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Steeling Demand: Mobilising buyers to bring net-zero steel to market before 2030

Supported by Breakthrough Energy

An analysis by Energy Transitions Commission and Material Economics for the Mission Possible Partnership's Net-Zero Steel Initiative

Steeling Demand: Mobilising buyers to bring net-zero steel to market before 2030

Steeling Demand: Mobilising buyers to bring net-zero steel to market before 2030 demonstrates that demand signals from steel buyers to steel manufacturers can help unlock investment decisions. Such signals will secure the next generation of breakthrough technologies needed for primary steel to become truly net-zero emissions. This is significant in an industry that globally accounted for 2.6 Gt of direct CO_2 emissions in 2019, representing about one-quarter of industrial CO_2 emissions and 7% of total energy sector emissions (including process emissions). This report provides the guidance needed to the critical stakeholders in the automotive, construction, renewable energy and white goods sectors on how to seize the associated commercial opportunity for steel buyers in being early movers and actively participating in the commercialisation of low-CO_2 primary steel production technologies.

This report was developed by the Energy Transitions Commission and Material Economics on behalf of the Net-Zero Steel Initiative, part of the Mission Possible Partnership. This work was supported by Breakthrough Energy.

The Energy Transitions Commission (ETC)

ETC is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C.

Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners.

Material Economics

Material Economics is a management consultancy firm advising leading businesses on how to reduce their environmental footprints and become more circular. The firm has published leading reports on climate change, heavy materials, and the circular economy, and has experience from more than 100 sustainability-related strategy projects in sectors such as heavy industry, buildings, finance, transportation, manufacturing, and food.

Breakthrough Energy

Founded by Bill Gates, Breakthrough Energy is dedicated to helping humanity avoid a climate disaster. Through investment vehicles, philanthropic programs, policy advocacy, and other activities, we're committed to scaling the technologies we need to reach net-zero emissions by 2050.

Mission Possible Partnership

Led by the ETC, RMI, the We Mean Business Coalition, and the World Economic Forum, the Mission Possible Partnership (MPP) is an alliance of climate leaders focused on supercharging the decarbonisation of seven global industries representing 30 percent of emissions – aluminium, concrete, chemicals, steel, aviation, shipping, and trucking. Without immediate action, these sectors alone are projected to exceed the world's remaining 1.5°C carbon budget by 2030.

MPP brings together the world's most influential leaders across finance, policy, industry and business. MPP is focused on activating the entire ecosystem of stakeholders across the entire value chain required to move global industries to net-zero.

Net-Zero Steel Initiative

Global carbon emissions from iron and steel production are currently around 2.3Gt per annum – or about 7% of global energy system emissions. Business-as-usual scenarios suggest that this could rise to 2.8Gt per annum by 2050. Multiple technology pathways to decarbonise steel production are already being developed, but, in a highly competitive sector, market signals are lacking to unlock further investment.

The Net-Zero Steel Initiative aims to mobilise steel industry leaders who want to work together to shape the favourable policy, market and finance environment required to transition to zero carbon emissions in steel.

Learn more at:

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Executive Summary

Primary low-CO_2 (and eventually CO_2-free) steel production will be essential for all actors in the value chain, spanning steel production and use, in order to reach voluntary and regulatory climate targets by 2030 and beyond. Decarbonising steel is also essential to reach net-zero emissions globally by 2050. From wind turbines to electric vehicles, steel will be an integral enabler of the energy transition but it is also a major part of the embodied carbon in many industrial products today.

The pressure to decarbonise is coming from a combination of factors, including policy action, scrutiny from finance players, and changes in consumer preferences. As pressure grows to deliver deep decarbonisation of production and products, the world needs solutions that reduce emissions associated with carbon-intensive materials such as steel in the short term and provide a foundation for deeper cuts in the 2030s and 2040s.

Early movers in the automotive, construction, renewable energy and white goods sectors can benefit from developing new low-CO_2 steel supply chains. For all these sectors, early action on low-carbon steel is attractive as:

- Steel is a major component of their value-chain emissions.
- They face significant and rising pressure from regulators and customers to decarbonise supply chains.
- Low-CO_2 steel will be a market differentiator in the next decade and it is hard to stand out with incremental CO_2 reductions.
- The premium for low-CO_2 steel is a small share of the total product cost.
- Buyers are sufficiently large to effect change in supply chains.

Corporates will need to be proactive if they want to access the first (likely scarce) volumes of low-CO_2 primary steel, seize early commercial opportunities in premium green markets, and provide differentiation amidst markets characterised by tight operating margins. Acting early will also allow companies to adapt to changing policies, such as anticipated regulations on lifecycle CO_2 emissions, and to market forces, such as rising carbon prices. They will need to engage 'upstream' in a way that is new to many steel buyers, but the potential pay-off is significant. Early movers already include Volvo's partnerships with SSAB, BMW and BHP Ventures' investments in Boston Metal, and Scania, Daimler and Kingspan's partnerships with H2 Green Steel (H2GS). Further examples can be found as more than ten corporates in the construction and renewable energy sectors such as Landsec, Multiplex and Ørsted, have signed up to the Climate Group's SteelZero initiative thereby pledging to secure 100% net-zero steel by 2050 at the latest.

Providing low-CO_2 primary steel to satisfy the demand of early mover corporates will require breakthrough production technologies to be brought to market. This paper explores the types of action required to catalyse investment in these breakthrough technology pathways. This paper shows how demand signals from steel buyers can help unlock these investments for low-CO_2 steel. It explores how such demand signals could be structured while meeting the commercial imperatives of sellers and buyers. It is based on interviews and workshops with more than 50 steel manufacturers, steel users, regulators and finance providers, and extensive analytical work on low-carbon technologies and value-chain dynamics. It provides options to help steel producers and buyers to design green demand signals and quantitatively describes the advantages and disadvantages of each.

The good news is that, compared to just four years ago, these breakthrough technologies have been validated. Nearly all major producers, as well as several new entrants such as Boston Metal and H2GS, are developing low-CO_2 production technologies at an increasing pace.

By 2030, if the right conditions are in place, current corporate announcements suggest 20 Mt of low-CO_2 steel could be available to the market – equal to approximately two-thirds of the steel used by the EU automotive sector. The recently released IEA's 'Net Zero by 2050' global roadmap to net-zero[i] includes the ambitious target volume of 180 Mt of low-CO_2 by 2030 requiring urgent action from all stakeholders.

These volumes will only be realised by 2030 if investment, supported by the business case illustrated in this report, takes place in the next five years. Today, the higher cost of low-CO_2 production, the so-called green premium, is the primary reason holding back the development and deployment of low-CO_2 steel technology. With no adequate package of policies (e.g., contracts for differences) yet in sight, steel manufacturers need an understanding that the green premium will be covered in part (or fully) to underpin investment in low-CO_2 steel production routes; otherwise, producers may delay vital investment decisions. Such a delay would make corporate emissions targets harder to reach and present a headwind to both steel manufacturers and buyers.

Defining 'low-CO_2' steel will also provide clarity to the supply chain, and accelerate the transition to a lower-carbon steel sector. Several steel producers are gradually transitioning to a portfolio of lower-carbon assets while exploring breakthrough production technologies that could enable production at near-zero emissions. Many of the proposed low-CO_2 steel production projects can achieve a footprint of close to 0.1 tonne of CO_2 per tonne of steel – a reduction of 95%. For buyers, few other Scope 3 emissions reductions will offer the combination deep emissions abatement potential, expected time-to-market and marketable value. An ambitious definition of low-CO_2 steel, pushing the footprint close to zero emissions will provide a product that can be clearly communicated to end customers and gives the suppliers clarity on a market for low-CO_2 steel.

How to unlock the opportunity:

- **Provide certainty of future demand:** From the demand side, buyers' commitments that are firm and precise (on volume, specifications and price) will do most to unlock investment. A short-term purchasing model is unlikely to sufficiently de-risk investments by producers in low-CO_2 steel assets; procurement models will need to adapt tenors to provide longer-term certainty. Ideally, offtake agreements would match the tenor of associated debt financing.
- **Cover an initial green premium:** First-of-a-kind investments in breakthrough steel production will cost 15-40% more per tonne of steel, depending on the technology employed and local market circumstances. While suppliers should carry some price risk, buyers will have to pay more if investments are to be viable.
- **Matching supply and demand in specifications and location:** Low-CO_2 steel supply and demand must match, not only in terms of aggregate volumes but also in terms of geography and steel grades, in order for the new trade flows to increase smoothly.

There are multiple ways to design, structure and deliver demand signals in order to underpin and bring-forward low-CO_2 steel investment. They range from direct offtake agreements to broader public commitments to procure specific volumes of low-CO_2 steel. They can be broadly grouped into three forms, although they are not mutually exclusive and steel buyers may find that the most suitable strategy evolves over time.

