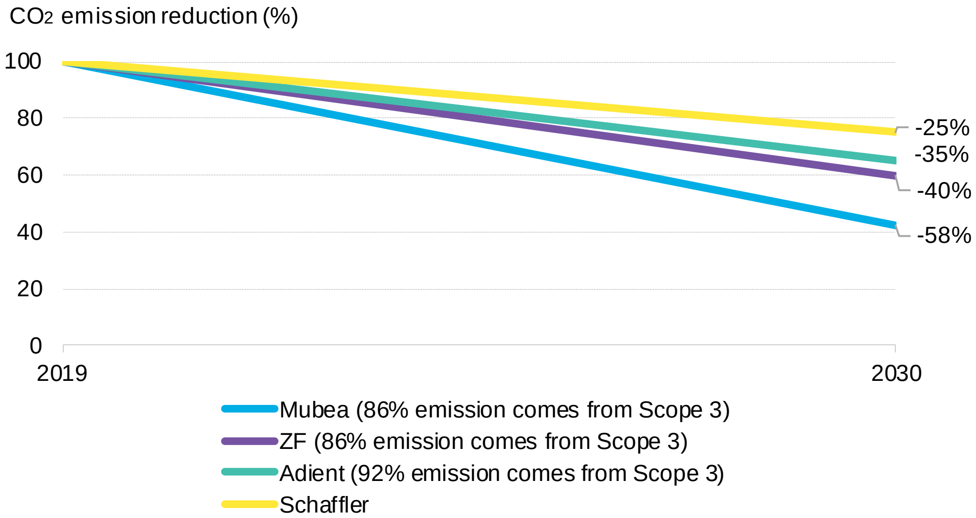
Case study: Automotive part manufacturers

Car companies and auto parts manufacturers are the most active group of low-carbon steel buyers. They are primarily deploying green steel in their flat products, especially the larger structures (such as the car body) where the use of steel is concentrated and more obvious to customers. For example, ZF Group is looking to apply hydrogen-based green steel in sheets and stamping parts, Adient to use it in seat structures, and Schaffler to deploy it in roller bearings. These firms believe there is a first-mover advantage in signing early long-term offtakes for low-carbon steel to prove their sustainability credentials to customers.

ZF, a car parts manufacturer and offtaker for H2 Green Steel (H2GS), is a good example. It considers sustainability as core to its competitiveness in the long term and links it to senior management remuneration. It sees hydrogen-based steel playing a key role in its decarbonization.

Three sectors have a relatively high potential to be early adopters of green steel: car and car parts, appliances and specialized building products

Figure 20: Scope 3 emission reduction targets among auto part offtakers of H2 Green Steel



Source: Company sustainability reports, BloombergNEF.

ZF has one of the most ambitious Scope 3 emission reduction targets among car part manufacturers. It is targeting an 80% cut in Scope 1 and 2 emissions, and a 40% drop in Scope 3 emissions by 2030, compared to 2019 levels (Figure 20). Steel comprises the largest source of its upstream Scope 3 emissions, at around 30%. It has signed an agreement with H2GS to purchase 250,000 tons of green steel annually from 2025, enough to meet 10% of its current steel demand.

Case study: Building and home appliance products

Specialized building product manufacturers could be good candidates for green steel offtake. For example, Kingspan, one of H2GS's investors and offtakers, is an Ireland-based specialized building products manufacturer. Its Scope 3 emissions account for 95% of its overall emissions, the largest part of which comes from supply chain materials, which comprise 86% of its Scope 3 footprint. It set a target to reduce Scope 3 emissions from primary supply partners by 50% by 2030, most of which would be coming from steelmakers.

Identifying a small group of early adopters is important for any new product

Appliance manufacturers are also likely to buy green steel. For example, Purmo, a Finland-based thermal radiator producer, set a target to purchase steel with 30% less embodied carbon by 2030. It has begun using a steel alloy in its products that employs less raw steel without sacrificing product quality or heat output, resulting in a 27% reduction in raw steel use and lower Scope 3 emissions from 2021-22. Its non-binding offtake with H2GS could theoretically replace 13% of Purmo's annual steel demand with green steel.

Considerations

Identifying a small group of early adopters is important for any new product. These companies demonstrate demand for the product and help the sector to scale and lower costs. The first offtake contracts can be smaller than the usual scale for the industry, as the first few plants will have limited capacity. But it is crucial that companies consider long-term fixed price contracts. Green steel suppliers can look for offtakers with the following features:

- Significant exposure to strict climate regulations
- Strong commitment to reduce Scope 3 emissions
- Large proportion of Scope 3 emissions coming from steel
- High-value final product, with materials making up a small proportion of the total cost
- High-end product sold to customers who care about sustainability

It is crucial that companies consider long-term fixed-price contracts

Table 4: Three sectors where green steel offtake potential is high

Criteria/company	Car and car parts	Appliances	Specialized building products
Scope 3 target			
Steel as a % of Scope 3			
Cost structure			
Product type			
Overall	**Very high**	**High**	**High**

Source: BloombergNEF. Note: The shades of green represent how strong a certain sector performs in certain criteria relevant for green steel offtake.

Shorten the supply chain in construction

The construction sector consumes over half of the world's steel, making it essential for clean steel demand. However, it is also the most complex and one of the sectors which may face greater cost-related challenges. Collaboration amongst buyers in procuring efforts, as appropriate in accordance with antitrust laws, could aggregate demand, and service centers could assist with tracking of supply and demand.

Context

The construction sector has a long and complex value chain. The end customer may want their project to contain green steel, but they currently have no easy way of sending this signal up the supply chain to the steelmaker as they do not directly interact.