- **Direct demand signals** include bilateral offtake agreements, which define the terms of the transaction many years into the future. They can be complemented by co-investment, which enables producer and buyer to share risks and rewards. Direct demand signals are relevant for buyers that directly procure large amounts of steel, such as major automotive OEMs, renewable energy OEMs, and large industrial manufacturers. Precise and defined, direct offtake agreements are likely to be the most impactful way to catalyse the necessary investment in breakthrough technologies.
- **Future purchase commitments** are commitments to purchase low-CO_2 steel, ideally with specificity on timing and volume, but which are not directed to a specific producer. Such forward commitments can be deployed by companies who procure steel directly but face significant uncertainty in precise the location and volume of their demand, such as construction companies. To maximize the potential impact at scale, these commitments should be aggregated, possibly via a buyers' campaign like SteelZero.

i International Energy Agency (2020), Net-zero by 2050

- **Indirect demand signals** are a commitment to decarbonize supply chains. These much broader signals can be sent by a wider pool of organisations, including investors and funds and end-user markets. Such a signal does not provide certainty of offtake to a steelmaker and is insufficient to underpin a business case for investment. If significant volumes of aggregated demand can be demonstrated, it could give steel producers and their financiers sufficient confidence in the scale of future addressable markets in order to unlock and bring forward the investment.

These challenges present a significant business opportunity and the next five years will be critical for investment. Long steel project lead times, mounting regulatory interest in and pressure on supply chain emissions and shifting consumer preferences mean that the time to act is now. The opportunity is clear and practical options are available for setting up demand signals. It would benefit steel manufacturers, buyers and regulators to engage even more ambitiously to move the steel industry across the low-carbon tipping point and realise the commercial and environmental opportunities.

- **Steel buyers**
  - For large, direct steel buyers: Build systematic understanding of the options and costs related to Scope 3 emissions abatement options, and engage in using significant predictable demand to unlock upstream investments and accelerating the transition to net-zero.
  - For steel buyers not engaged in direct bilateral negotiations: Engage in the buyers' club initiatives that will be set up for low-CO_2 steel (e.g., SteelZero), and commit to as large volumes as possible.

- **Steel producers**
  - Engage with high-volume customers in order to establish the necessary supply chain collaborations. This is a new, complex and more strategic type of customer relationship than for conventional steel transactions and will likely require senior engagement to get right.

  - Define the specifications in conjunction with consumers required to underpin investment in breakthrough low-CO_2 steel, and work with steel buyers and regulators to establish and adopt a common and workable definition of 'low-CO_2' steel.

- **Policymakers and public organisations**
  - Continue to provide a supportive R&D environment to foster innovation and technology cost reduction in the steel sector.
  - Use public procurement to incubate early markets for low-CO_2 steel between 2025 and 2030. For example, the public sector is typically a very large buyer of construction steels.
  - Lower the risk for first-mover investments into low-CO_2 steel. Investments will carry considerable risks that come with making early commitments and will be challenging to negotiate. Policy can help by assuming a portion of that risk through a combination of financial products and policy such as carbon contracts for differences (CCfDs) to reduce the uncertainty associated with the future price of carbon.
  - Set lifecycle emissions standards for key steel-using products, to drive the necessary technology deployment and uptake.

- **Steel end-consumers**
  - Advocate and opt, where possible, for products containing low-CO_2 steel over comparable products, and demand greater transparency on lifecycle and embodied emissions in consumer products.

Background: Steel industry transition

The steel industry has long been a pillar of economic growth and urbanisation. Steel is an essential component for many sectors, including construction, energy, automotive, machinery and white goods. Steel contributes 0.7% of world GDP and employs 6 million people worldwide, 2 million directly within steel mills.[ii] **However, the production of one tonne of crude steel currently emits on average 1.4 tonnes of CO_2. The industry accounts for close to 2.6 Gt of emissions which represents 7% of total global emissions from the energy and industry system.[iii]**

Meanwhile, global steel demand is forecast to grow to 2.5 billion tonnes per annum by 2050 from current production levels of 1.8 billion tonnes.[iv] It is anticipated that secondary (scrap-based) production will satisfy an increasing portion of this demand as a result of improvements in the recovery and recycling of end-of-life material. However, even in a more circular economy, over one billion tonnes per annum of primary steel (using iron ore feedstock as opposed to scrap) will be needed globally by 2050.[v] Under a business-as-usual scenario, the increase in demand would result in 2.8 billion tonnes annual CO_2 emissions from the steel sector in 2050. This figure greatly exceeds the remaining carbon budget for the steel industry envisioned by the IEA's beyond 2°C scenario,[vi] and the more stringent net-zero emissions target advocated by an increasing cohort of observers and countries. Material efficiency and efficiency improvements are important to keep down emissions, but new technologies are indispensable to keep within carbon budgets and eventually reach net-zero emissions (Exhibit 1).

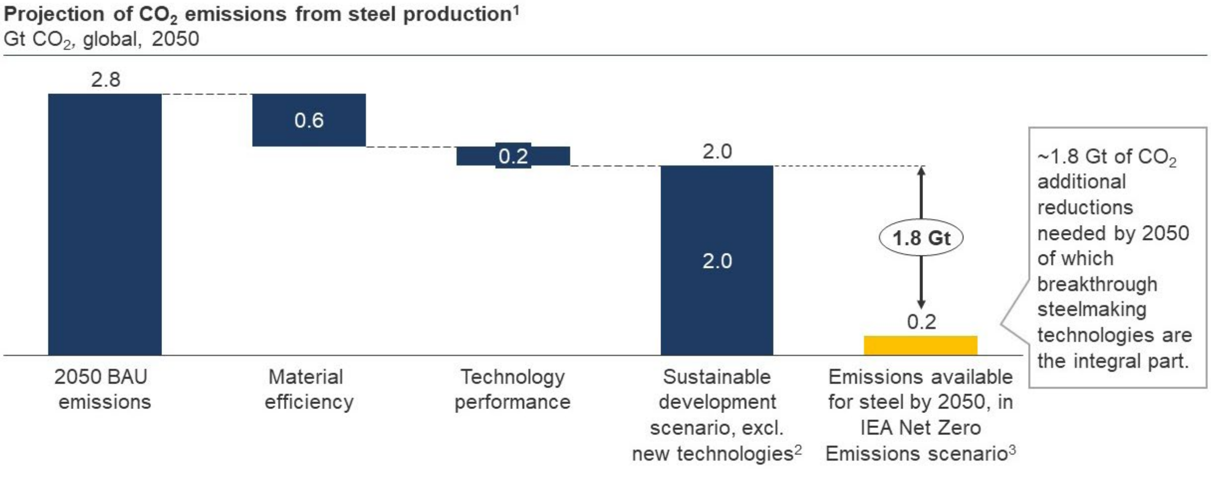


Exhibit 1: The steel industry will need new technologies to reach ambitious climate targets.

Source: 1: IEA (2020) Iron and Steel Technology Roadmap; 2: IEA (2017) Energy Technology Perspectives; 3: IEA (2021) Net-zero by 2050: A Roadmap for the Global Energy Sector.

ii World Steel Association (2021) World Steel Association. Available at: www.worldsteel.org (accessed May 2021)
iii International Energy Agency (2020) Iron and Steel Technology Roadmap
iv World Steel Association (2020) 2020 World Steel in Figures
v Material Economics (2018) The Circular Economy – A Powerful Force for Climate Mitigation
vi In the IEA scenarios, the Stated Policies Scenario is constructed by projecting forward current trajectory, shaped by existing and announced policies. The Sustainable Development Scenario assumes a more sustainable future for the steel industry, in which global absolute direct emissions fall by 54% between 2019 and 2050, while production levels moderately rise. In the Below 2°C Scenario, the energy sector reaches carbon neutrality by 2060 to limit future temperature increases to 1.75°C by 2100, the mid-point of the Paris Agreement's ambition range.

It is therefore critical that low-and eventually zero-carbon technologies are developed and deployed for primary steel production. Such technologies are technically feasible and have already been tested, but they are still far from commercialisation. It normally takes at least five years to bring new technology from laboratory testing to first-of-a-kind scale operations. Given this timescale and the long lifetimes of assets in the steel industry, breakthrough technologies for primary steel production with near-zero CO_2 emissions must be brought to commercial scale by 2030 at the latest to enable fast deployment across the world in the 2030s and 2040s. This paper focuses on how to address this challenge by mobilising steel buyers alongside steel manufacturers.

The development and deployment of low-CO_2 primary steel production technologies is currently hindered by the associated "green premium" (+15-40% cost increase after typical downstream processing). This premium results from increased capital and operational expenditures but it is expected to decrease with commercialisation, as greater volumes of production drive economies of scale and learning curve effects. At this stage, however, without favourable policies or a verified differentiated premium green market, this premium makes it hard to see the route to market for low-CO_2 steel. In that context, it is difficult for steel manufacturers to develop a compelling business case to invest in low-CO_2 steel production technologies. Although policies intending to accelerate industry decarbonisation are now being deployed in regions such as Europe and the United States, including through COVID-19 recovery plans, they are unlikely in of themselves to be sufficient to unlock early investment in the 2020s.

If that obstacle is not overcome in the 2020s, the commercial availability of low-CO_2 steel and its potential to drive CO_2 emissions reduction will be significantly delayed. This inertia would be detrimental for both steel manufacturers and steel buyers, who are under growing pressure to decarbonise. In sectors that use significant volumes of steel such as automotive and construction, addressing the carbon footprint of purchased steel will be central in corporate decarbonisation strategies, especially as companies are encouraged to address their supply chain emissions (i.e., Scope 3 emissions). A delayed deployment of low-CO_2 primary steel production routes would likely impose a more disruptive and higher-cost decarbonisation in the 2030s and 2040s for the steel industry to reach net-zero emissions by mid-century (including risks of stranded assets). These higher costs would in turn impact all steel-using value chains.

This paper aims to demonstrate that demand signals from steel buyers to steel manufacturers can and should help unlock investment decisions and secure the next generation of breakthrough technologies needed for primary steel to become truly net-zero emissions. It provides guidance to critical stakeholders on how to seize the associated commercial opportunity. We first outline the commercial opportunity for steel buyers in being early movers and actively participating in the commercialisation of low-CO_2 primary steel production technologies. This paper then describes different ways in which value-chain collaboration could be implemented to unlock those investments.

Chapter 1

Commercial opportunity for early movers in low-CO_2 steel

Sectors that consume significant amounts of raw materials are under increasing pressure from external stakeholders – chiefly policymakers, finance players, and consumers – to deeply decarbonise their supply chains. Corporates in those sectors will need to purchase lower-carbon and eventually zero-carbon materials. Steel will be among the key material inputs under scrutiny.

i. Pressure on supply chain emissions is increasing in major steel-using sectors

Steel is considered a critical material input in a broad range of engineering and construction applications due to its mechanical properties – strength, stiffness, toughness – and affordability. The construction and automotive sectors alone account for more than 60% of steel demand globally (52% and 12% respectively),[vii] followed by the machinery, metalware and energy sectors. The breakdown of demand in the European Union and the United States is shown in Exhibit 2.

The pressure to decarbonise is increasing in key steel-consuming sectors due to combinations of:

- **Growing policy incentives to decarbonise** (including via carbon prices, other forms of climate regulations, and dedicated financial support), and anticipation from the private sector that a growing number of jurisdictions will impose such policies and that carbon-related regulations will only tighten in future;

- **Increasing scrutiny from the financial sector**, with a growing number of equity players and

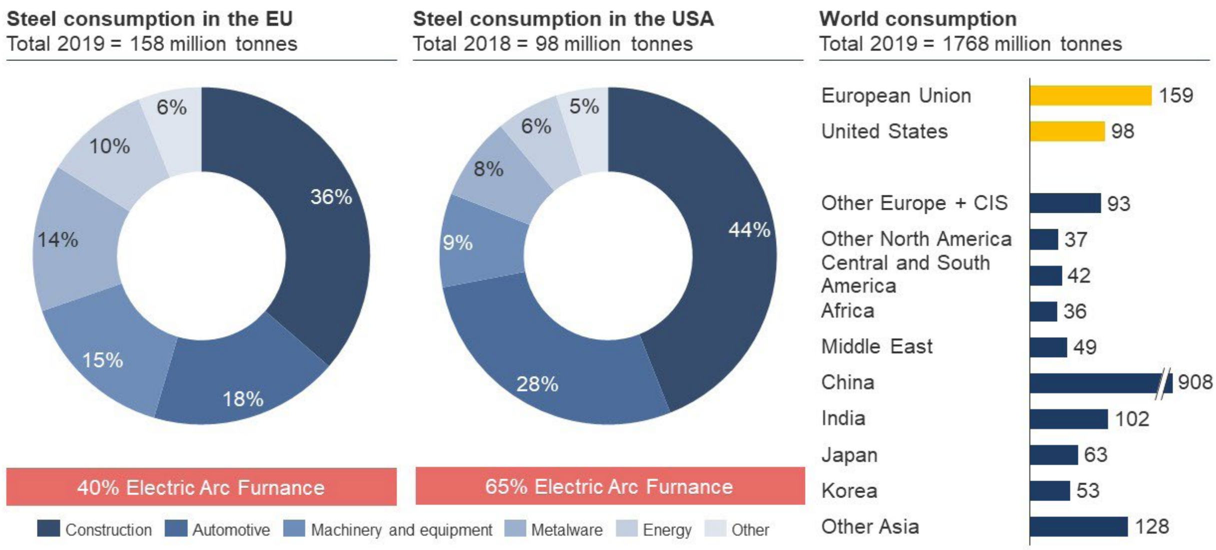


Exhibit 2: Steel consumption in the EU and the USA by sector and share of those regions in world demand.

Sources: EUROFER (2020) European Steel in Figures; AISI (2020) Profile 2019-2020; IEA (2020) Iron and Steel Technology roadmap; World Steel Association (2020) World Steel in figures.

vii World Steel Association (2020) World Steel in Figures lenders committing to climate-aligned portfolios and adding carbon-related criteria in their investment decision frameworks;

- **Changes in consumer behaviour**, driven by increasing awareness of climate and environmental impacts of consumption, leading to the development of new markets differentiated by climate and other environmental credentials.

Growing attention is being paid to lifecycle emissions, including supply chain emissions. Use-phase related emissions (e.g., fuel consumption in vehicles or heating in buildings) have long dominated total emissions from a lifecycle perspective and have been the main focus of decarbonisation efforts to date. But, as those emissions are reduced due to the decarbonisation of the electricity sector, the clean electrification of transport and building applications, and improved energy efficiency, supply-chain related emissions, in particular emissions from materials production, represent an increasing share of lifecycle emissions. Looking at passenger cars as an example: today, use-phase emissions from fuel consumption represent around 80% of total lifecycle emissions of an internal combustion engine vehicle; whereas use-phase emissions for a battery-electric vehicle in 2030 will represent less than 50% of lifecycle emissions.[viii] Due to this development, regulators, which have historically put strict demands on automotive producers to reduce tail-pipe emissions, are now increasingly considering lifecycle and embodied emissions in upcoming policies.[ix]

As a result, many companies are setting ambitious targets to reduce their lifecycle CO_2 emissions, including emissions upstream in their supply chain (Exhibit 3). For example, in the automotive industry, both Toyota and Volkswagen are aiming to be carbon neutral by 2050, Daimler and Jaguar Land Rover aim to reach neutrality by 2039 and General Motors by 2040. Volkswagen has an interim goal to reduce lifecycle CO_2 emissions by 30% by 2025, compared to 2015. In construction, Lendlease has set out to be 'absolute zero carbon' already by 2040. In white goods, Electrolux is aiming to be carbon neutral by 2050. Beyond those few examples, more than 1000 companies have now set or committed to set a Science-Based Target, with the number of new commitments growing every year.