One of the barriers to green steel adoption in the construction sector is the long and complex value chain

A long value chain not only complicates the alignment of incentives and offtakes, but also blurs the boundaries of Scope 3 emissions accounting. The embodied emissions of green steel are part of the Scope 3 emissions of construction companies and property developers, but may not be counted by property owners, tenants or investors.

Another difficulty for the construction sector is the misalignment of offtake timeframes. While green steel plants require long-term offtakes to secure financing, construction projects often procure steel in one-off purchases from different suppliers each time. This could be resolved by bypassing certain parts of the value chain: green steel procurers (such as service centers) could contract directly with end consumers, for example. Buying coalitions, where appropriate, could also create some demand certainty by aggregating demand across relevant parts of the value chain, compliant with antitrust laws.

Case study: Construction companies

Steel Processing Midland (SPM), a steel service center in the UK, sells 80% of its products to the construction sector. Traditionally, a project contractor would procure steel sections from a fabricator who in turn buys the raw materials from the service centers. SPM is trying to change this business model and actively engage with its downstream buyers.

SPM identified two types of project developers likely to adopt green steel – large technology firms that own data centers and logistic warehouses, and governments. This matches well with SPM's existing demand profile – up to 40% of its demand comes from warehouses and data centers, and 30-40% from infrastructure such as airports and transit stations. To encourage greater green steel adoption, SPM is working with its direct customers, the fabricators, to both educate them on the benefits and help them target the right project developers.

Powerful end users of construction steel have a significant role to play in stimulating green steel production

Some project owners using steel in buildings are signing direct offtakes with steel producers. The largest owner of IKEA stores, Ingka, is a good example of a consumer brand procuring green materials for its self-owned properties. Ingka signed an offtake agreement with H2GS to use hydrogen-based green steel in 50% of its warehouse rack purchases globally. This seems to be mostly driven by the company's ambition to be climate positive, rather than its own Scope 3 target, which focuses mainly on the carbon footprint of its products and its deliveries.

Considerations

Construction sector companies interested in decarbonizing their operations can work together, where appropriate in accordance with antitrust laws, to encourage green steel offtake over longer time periods. Upstream companies that are closer to steelmakers, such as service centers, could work with their customers (fabricators) to identify project developers willing to incorporate green steel products. Downstream players, such as project developers or engineering companies, could also consider if it is appropriate to aggregate demand (in accordance with antitrust laws) and approach green steel suppliers directly.

Powerful end users of construction steel have a significant role to play here. Strong demand signals from them would incentivize contractors, fabricators and service centers to stimulate the expansion of green steel. A collaboration between some of the world's largest and most climate ambitious property owners and developers, where appropriate in accordance with antitrust laws, could encourage this and could also lead to (improvements to or creation of) embodied carbon accounting standards. There are early versions of this in the First Mover Coalition, the Steel Zero alliance, and more recently the Sustainable Steel Buyers Platform.

Green steel procurement alliances

The First Movers Coalition was launched in November 2021 during the UN Climate Change Conference (COP 26). It has 85 members across seven hard-to-abate sectors. Of these, 25 companies have already committed to procuring some green steel, including H2GS offtakers Scania, ZF and Marcegaglia.

Steel Zero also focuses on green steel procurement. Member companies make a public commitment to buy and use 50% low-emissions steel by 2030, and 100% net-zero steel by 2050. There are 38 member companies, of which 24, or 63%, are part of the construction sector, such as structural steelwork providers, engineering companies and property developers. Most of these companies are based in the UK.

The Sustainable Steel Buyers Platform is an initiative convened by the Rocky Mountain Institute to align green steel buyers and sellers. Microsoft, US real-estate developer Trammell Crow, and solar hardware maker Nextracker are the founding members and jointly announced 2 million tons of green steel demand in the US. The group intends to issue a request for information to steelmakers this year and open up a formal request for proposals in 2024.

6.2. Consider different kinds of financing options

To ensure there are sufficient volumes of low-carbon steel by 2030, when most corporates hit their interim net-zero targets, commercial projects must start scaling now. The first step is to secure financing to build the plants. Securing either debt or equity for a novel project can be difficult. Investors want to see guaranteed revenue streams for the lifetime of the project, and a healthy internal rate of return on their investment. These steel plants are also combining a series of technologies, some of which have yet to be proven at commercial scale, which can make traditional debt or equity investors nervous. Even many government entities, offering project debt, do not take technology risk on loans.

Commercial green steel projects would need to start scaling now to ensure there are sufficient volumes of low-carbon steel by 2030

Startups looking to finance low-carbon steel projects can have it particularly hard, as they have no track record of building these facilities, and often have to rely entirely on expensive venture capital and private equity financing. Public steel companies face their own challenges from investors or lenders expecting a certain level of financial returns. The capital allocated to a clean steel plant would usually make a better return if spent on a gray steel plant, making it hard to justify financially. Some institutional investors are willing to take a risk on a green project because of their own green investment targets. Unfortunately for the steel industry, many of these types of investors do not see lending to a large industrial emitter, such as a public steel company, as aligning with their own sustainable investing criteria.

Clean steel project developers seeking to de-risk their plants as much as possible could look for investors who have a vested interest in the project and highlight the sustainability benefits of the project to investors looking to make green deals.

De-risking the project finance for first-of-a-kind projects

Context

Securing debt or equity financing for a first-of-a-kind project can be difficult

Securing debt or equity financing for a first-of-a-kind project can be difficult. Investors want to see guaranteed, and steady, revenue streams for the lifetime of the project, and a healthy internal rate of return on their investment. While many private equity investors and banks are precluded from taking technology risk in their investments, there are ways for steel companies to overcome these challenges, including securing offtakes, optimizing project costs and targeting specific types of green investors.