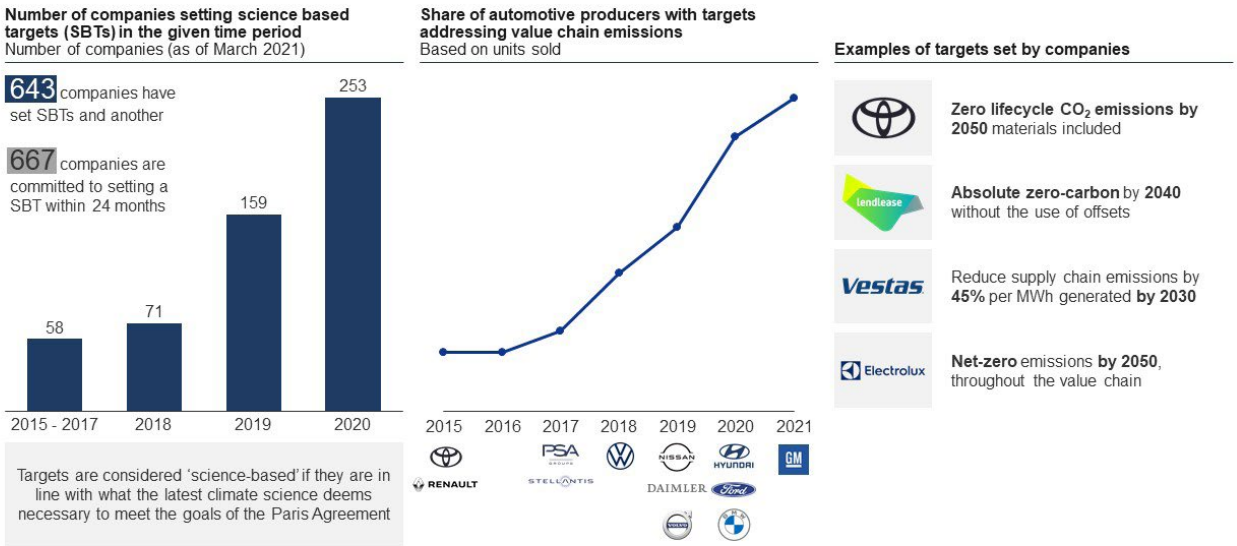


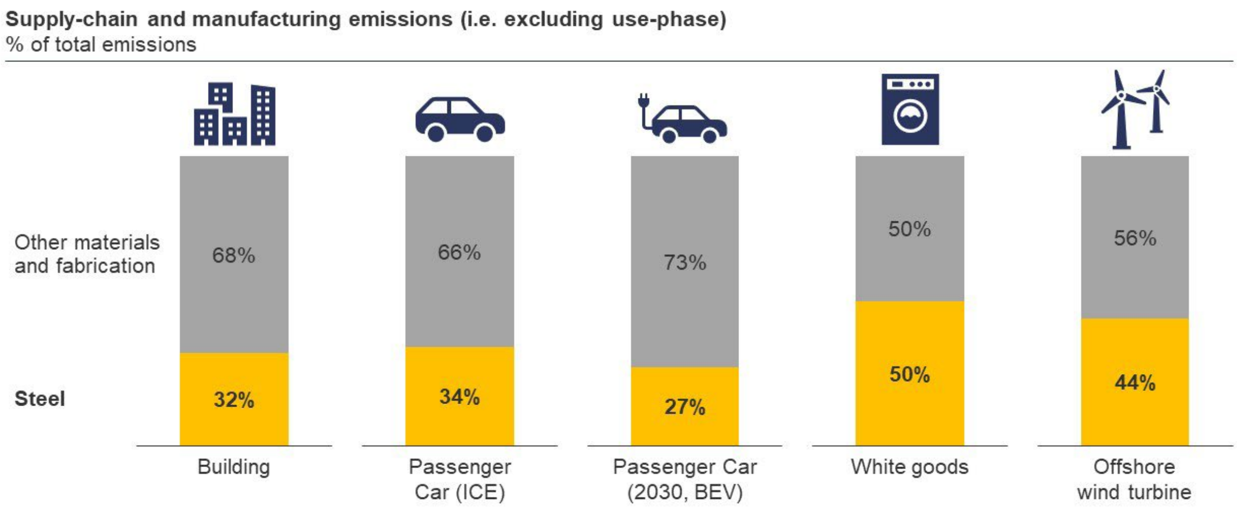
Exhibit 3: The number of companies setting ambitious climate targets is steadily on the rise.

Source: International Organization of Motor Vehicle Manufacturers (2017) Correspondents Survey World Ranking of Manufacturers; Science Based Targets (2021) Companies Taking Action. Available at: https://sciencebasedtargets.org (Accessed March 2021); company annual reports and public announcements.

viii Material Economics & Energy Transitions Commission's analysis based on Ricardo (2020) Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA; WEF(2020) Raising Ambitions: A new roadmap for the automotive circular economy; IEA (2020) World Energy Outlook 2020

ix Embodied emissions are greenhouse gas emissions that have occurred earlier in a value chain. For example, the emissions that occurred when producing the steel that goes into a white goods product are called embodied (and sometimes embedded) emissions of the product. Embodied emissions contribute, alongside use-phase emissions, to the lifecycle emissions of the product.

For key steel-using sectors, this increasing pressure to decarbonise supply chains will rapidly necessitate addressing emissions from steel production, as steel generally represents a significant percentage of their supply chain and manufacturing emissions. For example, steel represents about one-third of supply chain and manufacturing emissions for buildings and cars and close to half those of renewable energy equipment and white goods (Exhibit 4).



Note: **Passenger cars:** ICE = Internal Combustion Engine; BEV = Battery Electric Vehicle. Use phase included upstream emissions based on EU average emission factor for electricity, assuming a reduction of 40-50%.

Exhibit 4: Steel represents a major share of materials and manufacturing emissions in several key products.

Source: Material Economics & Energy Transitions Commission's analysis based on multiple sources.[x]

ii. A few sectors are more likely to be early champions for low-CO_2 steel

Certain demand sectors are likely to be better positioned to act as early champions for green steel and are already showing the way. These sectors will be under greater pressure to decarbonise, usually purchase high volumes of steel (making them both more incentivised to address steel emissions and more influential on the steel market), and be able to pass through the cost of low-CO_2 steel to end consumers. They would also ideally operate in a relatively concentrated market and purchase steel directly from producers (to limit the number of decision-makers involved and the complexity of engaging them in demand creation). Within each sector, there will likely be specific use-cases that are better suited as first applications of low-CO_2 steel, and better matching the criteria outlined above.

We have identified four sectors with strong incentives to adopt low-CO_2 steel which best meet the criteria above. The sectors with the greatest potential have a combination of volume, concentration and pressure to decarbonise – see Exhibit 5 and can help shape future steel markets:

- The **automotive** sector accounts for 55 million tonnes of consumption of steel in the EU and USA.[xi] In the electric vehicle segment alone, which is the application with the strongest incentive to decarbonise steel due to the importance of green credentials, demand is forecast at 8 million tonnes by 2030.[xii] Original Equipment Manufacturers (OEMs) purchase a

x Material Economics & Energy Transitions Commission's analysis based on Ricardo (2020) Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA; WEF(2020) Raising Ambitions: A new roadmap for the automotive circular economy; IEA (2020) World Energy Outlook 2020; IRENA (2019) Measuring the socio-economic footprint of the energy transition: the role of supply chains; Siemens Gamesa (n.d.) Environmental Product Declaration SG 8.0-167 DD; World Green Building Council (2019) Bringing Embodied Carbon Upfront, Reale et al (2020) Environmental impacts of household appliances in Europe and scenarios for their impact reduction.

xi EUROFER (2020) European Steel in Figures; AISI (2020) Profile 2019-2020

xii Material Economics & Energy Transitions Commission's analysis considering 7 million BEV passenger car units sold in the US+EU in 2030. Based on BloombergNEF (2020) Electric Vehicle Outlook and Ricardo (2020) Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA variety of steel types, and usually deal directly with steel manufacturers.

- The **construction** sector accounts for 100 million tonnes in the EU and USA.[xiii] It consumes the largest volume of steel, although a large share is secondary steel (70% in the mature markets of EU and USA)[xiv] and the value chain is relatively fragmented.

- The anticipated growth of the **renewable energy** market means that, by 2030, this sector is forecast to consume 5 million tonnes of steel in the EU and USA.[xv] Most steel used in manufacturing solar panels and wind turbines is produced via the primary route.

- **White goods** represent 7 million tonnes of steel consumption in the EU and USA.[xvi] The sector is highly regulated to address environmental issues. It generally purchases directly from producers.

Sectors identified as most promising | Most favourable conditions | Intermediate favourable | Challenging conditions

	Potential volume	Market concentration	Pressure to decarbonise
Construction	High	Highly fragmented market(s)	Advanced economy and city-level pressures growing
Mechanical engineering	Moderate due to fragmented end-uses	Sector dependent but typically concentrated	Low, with limited policy and end-user scrutiny
Automotive	High	High amongst leading OEMs and component makers	High and growing as LCA becomes more important with EVs
Other transport	Moderate due to fragmented end-uses	Sector dependent but typically concentrated	Typically lower than automotive
Oil & Gas	Potentially high but dependent on wider energy market	Concentrated buyer community	Decarbonizing materials in supply chain is low priority
Renewable energy	Probably fastest-growing market in next decade	Fairly concentrated manufacturing	Perceived as clean sector, but LCA increasingly scrutinised
Domestic appliances	Moderate due to large number of end-use products	Diffuse market but existing precedents for standards	Growing in consumer-exposed sectors
Metal products	Limited	Diffuse market	Growing in consumer-exposed sectors
Defence	Middling but concentrated	Concentrated buyer community	Low awareness; potential for procurement standards
Misc	Low and diffuse	Low and highly diffuse	Diffuse and not coordinated

Exhibit 5: The markets with the greatest potential have a combination of volume, concentration and pressure to decarbonise.

iii. The automotive sector will be a leading sector for low-CO_2 steel demand

The automotive sector is undergoing a profound transformation driven by three major trends. First, consumer sentiment has shifted in favour of electric mobility, low-emissions manufacturing, and sustainable materials. Secondly, more than half of all global emissions are now covered by some form of 'net-zero' target. Third, the financial industry is growing increasingly sophisticated in its approach to scrutinising the degree of climate alignment of corporate strategies. Automotive OEMs that can adapt to these trends will open strategic opportunities. Purchasing low-CO_2 materials and steel, in particular, could be a differentiating factor.

The automotive sector is decarbonising rapidly. Automotive OEMs representing 56% of global annual vehicle production have set long-term (2040-50) climate neutrality targets spanning Scope 1, 2 and 3 emissions. Major OEMs including Daimler, GM, JLR, Volvo and Volkswagen are setting bold commitments to transition towards mass electrification of vehicle portfolios. Large-scale electrification, however, will be insufficient to achieve full decarbonisation of vehicles.

xiii EUROFER (2020) European Steel in Figures; AISI (2020) Profile 2019-2020
xiv Material Economics & Energy Transitions Commission's analysis based on: Muiris C. Moynihan, Julian M. Allwood (2012) The flow of steel into the construction sector and Cullen et al (2012) Sustainable Materials with Both Eyes Open
xv Material Economics & Energy Transitions Commission's analysis based on: IRENA (2020) Power generation costs; Siemens Gamesa (n.d.), Environmental Product Declaration SG 8.0-167 DD
xvi EUROFER (2020) European Steel in Figures; AISI (2020) Profile 2019-2020

As tailpipe emissions trend to zero with increasing penetration of battery electric vehicles (BEVs), emissions from vehicle materials are set to increase in both absolute and relative terms. Already, 30-50% of a vehicle's overall material emissions comes from steel and batteries, but advances in decarbonised battery materials and battery production mean relative emissions from automotive steel will rise. By 2030, steel will represent 15% of automotive emissions, making it the next frontier in the industry's efforts to reduce its carbon footprint.

The shift towards platform-based BEV architectures also means that OEM differentiation of electric drivetrain or battery will be increasingly hard to achieve (relative to engine horsepower, torque, and drive dynamics). Unlike batteries, where a select number of vendors possess central roles in the battery cell and pack supply, the automotive steel supply chain is fragmented. This means that low-CO_2 steel presents a rare opportunity for genuine brand differentiation from peers, but the window of opportunity will be limited and gradually eroded as its production becomes widespread in the 2030s.

Additionally, as vehicle tailpipe emissions fall, regulators will look for new approaches to address vehicle emissions. By 2023, for example, the European Commission intends to assess the feasibility of harmonised and consistent reporting of full vehicle life cycle emissions, which can then be tied to targets that will be tightened over time. As with tailpipe standards, a high degree of global harmonisation of regulations should be anticipated. Such regulation will necessitate detailed understanding by OEMs of materials decarbonisation options, costs, and relative timelines of availability, presenting a new set of priorities for sourcing strategic materials.

Those who invest early will be best placed to capture opportunities for meaningful differentiation on environmental performance and to meet emissions targets, both voluntary and regulated. They will also gain access to valuable materials IP and early specification (e.g., Verband der Automobilindustrie) approvals, the opportunity to pre-empt and avoid complex late-stage changes in sourcing strategies, and the option to lock in supply of the first volumes of CO_2-free steel. Scania, for example, has stated the investment in H2 Green Steel provides "good opportunities to, among other things, secure future deliveries".[xvii]

iv. The construction sector could require large volumes of low-CO_2 steel

Most attention in the construction sector has been on use-phase emissions and much has been achieved in new builds – a European building of the 21st century consumes less than half of the energy of a 1970s building of an equivalent area and function. But as use-phase emissions reduce, awareness of emissions from construction and materials inputs increases. Addressing those emissions will soon be a necessary part of marketing buildings or infrastructure as "green".

The premium associated with green buildings is well documented. According to Dodge Data and Analytics, most developers value the premium in asset valuation over 5% compared to similar buildings and empirical studies confirm those values.[xviii] Although this premium partly reflects lower running costs associated with better use-phase performance, it also arises from improved habitability and from the "virtue signalling" quality of a "green building", especially from corporates and the public sector. As use-phase emissions decrease, this premium is expected to shift to low-embodied carbon buildings.

Developers and contractors are increasingly committing to reduce their carbon footprint. Bouygues, Skanska and, Laing O'Rourke are among the companies setting Scope 3 targets (related to the supply chain and use of products). Private customers are requiring lower embodied carbon in their buildings – Microsoft's new headquarters aims for 30% less, Atlassian's new headquarters are designed to save 50%. The public sector – which represents up to 20% of the construction market in the US – is also increasingly integrating embodied carbon criteria in public buildings and infrastructure projects.

An expansion of building standards to embodied emissions is also being considered in several regions. Some European countries are already embedding lifecycle assessment and embodied carbon in their regulations. In 2018 the Netherlands put a cap on embodied emissions in buildings.

xvii Volkswagen (2021) Fossil-free steel a giant step in Scania's decarbonisation. Available at: https://www.volkswagenag.com/en/news/2021/03/scania_fossil_free_steel.html (Accessed May 2021)
xviii Dodge Data & Analytics (2018) World Green Building Trends 2018

Finland is developing similar regulation to be in place before 2025 and France is setting up a pilot with the same goals. The European Commission has a framework in place, establishing common language on sustainability and life-cycle assessment for the built environment.

Building materials are some of the largest sources of global emissions: both steel and cement each account for 7% of emissions– of which half of the steel emissions can be attributed to buildings and construction.[xix] Reducing material usage through re-use of components and structures, more material-efficient design, and lower construction waste is likely to be the most cost-effective option to reduce embodied carbon in the first instance. However, to significantly reduce embodied emissions, the construction sector will have to shift to lower – and eventually – carbon-free materials.

The sector has long been a large market for secondary (scrap-based) steel – for example, in the form of rebar, which has lower emissions than primary (ore-based) production. Scrap-based steel has three advantages: it does not require extraction of new raw material (a carbon-intensive activity), its production has much lower energy requirements, and it is produced using electricity, which can be decarbonised without reinvestment in the steel production facilities.

But some construction applications – steel sheets in composite slabs, roof purlins, plates structures – require more primary (ore-based) steel. To develop projects with close to zero embodied emissions, the construction sector will need to access carbon-free primary steel meeting the technical specifications required for those components.

xix World Green Building Council (2019) Bringing Embodied Carbon Upfront

Chapter 2

Time for value-chain collaboration on low-CO_2 steel

The automotive, construction, renewable energy and white goods sectors are all likely to present early demand for low-CO_2 primary steel. However, corporates face a significant challenge: to cut supply-chain emissions deeply, they will need low-CO_2 steel products that are not currently on the market due to their low technology readiness. Therefore, steel buyers have a real commercial interest in ensuring that low-CO_2 primary steel becomes a reality as soon as possible.

i. A breakthrough around the corner – truly low-CO_2 steel at scale is within reach by 2030

Providing low-CO_2 primary steel to early demand sectors will require breakthrough production technologies to be brought to market. Other solutions offer incremental improvements of emissions in primary steel production – for example, retrofitting carbon capture and storage (CCS) on existing blast furnaces, or replacing a share of the fossil-fuel input with bio-based products. These can represent useful steps to reduce CO_2 emissions from steel production in the short term and increase the chances of not exceeding the carbon budget available by 2050 to keep temperature rise below 2°C and as close as possible to 1.5°C. However, they will not provide a way to near-zero CO_2 emissions. If the steel sector is to access truly low-CO_2 (and eventually carbon-free) primary steel by 2030, targeted efforts are required to bring breakthrough technology to market (Box 1, Exhibits 6 & 7).

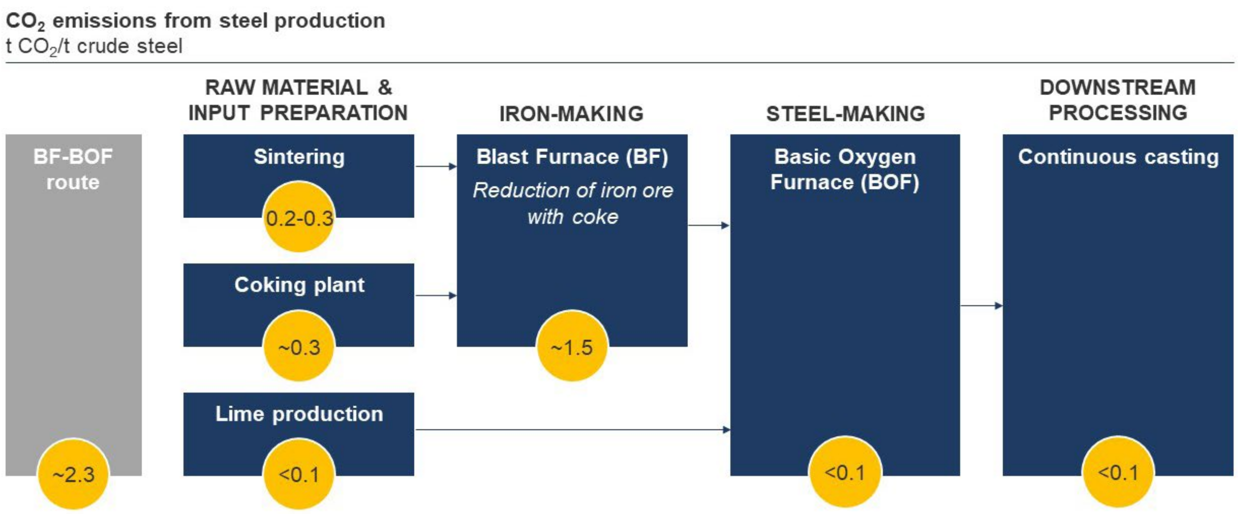


Exhibit 6: CO_2 emissions from conventional primary steel production, tonnes CO_2 per tonne of steel.[xx]