Case study: H2 Green Steel

H2GS completed €3.5 billion in debt financing for its first plant in Boden, Sweden in October 2022 and has also secured €1.8 billion in equity financing. The debt was raised from a consortium of 15 financiers. H2GS managed to secure its financing because:

- It signed binding 'take-or-pay' agreements for 40% of its 2025 output, and term sheets for another 20% of the output. The offtake agreements were signed with 23 customers and have a duration of five to seven years. Signing offtakes with 23 customers, rather than just a few, also lowers counter-party risks.
- It locked in the cost of half its electricity demand electricity (a significant portion of its operating expenditure) through two, seven-year power purchase agreements with existing hydro plants. This eliminates the risk involved in building new renewable projects and in fluctuating wholesale power prices.
- It received a guarantee from national credit agencies. This serves as a safety net for debt financiers to get repaid if the project defaults. The NEOM hydrogen project received debt financing in 2023 with a similar credit guarantee from the Saudi Arabian government.
- It is sourcing equipment from established suppliers and recruiting veterans from the steel industry, which turns technology risk into operational risk that investors can accept.

The most important actions appear to be signing long-term contracts for the steel offtake and for the renewable electricity supply

Table 5: The debt financing details for H2 Green Steel's Boden project

Debt type	Financier	Volume
Senior debt	AB Svensk Exportkredit (SEK), BNP Paribas, ING, UniCredit, Societe Generale, KfW IPEX-Bank	€3.3 billion
Senior debt	European investment bank	€750 million
Junior debt	Leading infrastructure funds	€500 million
Export credit-linked guarantee	Export credit agencies, including Euler Hermes	Covering 95% of the €1.5 billion senior debt
Credit guarantee	Swedish National Debt Office	Covering 80% of the €1 billion senior debt

Source: BloombergNEF, H2 Green Steel.

Considerations

H2GS has shown that de-risking a hydrogen-based steel project is possible. Both steelmakers and financiers can use this list of factors as a template. The investors agree that it was valuable to sign long-term contracts for the steel offtake and for the renewable electricity (or hydrogen) supply. Guarantees from governments or policy banks are also very important to give more confidence to private investors. The developer can also bring in more risk-seeking investors through junior debt lenders, to increase the project's debt ratio without diluting ownership. All these tactics also work to attract specific types of investors, such as climate-focused growth equity funds, that otherwise would be unlikely to touch first-of-a-kind projects.

Spinning out new green businesses for fundraising

Context

Public steel companies could look to spin out a green subsidiary or create a joint venture

Many large public steel companies are funding their green steel demonstration projects in part through government grants. However, to scale these to commercial facilities, private funds are required to make up the balance. As public companies, they could raise debt or equity from the public markets, but this could prove challenging if the internal rates of return are not as good as the market is used to seeing for this company. The money could come from issuing green bonds or other forms of sustainable finance but this has not been a popular route to date, partially because the green bonds may not offer preferential rates, and because of the lack of clarity on which low-carbon steel projects qualify as 'green'.

Another option, proposed here, is to spin-off a green subsidiary (either publicly or privately) that is easier to invest in. This is a common practice for the utility sector in the US and for vehicle manufacturing companies in Asia. Many regulated utilities (mostly owning fossil-fuel assets) in the US have spun off arms that invest in renewable assets and explore new green business opportunities. For example, Exelon, the country's largest utility, spun off Constellation in 2022. Constellation is a publicly traded company with a number of private investors. It primarily supplies low-carbon power to commercial customers and has an active venture capital arm. It can now be classed as a 'green' investment since it is fully separate from Exelon's fossil-fuel assets.

Automotive company Tata Motors spun off an arm dedicated to making electric vehicles in October 2021, raising $1 billion from TPG Rise Climate and ADQ to do so. TPG Rise Climate has a mandate to invest equity into green businesses, and could not have done so directly into Tata.

Case study: SSAB

Getting offtakers to be the investors can help the projects to secure financing

Swedish steel company SSAB has chosen to produce its first hydrogen-based steel through a joint venture – the Hybrit project. This JV is between SSAB, Sweden's national iron ore company LKAB and Swedish utility Vattenfall. Having LKAB and Vattenfall as partners is key to making the project viable, as they could provide the high-quality sponge iron ore and clean baseload power needed for hydrogen-based green steel production. SSAB's first shipment of hydrogen-based green steel will go to three existing Swedish customers: automotive manufacturer Volvo, mining equipment manufacturer Epiroc, and watchmaker Triwa.

Considerations

Public steel companies can copy a successful model from other sectors – either spinning out a green subsidiary or creating a joint venture. Both options could allow them to attract equity and debt from investors with a green mandate and move a riskier and more expensive investment further from the public shareholders of the parent company.

Offtakers as project investors

A $1 billion advanced market commitment is being used to scale up carbon removal technologies

Context

In the early days of the LNG sector, offtakers took a stake in the project. These offtakers were often governments that wanted access to the liquefied natural gas as a long-term energy security play. As part of that offtake deal, they committed to finance part of the project. This provided evidence of both demand and existing financial support to other potential investors. In the case of green steel, technology and engineering firms could play this role, with the expectation that a larger clean steel sector will create greater demand for their services.

Offtakers can also pay for the purchase in advance, like the 'advanced market commitment' (AMC) program founded by Stripe, Alphabet, Meta and others. This would give project developers the funds to build and scale the technologies while reducing the need for external financing sources.