Source: Material Economics & Energy Transitions Commission's analysis based on multiple sources.

xx Material Economics & Energy Transitions Commission's analysis based on: Smil (2016) Still the Iron Age

Box 1 – An overview of steel-making technologies

Steel production today

Crude steel is produced mainly through two different routes. The 'integrated route', uses a blast furnace and then a basic oxygen furnace (BF-BOF) to produce iron and then steel from iron ore and coal, is the main route for primary steel production.[xxi] The other main production route uses electric arc furnaces (EAF) to melt scrap steel into secondary crude steel. In Europe, 59% of production is through the BF-BOF and the remaining 41% from EAF. The corresponding numbers for the U.S. are 32% and 68% . In addition to the coal-based BF-BOF route, iron ore can also be reduced using natural gas through Direct Reduced Iron (DRI), which in turn can be further processed into primary steel in an EAF. In this process, the iron ore is reduced in solid-state (rather than in a blast furnace), which together with the use of natural gas instead of coal makes it less emissions-intensive than the BF-BOF route.

Crude steel from these routes is formed into slabs. These are further processed downstream at the steel plant through hot rolling, cold rolling and coating processes. Steel products finally sold on the market are mainly flat products (e.g. plate, coil) and long products (e.g. tubes, rebar).

Low-CO_2 steelmaking technologies

H2-DRI route
Swapping hydrogen for natural gas in the DRI route, coupled with an EAF powered with renewable energy sources can push down the CO_2 emissions per ton steel to nearly zero. This is referred to as 'Hydrogen Direct Reduced Iron' (H-DRI). Reducing iron ore with hydrogen is technically feasible. Even in a natural gas-based DRI process, some 50% of the reduction of iron is done by the hydrogen contained in the natural gas, with the remainder done by carbon, which then creates CO_2. However, there has never been a commercial reason to increase the share of hydrogen. Further development is required to bring this option to industrial scale. The hydrogen production must itself be CO_2-free, either by capturing the CO_2 and reducing considerable methane leakages in the natural gas value chain from production or by using zero-emissions electricity. To achieve near-zero emissions, the EAF process must also be made largely fossil-free. If hydrogen is produced from water via electrolysis, 3-4 MWh of zero-carbon electricity is needed per tonne of crude steel produced (including electricity for EAF).

This route is also well suited to the use of steel scrap as part of the iron input, as the sponge iron from the DRI-process can be mixed with steel scrap and melted in the EAF together. This allows the production of primary steel with a higher share of scrap input compared to the BF-BOF route (from ~20% up to ~50/60%).

Electrolysis route
As opposed to carbon-based reducing agents used in traditional steelmaking, the electrolysis route involves using electrons as the reducing agent; pure oxygen is the only flue gas produced. Electrolysis is a mature processing route used today for certain metals such as aluminium and lithium. However, the electrolysis of iron ore has not yet been commercialised due to large energy requirements and complications with developing suitable anode and cathode materials capable of withstanding the extreme process conditions (temperatures of over 1500°C). Two types of electrolysis routes being investigated:

1. Electrowinning (EW) – iron ore grains are suspended in an alkaline sodium hydroxide solution at a temperature of 110°C resulting in a solid iron product.

2. Molten ore electrolysis (MOE) – iron ore is dissolved in a mixed oxide solvent (such as silicon oxide and calcium oxide), at roughly 1600°C resulting in a molten iron product.

As the electrolysis process produces no CO_2, if the electricity powering it is CO_2-free as well,

xxi BloombergNEF (2020) BOF/EAF ratios and primary/secondary supply in crude steel production in major countries and regions, 2018 the whole operation could theoretically become zero-carbon. The energy consumption of the process depends on several factors including cell configuration, the chemistry of the electrolyte, and the process temperature. Engineering problems remain to be solved before electrolysis can be deployed at a commercial scale in iron ore treatment as sintering or pelletizing.

Smelting reduction route with CCS & low-CO_2 inputs
One fossil-based route to near-zero emissions would replace the current blast furnace with smelting reduction, coupled with CCS and a portion of bio-based input. In direct smelting, the coking plant, sinter plant and blast furnace are all dispensed with. Instead, iron ore is injected into a reactor alongside powdered coal. The ore is liquified in a cyclone converter furnace and drips to the bottom, and the coal reduces the ore to iron in a molten state. The molten metal can then be reprocessed to steel in a basic oxygen furnace, as in the standard BF-BOF route.

The rationale for a switch from BF-BOF to smelting reduction has historically been to reduce energy consumption by up to 20%, to replace expensive coke with much cheaper coal, and to find a production route with lower CAPEX intensity. Direct smelting also has features that make it a good match with carbon capture. By replacing several processing steps with a single reactor, it creates a single source of CO_2 for nearly all the emissions from ironmaking. In total, some 90% of emissions could be eliminated through CCS. The fuel flexibility of the process also makes it possible to introduce a share of biomass instead of coal, for a lower-carbon solution.

BF-BOF Route with CCUS & low-CO_2 inputs
The final option for nearly CO_2-free production is to substantially modify the operation of the current blast furnace route, combining it with both carbon capture and utilisation and carbon capture and storage. The idea is to combine the gases produced from the main carbon sources (coke oven, blast furnace, and basic oxygen furnace) with hydrogen to produce syngas for chemicals production (instead of burning them for electricity generation, as is done today). The main advantage of this route would be to find a way to continue using the existing blast furnaces. However, for this to be compatible with net-zero CO_2 emissions, very major additional industrial processes and strict criteria would be required. Specifically:

1. The majority of inputs must be circular or bio-based carbon. Today, the advanced operation of blast furnaces can allow the share of coke to be as low as 50%, with the remainder typically coal or petcoke. Industry experts hypothesise that the share of coke could be reduced to 25%, and the remaining 75% could then consist of end-of-life plastics or biomass as alternatives to (new) fossil carbon.

2. Integration of all main processes. For deep CO_2 cuts, the gases from the coke oven, blast furnace, and basic oxygen furnace must all be diverted for reprocessing to chemicals.

3. Large-scale carbon capture to offset fossil carbon input. The residual CO_2 would have to be permanently stored (not used), in order to offset the fossil carbon used. This could amount to 25% of the total, depending on how much hydrogen is added, but it may need to be more.

4. Outputs restricted to circular products. The chemicals produced would need to be used exclusively for products that themselves are nearly fully recycled. If used for single-use chemicals or fuels, or if plastics were only partially recycled as happens today, emissions would only be postponed briefly until end-of-life plastics were incinerated (almost half of plastic has a lifecycle of just one year).

5. Other inputs must be fossil-free: The processes would rely heavily on hydrogen, which must come from a CO_2-free source.

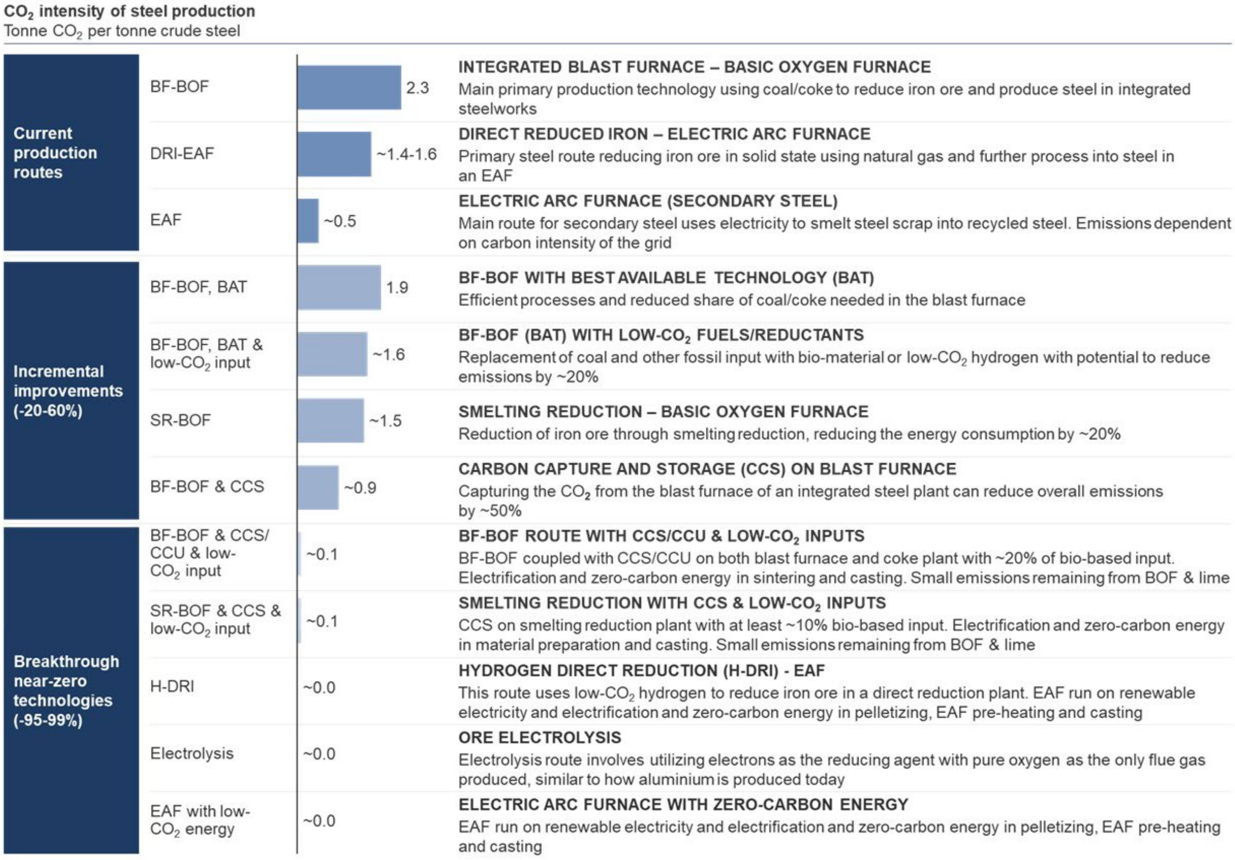


Exhibit 7: Several steel-making technologies can reduce CO_2 emissions, but only a few breakthrough technologies can reach near-zero emissions.

Note: Scope for crude steel according to IEA definition including raw material & input preparation (coking, sintering etc.), iron making, steel making and continuous casting. These numbers are estimates and the exact emission factor could vary for different set-ups.

Source: Material Economics & Energy Transitions Commission's analysis based on multiple sources.[xxii]

Two fundamental technology pathways can reach near-zero-carbon emissions in primary steel production:

i. **Carbon avoidance**, either through direct reduction of iron ore using green hydrogen coupled with an electric arc furnace or via direct electrolysis of iron ore.

ii. **Carbon capture and storage**, for emissions from blast furnaces and other fossil-fuel-based production. This approach cannot achieve emissions close to zero on its own (given that capture levels cannot reach 100%), so needs to be complemented with other technologies. Carbon use can be deployed as a transitional option only, as it does not allow for reach net-zero emissions.

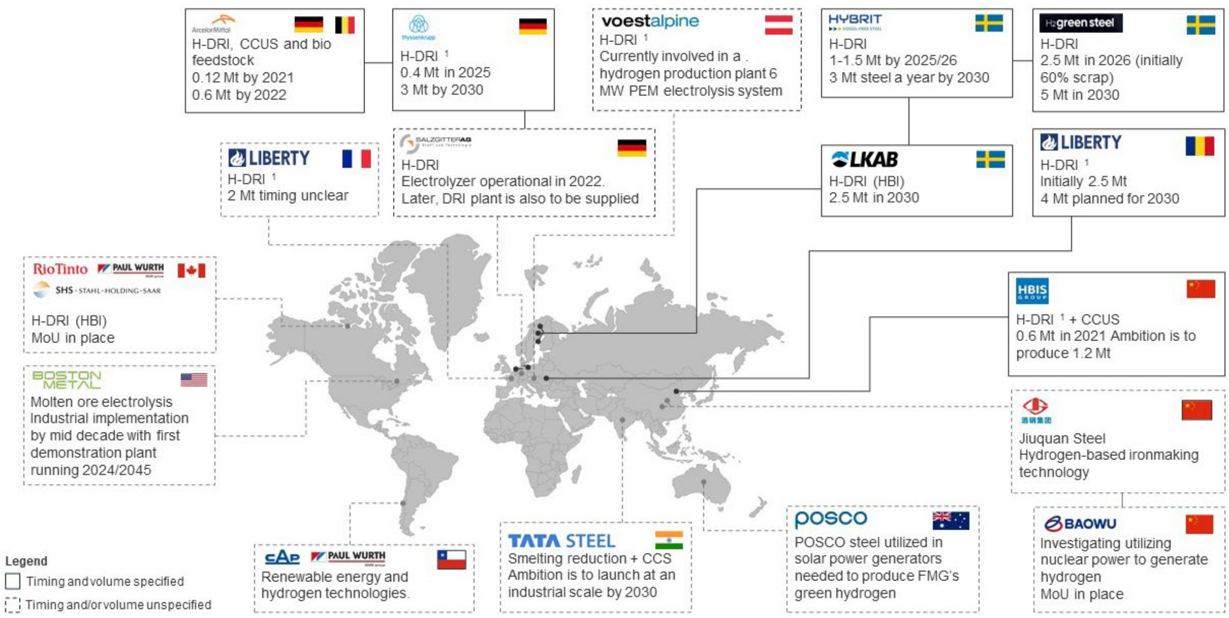
Breakthrough technologies need to be deployed at scale before 2030 to enable both steel manufacturers and buyers to meet their climate targets. Costs and therefore the most cost-efficient production technology among the available options will vary greatly by geography. They will depend on local energy prices and on external factors, such as whether the development of a wider hydrogen economy would drive down hydrogen prices. Geographies with access to cheap, clean electricity

xxii Material Economics & Energy Transitions Commission's analysis based on; IEA (2020) Iron and steel Technology roadmap; Milford et. Al. (2013) The last Blast Furnace; Van der Stel (2013) Development of the ULCOS blast furnace; Thyssenkrupp (2019) Hydrogen instead of coal. Thyssenkrupp Steel launches pioneering project for climate friendly steel production at its Duisburg site; Expert interviews.

are likely to prefer hydrogen-based technologies or electrolysis. CCS could potentially be more cost-effective for steel plants located in geographies with higher costs of renewable electricity, with easy access to carbon sequestration capacity, and where it is beneficial to retrofit an integrated steel plant to leverage existing downstream production capacity. In order to reduce risks of path dependency, these different technologies need to be proven by several companies and preferably in several geographies. This will take time, and the sector does not have a long time to transition due to long asset lifetimes.

The good news is that those technologies are now in sight for the first time. This is a complete change from the perspectives of only 3 or 4 years ago. Both incumbents and new entrants are developing low-CO_2 production technologies at an increasing pace: Planned investments into low-CO_2 primary steel production capacity would see growth from 3.2Mt in 2025 to 8.2Mt in 2026.

As of March 2021, by 2030, around 20 Mt of low-CO_2 steel could be available if the right conditions are put in place equal to 1% of global production, and 8% of EU and USA production combined (Exhibit 8). Most of the more defined plans are from European players (over 90% by announced volume). A large portion of existing primary steel assets come to end of life by 2030 in the region, and a combination of high policy and societal pressure to decarbonise is incentivising manufacturers to consider low-CO_2 options in this investment cycle. Early announcements from other regions show a growing interest in net-zero technologies outside Europe, especially as new countries join the cohort of net-zero commitments. Many announcements focus on the Hydrogen Direct Reduced Iron (H-DRI) route, but other near-zero technologies are being announced. Most projects are driven by incumbents, but new entrants focusing solely on low-CO_2 steel, like Boston Metal or H2 Green Steel, are also starting to appear.



1 If hydrogen is not available in sufficient quantities by production start, then plant will be operated using natural gas
2 Initially mixture of natural gas and hydrogen eventually 100% hydrogen
3 Production initially using natural gas and transitioning to hydrogen, as production technology becomes cost effective
4 70% hydrogen concentration in reduction gas. Hydrogen is to be extracted from the co-products of a natural gas-based process to make vinyl acetate
5 Hydrogen fraction unclear.

Exhibit 8: As of Q1 2021, a range of companies are preparing to make investments in low-CO_2 steel.

Note: Initially utilising only natural gas or a mixture of natural gas and hydrogen as the reducing agent. These commitments include varying degrees of a shift to hydrogen ranging from when hydrogen technology becomes cost-effective to commitments to shift to 100% hydrogen as the reducing agent. Hot Briquetted Iron (HBI). Polymer Electrolyte Membrane (PEM). Fortescue Metal Group (FMG).