Case study: H2 Green Steel

Seven out of the 23 offtakers that H2GS secured also have equity stakes in the company. They include automotive parts maker Schaeffler, steelmaker Marcegaglia, automaker Mercedes-Benz and steelmaker Bilstein Group. H2GS is also procuring equipment and services from some of its offtakers. Hitachi Energy is providing digitalization and operational expertise to the project, while Kobe Steel's wholly owned subsidiary, Midrex, is supplying the DRI technology.

Case study: An advanced market commitment

An advanced market commitment is an innovative funding mechanism where buyers commit funds to the suppliers in advance. The concept was borrowed from vaccine development a decade ago, where donors gave money to vaccine developers for research and development in exchange for a promise to sell the vaccines at affordable prices to low-income countries. A group of tech companies launched the Frontier initiative in 2022 to commit $1 billion through advanced market commitments by 2030 for CO_2 removal technologies. While the majority of the funds will only be paid when the credits are delivered, Frontier also has a program where early-stage suppliers can receive payment upfront to help finance their plants.

Considerations

Steelmakers could solicit offtakers to become equity investors

Steelmakers could solicit offtakers to become equity investors, by demonstrating that this will make it easier to secure external financing and improve the project's likelihood of success. They could also try innovative funding mechanisms such as an AMC, where offtakers can directly fund the projects through an upfront payment in exchange for the delivery of a certain volume of products.

This is complementary to spinning off a subsidiary or setting up a joint venture. SSAB's Hybrit JV structure allows its resource providers to become stakeholders. Setting up a separate entity gives greater flexibility for the ownership structure, which might incentivize offtakers or suppliers to get more involved and reduce the credit risk for project finance.

6.3. Lower the cost of clean steel as soon as possible

Green steel demand will rise as costs fall, but this cannot happen without a few early movers. In order to reach net zero by 2050, steel companies would need to start investing in decarbonization technologies today. Routes to rapidly lowering the costs of hydrogen-based steel include securing long-term access to 24/7 clean power and gaining expertise in hydrogen-based production through using gray hydrogen in existing and new steel plants.

Accessing low-cost 24/7 clean power

Context

Building a portfolio of 24/7 clean power supply is challenging

Hydrogen-based steelmaking requires cheap clean power to produce economic green hydrogen to make iron and power the steelmaking. Building a portfolio of 24/7 clean power supply is challenging due to the high cost of long-duration energy storage and firm clean power generation. This either comes from nearby hydropower, geothermal, nuclear or batteries, or from a well-structured virtual 24/7 clean power PPA. The latter is an early-stage product and may not be accepted by regulators or investors for a while.

To prioritize access to cheap clean power, hydrogen can be made offsite and transported to the steel plant, or the reduction of iron could be situated near renewables resources, so as to co-locate the hydrogen production.

Case study: Hydrogen and power procurement for green steel

Examples of projects sourcing green hydrogen offsite include ArcelorMittal's plans to source from Vattenfall's Moorburg electrolyzer plant, and Salzgitter signing an MOU with EWE to buy green hydrogen from its 40 megawatt (MW) electrolyzer plant, while also building a 100MW electrolyzer of its own.

SSAB, H2GS and Posco are choosing to make their own hydrogen onsite, to reduce the supply-chain risk and improve control over feedstock costs. H2GS's plant will be based in Sweden in part because of access to existing hydropower. H2GS has secured a seven-year hydropower supply contract of 2 terawatt hours (TWh) per year with Statkraft, the latter said, and two power contracts of 2.4TWh per year with Fortum, this company said. The timeframe matches the steel offtake contracts and the volume of power supply accounts for about half of the electricity needed for H2GS's first production phase of 2.5 million tons of steel. On top of the long-term PPAs, electricity will be purchased in the open market, most likely from onshore wind projects.

Countries that might be able to provide 24/7 clean power include Brazil, Norway, Canada, China

By combining hydro and wind power, H2GS claims to be able to achieve $34 per megawatt-hour (MWh) for 24/7 clean power, excluding transmission costs. Transmission costs can add up to $25 per MWh to the cost in some European countries, according to BNEF estimates, but are typically around €4 per MWh ($4.2 per MWh) in Sweden, according to ENTSO-E. The corresponding green hydrogen costs, excluding transmission costs, would be $2.86 per kg in 2026, compared to renewables-plus-batteries at $9.08 per kg assuming an 80% utilization factor[11]. This translates into a green steel production cost of $686 per ton[12]. The green premium implied is less than $200 per ton compared to conventional steel (the German benchmark is $500 per ton).

Considerations

Signing PPAs with existing hydro, geothermal or nuclear plants is a good way to secure cheap 24/7 clean power. Countries with a large hydro portfolio include Norway, Canada, Brazil and China. Countries with large geothermal capacity include the US, Turkey, New Zealand and

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[11] See BNEF's *Hydrogen Electrolyzer Optimization Model (H2EOM 1.0.2)* (web | terminal) for more.

[12] See BNEF's *Steel Production Valuation Model* (SteelVal 1.0.1) (web | terminal) for more.

Southeast Asia (Indonesia and Philippines). Countries where nuclear power has a significant share include the US, Canada, China, France and South Korea.

This could lead to a shift in the location of new iron and steel mills. Whereas today they are located near iron ore and/or their demand centers, the most important factor in the future could be co-location with 24/7 clean power. This relocation is most likely to happen slowly, and to countries where there are also good quality iron ore deposits, such as Canada and Brazil. The right form of power market is also important, where green industry can easily get access to long-term clean power PPAs. For example, POSCO is looking to produce green hydrogen and potentially direct reduced iron in Australia, before shipping the intermediate products back to South Korea for processing in EAFs. Compared to relocating the whole process overseas, keeping the final steelmaking process domestic might be a more realistic option. This could make the relocation politically easier to justify, while also making sure the final products are tailored to the local market demands.

New-build DR-EAF plants can technically run on up to 90-95% hydrogen from 2026 but more technology testing is required

For projects where access to clean dispatchable power is limited, companies can sign multiple PPAs with solar and wind projects. Although it could be technically challenging to piece together different PPAs to make 24/7 clean power, companies such as Google and Microsoft have committed to 24/7 carbon-free power targets. Energy providers such as AES are using their experience in power trading to deliver reliable renewable power to these companies. Steel makers or hydrogen developers could potentially use the structure of these 24/7 clean power PPAs as well.

Consider hydrogen-based steel technology testing

Context

Running a direct reduction furnace on 100% hydrogen has yet to be proven at commercial scale. Existing natural gas-based DR-EAF plants can run on up to 30% pure hydrogen and require equipment modifications to go higher. New-build DR-EAF plants can technically run on up to 90-95% hydrogen starting from 2026. Switching to a hydrogen-based production process requires a meaningful investment into the DRI equipment (roughly 20% of equipment and balance of plant capex), as well as the development of a green hydrogen and green electricity supply chain. Not all steelmakers can take on these costs without a significant customer commitment. This is particularly challenging for steelmakers in China, where there has not been a strong push to decarbonize from either the regulators or customers. Rather than committing to all of this investment upfront, steelmakers are testing the technology in parts.

Case study: HBIS

Steel companies could review the lowest cost route to testing commercial scale DR-EAF in their region and pursue it

HBIS is China's fourth-largest steel maker. It plans to gradually shift production from emissions-intensive blast furnaces to EAFs using mostly scrap or DRI made with hydrogen. It recently commissioned a 0.6 million-ton pilot DRI plant, and is aiming to build a 3 million ton hydrogen-based DRI plant coupled with EAFs (H2DR-EAF) by 2025.

The company recently commissioned a pilot DRI plant using gray hydrogen from purified coke oven gas as a reducing agent. Coke oven gas is a byproduct of coal coking plants, which steel companies often own to produce the fuel needed for steelmaking. As steel producers face sluggish demand from the construction sector in China, they are struggling with single-digit profit margins. Making use of this 'free' byproduct gives them a way to test a new technology with minimal costs.

Takeaways

Steelmakers could begin to reduce technology risk by reviewing technologies to find the lowest cost route to testing low-carbon production in their region. Chinese steelmakers have access to cheap gray hydrogen as byproducts of coal coking or industrial process, while some European players, such as ArcelorMittal, are planning to run new DRI plants with natural gas, then gray hydrogen, and ultimately green hydrogen as feedstock costs fall.

To be successful, companies should consider a clear transition plan and product roadmap for when and how they will switch to green hydrogen. Plans for new DRI plants can include the potential to build large green hydrogen facilities nearby or source green hydrogen via a pipeline or terminal.

Section 7. Policy considerations

Without adequate policy support, low-carbon steel will struggle to compete

Companies will not decarbonize steel production alone. And while green steel demand is growing, without adequate policy support, low-carbon steel will struggle to compete. Policymakers can complement the commercial actions in the previous section by:

- Bringing industrial emitters into carbon pricing schemes and ensure they bear the cost of 100% of their emissions
- Developing low-carbon steel standards and emissions reporting methodologies
- Creating public procurement programs for green steel
- Include embodied carbon emissions in building regulation and labeling

7.1. Incorporate industrial sectors in carbon pricing policies

Carbon markets can be instrumental in decarbonizing the steel sector. By taxing companies based on the emissions intensity of their product, steel producers are incentivized to switch to low-carbon production routes. The EU illustrates a starting point for other markets, with some of the highest carbon prices in the world and a new border tariff due to come into force in earnest in 2026 to protect local green steel manufacturers from being undercut on price by dirtier imports.

Context

Carbon markets are technology neutral and incentivize emitters to find the lowest-cost, most efficient route to decarbonize. The revenues from carbon taxes can then be invested into supporting these net-zero technology pathways. However, to date there are no carbon markets in the world that sufficiently support industrial decarbonization. Most exempt industry entirely or provide it with sufficient free allocation to be unofficially exempt. This is done by governments mostly due to the fear of losing strategic manufacturing capacity and jobs if producers must bear the full cost of their emissions. However, there are ways to implement effective carbon policy while also avoiding ‘leakage’ of industrial assets. These include an import tax on industrial products with higher embodied emissions and subsidies for domestic industries to help them decarbonize.

Policy case study: The EU ETS and CBAM

Though blunted by the localization of steel consumption, CBAM has the potential to be a key policy instrument

A major driver of decarbonization initiatives in Europe has been the EU ETS. The carbon trading scheme’s relatively high prices have prompted action by most companies currently covered by the program. However, industrial assets (including steel mills) are exempt from paying the full carbon price through a supply of free allowances that offset most of their CO_2 emissions.

The EU intends to phase out this free allocation. Starting in 2026, the volumes of free annual allowances will shrink, finally being removed entirely by 2034. This slow phase-out has prompted some local steel mills to start setting net-zero targets and announcing new green capacity, but there have been few low-carbon plants commissioned.

With the introduction of the EU’s Carbon Border Adjustment Mechanism (CBAM), imported steel will be subject to carbon prices, protecting green industries within the EU and prompting producers to seek to access the common market to shift to low-carbon production routes. While imports comprise less than 20% of steel consumption in Europe, CBAM has the potential to be a key policy instrument for steel decarbonization as major producers like China see steel demand affected[13] by turmoil in the domestic property market and producers are increasingly looking to export their products.

Considerations

To stimulate demand, high enough carbon prices will be needed, like those in Europe

The EU ETS, when it includes industrial emissions, combined with a policy such as CBAM could provide a blueprint for carbon market policy. High carbon prices (of around $80-100 per ton of CO_2) are most likely to stimulate demand. In most regions, this high price may not be possible. However, a lower carbon price could incentivize steelmakers to switch to cleaner processes if combined with a supply-side policy that subsidizes clean hydrogen production, clean power, or carbon capture. While it is likely that most carbon prices will increase as time goes by, it could be wise for governments to also implement a carbon contract for difference (CCfD) to protect sectors from becoming uneconomic if carbon prices fall. For instance, a CCfD for hydrogen could be designed so that the government tops up the lost revenue of a green hydrogen maker compared to a gray hydrogen maker, when the carbon price is too low to compensate for this.

In regions such as the EU, where industry is technically included in carbon markets, policymakers should consider shortening the time frame for the phase-out of free allocations. The current phase-out was announced in 2022 and will not begin until 2026. However, for steel and other industrial products, the phase-out might be even slower and will not be fully in force until 2034. This long period of phasing-in means that steel producers will simply pay the relatively small carbon bill due for many years, slowing the adoption of new technologies. The routes to steel decarbonization are well understood and close to commercialization. Policy can give them the final push to broaden deployment, and should do that well before 2030.

7.2. Develop low-carbon steel standards and methodologies

Most green steel buyers today define their own criteria for what is ‘low carbon’ and engage in lengthy due diligence processes with suppliers. While it is not necessary to have one global standard for low-carbon steel, the development of regional standards would simplify the buying process for companies,and encourage more efficient and transparent pricing.

Context

No national or supranational standards and methodologies exist that define what constitutes low-carbon steel

There is currently no consensus on a green steel standard, and most of those available have been created by the private sector and non-governmental organizations. Proposals have been put forward by industry groups like the World Steel Association and the Global Steel Climate Council (GSCC). Standards vary in their accounting methodologies, whether to focus on CO_2 or global warming potential, what the system boundaries for embodied carbon are, and whether to require green steel to consider social, governance, and biodiversity factors as well as emissions.

In terms of emissions boundary conditions, steel production can be split into five areas. These are:

- **Upstream**: Emissions embedded in production inputs, such as mining iron-ore, coal and lime. This would also cover grid electricity and emissions from sourcing scrap steel.

[13] See BNEF’s *China’s Property Slump to Haunt Steel Demand for Years* (terminal) for more.

- **Raw material preparation**: Emissions from processing iron-ore in either pellet or sinter plants, lime kilns and coke ovens
- **Iron and steelmaking**: Emissions associated with reducing iron ore and producing steel. This includes the use of energy generated onsite to provide heating, and the emissions generated chemically from carbon electrodes, additives or reducing iron ore.
- **Downstream**: Emissions associated with finishing steel products, including hot and cold rolling and coating crude steel.
- **Auxiliary processes**: Emissions from producing the oxygen used in a BOF.

Table 6: GSCC emissions intensity for flat steel products

Year	Metric tons of CO2e per ton hot rolled steel
2022	1.84
2025	1.63
2030	1.31
2035	0.99
2040	0.69
2045	0.40
2050	0.12

Source: BloombergNEF, Global Steel Climate Council.

The World Steel Association, alongside the GSCC, set the most exhaustive system boundary for the reporting of emissions, encompassing the upstream emissions and embodied emissions of recycled steel. Responsible Steel, and the sustainable steel principles on which the Climate Bonds Initiative derives its own standards, both exclude upstream emissions, with Responsible Steel only partially covering auxiliary processes (Table 7), though it has a much more exhaustive list of non-emissions sustainability considerations.

Another key difference is in the numerical targets for low-carbon steel. Responsible Steel is one of few bodies that does this, proposing a tiered approach that considers the extent of scrap utilization. In its standard, near-zero steel would have an intensity of 0.05-0.4 tons of CO_2 per ton of steel. The GSCC proposes a pathway for what is considered low-carbon steel from now to 2050, based on its global warming potential, with recycled steel as the standard for green steel today. Table 6 shows the glide path for flat products specifically.

Table 7: System boundary of emissions calculations for select proposals

Methodology	Upstream	Raw material preparation	Iron and steelmaking	Downstream	Auxiliary processes
World Steel Association	Green	Green	Green	Green	Green
Climate Bonds Initiative	Red	Green	Green	Green	Green
Global Steel Climate Council	Green	Green	Green	Green	Green
Responsible Steel	Red	Green	Green	Green	Yellow

Source: Global Efficiency Initiative. Note: Red indicates a lack of coverage, Yellow indicates some coverage and Green indicates complete coverage of an area. This is not an exhaustive list of methodologies.

Considerations

Policymakers can take the lead in shaping low-carbon steel standards and methodologies in their jurisdictions and certify third parties to provide independent verification for products.

Ideally, emissions thresholds for low-carbon steel decline over time in line with a net-zero scenario. Carbon removals (a form of permanent carbon offset) could be used to meet thresholds but only to a limited extent, say between 10-20% of emissions, and would come with a requirement to report on the use of carbon removals. The standard would include different levels of certification – such as full emissions reduction and partial emissions reduction – based on absolute emissions and require a yearly progress and disclosure report.

Verification can be done by accredited third parties and based on current ISO standards for life cycle emissions reporting. While these standards have been broadly adopted, they may need to be adapted specifically for steel.

7.3. Government incentive programs to create green steel demand in construction

The construction sector is the largest consumer of crude steel products

The construction sector is the largest consumer of crude steel products. It is also one of the least likely to adopt hydrogen-based steel, due to cost-related challenges. Simultaneously, the public sector is a major consumer of construction services and goods. Public procurement therefore could play an early role in driving steel decarbonization.

Context

Globally, public procurement accounts for 25% of steel demand. This means over 470 million tons of demand that could be made low-carbon, if governments factored emissions into procurement processes. Green or sustainable public procurement (GPP) programs are initiatives by government bodies to do just that. The scope of such programs is wide, ranging from public buildings to transport infrastructure projects.

The success of a GPP is dependent on the information disclosed regarding a products environmental impact

Steel products have not featured prominently in GPP schemes. For the few that do include steel, such as South Africa, the focus has been on the repurposing of scrap steel. Efforts such as this do not send strong signals to steelmakers to invest in new low-carbon steel projects. California, in the US, presents the only procurement jurisdiction where a mandatory GPP that considers steel emissions is active. Although it has yet to be implemented, the Buy Clean Initiative in the US will also include steel and has already published proposed emissions thresholds.

Policy case study: Buy Clean California Act

The Buy Clean California Act was made law in 2017 with compliance required since 2021. It governs the procurement of steel for use by California's state government, both direct and indirect – on other words, steel purchased by contractors. The GPP covers four categories of steel products, with emissions thresholds based on average industry emissions (Table 2). These thresholds heavily favor scrap-based EAF steel production, whose carbon intensity can be lower than 0.4 tons of CO_2e per ton of steel, and which makes up 70% of US steel capacity. However, California aims to reduce the required threshold every few years, making it increasingly hard for steel companies to sell to the state government without investing in new green capacity.

Policy case study: The Netherlands CO2PL

The Netherlands' CO_2 performance ladder (CO2PL) is both a GPP instrument and a tool to help organizations reduce emissions. Dutch public procurement bodies have used the CO2PL since 2010 for such things as infrastructure, waste management and health care.

Low-carbon steel can be procured under a competitive auction system, and must qualify below a general emissions threshold

The CO2PL does not explicitly set carbon emissions thresholds for organizations, rewarding instead continuous emission reductions associated with their product or service. Bodies submitting bids are required to develop CO_2 reduction plans then, based on the results, they are categorized into five tiers. Bidders with higher emission reductions will be put in a higher tier, which would result in a greater reduction in their bidding prices and therefore a greater chance of winning the contract. Emissions reporting is required by companies participating in the procurement process and emissions reductions are verified by third parties. In 2017, organizations certified on the CO2PL were found to lower carbon emissions at twice the speed of the Dutch average. Other European states seek to replicate this success and are exploring the approach in the development of their respective GPP schemes.

Considerations

Firstly, policymakers could include steel in their green public procurement programs, considering its significant carbon footprint and the large volumes that governments buy. Not all uses of steel need to be targeted at the onset. Ideal projects will strike a balance between making sure enough green steel is being procured to drive new project investment, while being conscious of the incremental cost of the green steel on the project.

The design of a low-carbon steel procurement program could be as follows: low-carbon steel is procured under a competitive auction system with a general emissions threshold for a producer to meet to qualify. A CO2PL structure would then kick in, with producers awarded bonuses, for instance additional green price premiums, the further they decarbonize their steel product. When implementing a CO2PL for steel, it is important that additional thresholds be incrementally strict, and in line with the standard developed in 7.2.

Regulated entities, with a guaranteed rate of return, could be mandated to procure low-carbon steel with a portion of costs passed on to the government. For countries where publicly funded infrastructure is less prevalent, or the government does not have the budget to bear any green steel premium, the government can provide incentives for private sector developers to adopt green steel. Fast-tracking the permitting process could be one way, as these can often be long and complicated processes.

7.4. Include embodied carbon emissions in green building regulation and labeling

Governments are beginning to act on embodied carbon emissions through building regulations

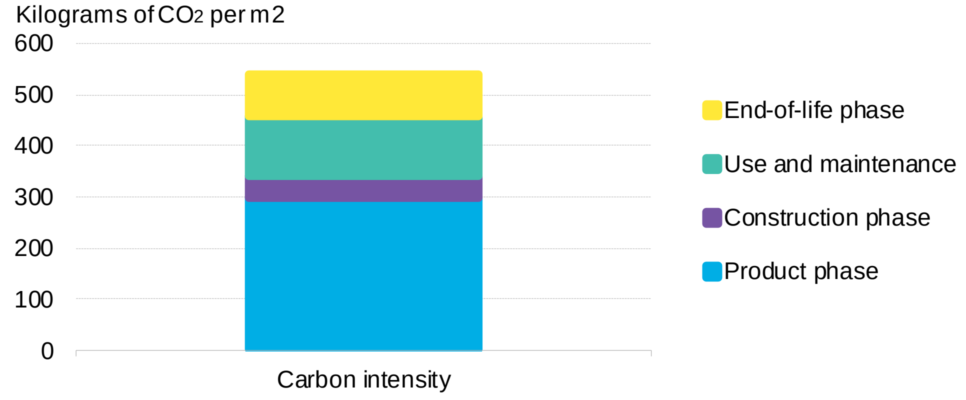
Through regulation, mandates and voluntary reporting, some governments are making progress in reducing the embodied emissions of new buildings. While the carbon thresholds are not stringent enough today to incentivize investment in new green steel plants, these policies are a good way of collecting emissions data and socializing the significance of embodied emissions amongst tenants, real estate companies and investors.

Context

Governments are beginning to act on the embodied carbon emissions in buildings through lifecycle emissions reporting regulation. Cities have been major drivers of this. The most common route to comply with the reporting is to produce environmental product declarations (EPDs) that standardize the carbon footprint calculation of the materials used to construct the building. Whole-building lifecycle assessments can be conducted based on these, and used to benchmark limits.

Once reporting is in place, some governments are using this data to set realistic emissions thresholds for new builds. Ramboll, a Danish construction and engineering company, found in a 2022 study that the lifecycle embodied emissions of an average building in the EU is 500-600kg of CO_2e per m^2. The majority of this, around 300kg of CO_2e per m^2, comes from emissions in producing the materials (product phase in Figure 21).

Figure 21: Embodied emission estimated on 769 EU buildings in 2022



Source: Ramboll 2022, BloombergNEF.

Given that concrete and steel comprise significant amounts of most buildings, and that they are materials with large carbon footprints, it makes sense that these kinds of government regulations would have a positive impact on low-carbon steel demand.

The energy use of a building will impact its Scope 2 emissions

The increasing amount of EPDs for commercial building materials might have a positive knock-on effect for voluntary disclosure. Many real-estate companies voluntarily subscribe to building standard labels run by LEED, BREEAM and others, that rate buildings on their operational emissions (among other sustainability factors). For sustainability-focused building owners or real-estate investors, these types of building certifications are important, as a public mark of their green credentials. Some investors may decide to only invest in companies that own Gold or Platinum LEED certified buildings, for example. These ratings are also important for commercial tenants with their own net-zero goals, as the energy use of a building will impact their Scope 2 emissions.

While operational emissions have been the focus to date of these types of building standards, the gradual increase in availability of embodied carbon emissions data could help drive change. LEED includes the ability for new-builds to collect additional points for any reduction in the embodied carbon of a building, while BREEAM offers credits to new-builds that reduce the lifecycle emissions of the building through the materials used. BREEAM intends to develop a new 'carbon' category in its scoring system, to include both embodied and operational emissions.

Case study: Toronto Green Standard

The Toronto Green Standard (TGS) is a public building standard, not dissimilar to LEED and BREEAM, first announced in 2010. It sets sustainable design and performance requirements for new buildings, private or public. The standard assigns new commercial developments to one of three tiers based on certain criteria. These criteria include air and water quality, circular economy, biodiversity and building energy and emissions. In 2023 the TGS included a requirement to use lower-carbon construction materials, including steel.

All government-owned buildings are required to conduct upfront embodied carbon assessments and have an emissions intensity of 250kg of CO_2e per m^2 or lower. For private developers, there are three tiers. The first tier – reporting of upfront embodied emissions – is mandatory for all new buildings. Achieving subsequent tiers, however, allows private developers to claim partial refunds on development charges (Table 8).

Table 8: Refund awarded based on project tier, for the Toronto Green Standard

Level	Development charge refund
Tier 1	0
Tier 2	25%
Tier 3	50%

Source: BloombergNEF, Toronto City Government

To meet the tier 3 requirement, for mid- to high-rise residential and non-residential projects, the upfront embodied emissions should be less than 250kg of CO_2e per m^2. A similar requirement applies to low-rise residential buildings with heated floors as well.

As the product phase emissions in Toronto for new builds today is between 116 and 561kg of CO2e per m^2, with an average of 191kg of CO2e per m^2, the tier 3 requirement is not very aggressive. Most of the buildings might be able to meet this threshold by simply adopting new design and switching to low-cost material substitutions, such as wood and earth materials. This means it might not be sufficient to drive investment in new green steel projects. However, like others, this policy is consistently revised (every three years). At the next revision, the voluntary requirements for the private sector may become mandatory.

Considerations

To make deep decarbonization cuts, and incentivize green steel investment, green building standards would need to get more stringent over time

Policymakers can support efforts to increase the reporting of embodied emissions in whole-building lifecycle assessments for new commercial buildings. As the reporting format, cradle-to-gate EPDs could be used, covering the upstream emissions associated with the production of said emissions. ISO standards and EN (European Standard) governing the construction of EPDs could be a good certification framework.

It makes sense for each city or jurisdiction to set its own emissions thresholds per square meter, based on local conditions, base-case emission assumptions and any cost-implications for developers. That way, the government can stimulate the market as it sees fit.

To make deep decarbonization cuts, and incentivize green steel investment, these standards would need to get more stringent over time. If the cradle-to-gate emissions benchmark in the city or country is 300kg of CO_2e per m^2, the government has to aim for below 200kg of CO_2e per m^2 to incentivize the use of low-carbon steel and cement. There would be a clear pathway for the emissions intensity threshold over time, so that investors and real estate developers could plan ahead and invest in the required technologies needed for compliance in the future.

The tiering approach that Toronto uses might be an effective measure for more cities, as it sets ‘stretch goals’ for developers and rewards their efforts. This is better than setting a mandatory threshold, which, if loose, might incentivize everyone to do the bare minimum, but if too stringent might discourage the industry to take actions.

Finally, it would be helpful if policymakers were to work with building standards organizations such as LEED and BREEAM to align on similar embodied carbon emission thresholds. For example, the reporting data the cities collect could help LEED and BREEAM as they look to develop clearer methodologies and scoring systems around embodied carbon building labels.

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