Source: Company targets and public announcements.

ii. Value-chain collaboration is required now to make breakthrough steel a reality before 2030

It is imperative for both steel suppliers and steel buyers that the low-CO_2 steel projects listed above are carried through to validate new production technologies at commercial scale by 2030, make initial volumes of low-CO_2 primary steel available for early movers across the steel-using markets, and enable a faster decarbonisation pathway in the 2030s and 2040s. Given investment cycles of around 20 years in the steel industry, these breakthrough technologies need to be proven at scale by 2030 if the entire industry is to transition to net-zero by 2050.

However, realising these announcements depends on investment decisions in the near term, as lead times to bring technologies to first- and second-of-a-kind commercial-scale production are at least 5 years. Final investment decisions for these projects have often not yet been taken. The large investments that lie ahead for steel suppliers need to be de-risked in order for the steelmakers (and their financiers) to pursue them. A commercial-scale low-CO_2 production plant, with a capacity of 1Mt/year, can cost somewhere between $600-800 million,[xxiii] which is a major investment in a steel industry currently characterised with low margins and under intense international competition. As a comparison, a full retrofit of an existing conventional plant of similar size would cost around one-third of that.[xxiv]

To invest, steel manufacturers need to be confident that they will be able to sell the low-CO_2 steel at a premium price, reflecting the cost production premium. Indeed, a first-of-a-kind investment can expect to incur +15-40% cost increase, depending on technology and local circumstances (Exhibit 10). Policy developments may narrow and eventually close this cost differential and make low-CO_2 steel cost-competitive in wholesale steel markets, either through carbon pricing and provision for creating a level playing field between high and low carbon production. It is unlikely that policymakers will create such conditions in the very near term to underpin an initial wave of breakthrough steel technologies. The projects will represent a significant expenditure for governments, so investment support is likely to be time and volume-limited and insufficient to support the current pipeline of 20 Mt of low-CO_2 production by 2030.

For steel buyers, access to low-CO_2 steel before 2030 will require further forceful intervention. Value chain collaboration can play a major role in bringing these breakthrough technologies to market. Steel buyers can strengthen the business case for investment by demonstrating a critical volume of stable future offtake and willingness to recognise and pay a premium for a product differentiated by its very low-CO_2 emissions.

iii. Steel buyers have a commercial interest in being early movers

Early movers will reap the benefits of their support for the development of new low-CO_2 material supply chains. Taking proactive action will enable them to:

- **Secure access to the first (scarce) volumes of low-CO_2 primary steel:** Based on analysis for this report, demand will likely exceed the supply of low-CO_2 steel in the near future. In the automotive industry alone, the climate targets of 8 large OEMs already imply a demand as much as 20 million tonnes of low-CO_2 steel by 2030[xxv] or the total output of all low-CO_2 plants currently in the pipeline. Additional demand from other sectors is likely to accentuate that scarcity. Corporates that lock in low-CO_2 steel supply will have an edge over their competitors.

- **Seize early commercial opportunities in premium green markets – and differentiate themselves from competitors:** The marketing potential of being a value chain collaborator focused on reducing emissions can often be leveraged from the date of the announcement, even before the actual low-CO_2 product is used commercially. As described in Chapter I, the commercial value attached to "green markets" varies but has been demonstrated in key steel-using sectors like automotive and construction.

- **Anticipate rather than react to upcoming regulations:** By structuring new supply chain and procurement practices early, proactive

xxiii Material Economics & Energy Transitions Commission's analysis based on investments needed per tonne crude steel capacity. Sources: Eurofer (2013) A steel roadmap for a low carbon Europe 2050; Global CCS Institute (2017) Global Costs of Carbon Capture and Storage; Vogl, V., et al (2018) Assessment of hydrogen direct reduction for fossil-free steelmaking; Schmidt, O., et al. (2017) Future cost and performance of water electrolysis: An expert elicitation study; Fischedick, M., et al. (2014) Techno-economic evaluation of innovative steel production technologies; Expert interviews with representatives from steel producers

xxiv Based on investments needed per tonne crude steel capacity in Eurofer (2013) A steel roadmap for a low carbon Europe 2050

xxv The scope 3 percentage reduction goal is assumed proportional to the percentage reduction in emissions from steel (i.e., scope 3 emission sources are abated equally).

steel buyers will be better prepared than their competitors to adapt to changing policies, including rising CO_2 prices and potential new regulations on lifecycle CO_2 emissions.

Steel buyers should not compare the purchase of low-CO_2 steel with other decarbonisation options purely on a short-term CO_2 abatement cost basis. There will likely be lower-cost alternatives to achieve incremental CO_2 reductions (both in steel and other materials) in the short term, but these will be limited in scale and are unlikely to offer the value proposition associated with offering a product with low-CO_2 steel. Most importantly, focusing on incremental improvement will not help to progress the availability of low-CO_2 steel products that they will need in the longer-term.

To provide a clear commercial opportunity for the steel buyers and to be effective in unlocking investment from steel manufacturers, these collaborations must address three challenges:

Challenge 1: Providing certainty of future demand

Steel buyers can play an important role in enabling final investment decisions in breakthrough technologies by providing steel manufacturers and their financiers with greater certainty around a future market for low-CO_2 steel.

This can be achieved through different mechanisms, described at more length in Chapter III, including direct bilateral offtakes or public announcements of future purchase. The more buyers' commitments are firm and precise (in volumes, specifications, and price), the more effective they will be in unlocking investment. By lowering risks, demand signals could also enable steel producers to access a lower cost of capital for those projects, with a favourable impact on the cost differential between low-CO_2 and conventional steel.

To support the development of breakthrough technologies that can reach zero emissions, any demand-side commitment must be coupled with a narrow definition of low-CO_2 steel (Box 2 and Exhibit 9). If the definition is too broad, it could enable steel manufacturers to meet this new "green demand" with volumes produced via the scrap-based EAF route or via production routes which only enable partial emissions reduction (as described in Exhibit 7 on the next page).

This would allow short-term emissions reductions for both producers and users but would fail to accelerate investment in the breakthrough technologies that will be indispensable in ultimately reaching net-zero emissions. Only a stricter definition – agreed bilaterally between a producer and a buyer, or underpinned by a standard recognised across the industry – can achieve this objective.

Challenge 2: Enabling an initial green premium

'First-of-a-kind' investments in breakthrough steel production can expect to incur +15-40% cost increases per tonne of steel, depending on technology and local circumstances (Exhibit 10). The first production units will usually see increases in both capital expenditures and running costs, given the increased cost of equipment for immature technologies, higher financing costs due to higher risk, and less optimal operational profiles for first-of-a-kind plants. The total cost increase referred to as the "green premium", will be site-specific, as the cost implications will depend on local conditions (such as energy costs, proximity to iron ore sources and customers, labour costs, etc.) and the overall development of input prices such as the cost of renewable electricity and green hydrogen[xxvi,xxvii]. This additional cost is equivalent to an abatement cost of \$50-\$120 per tonne of CO_2 avoided, assuming the low-CO_2 steel is replacing steel produced in a blast furnace emitting 2.3 tonne of CO_2 per tonne of steel. It is expected that this cost will be reduced to \$20-\$95 per tonne of CO_2 avoided in the long term, as the technologies mature and full-size production plants are established.

However, when looking at the end-consumer products, the use of breakthrough steel will represent only a modest cost increase as a percentage of the overall product cost as per Exhibit 11. Using breakthrough low-CO_2 steel in a passenger car, a building or a wind turbine is likely to increase the cost of the final product by 0.5%, 0.7% or 0.8% respectively. Given the magnitude of these costs and given the additional potential to market a premium green offer to customers, it is highly likely that this additional production cost can be passed on to the end consumers without disrupting the economic model of companies operating in those value chains.

xxvi The actual price of steel products is dependent not only on the cost of crude steel but on the level of downstream processing where the crude steel is processed into flat and long products through hot rolling, cold rolling and coating. For example – crude steel costs can range around \$400-\$500 per tonne (highly depending on the cost of iron ore, coking coal and other inputs). An automaker can see a price of \$750-850 per tonne for a cold-rolled coil of galvanized steel, and a construction company can see a price of \$500-550 per tonne for rebar.

xxvii MEPS International (2021) Europe steel prices

Box 2 – Defining low-CO_2 steel

Today, several definitions of 'low-CO_2', 'green' or 'sustainable' steel are being used interchangeably across the industry. It is important to recognise that there is no right or wrong definition, but that each definition will serve a different purpose. Exhibit 9 outlines different approaches and indicates what impact those different definitions are likely to have on technology deployments in the 2020s.

Definitions based on company-level commitments encourage steel manufacturers to adopt climate-aligned decarbonisation strategies but are unlikely to provide enough clarity on future demand for low-CO_2 steel to underpin early investments in breakthrough technologies. Various product-based definitions are likely to support a maximisation of scrap-based production as well as incremental improvements in existing production technologies in the 2020s but would only support breakthrough technologies in the longer term once the potential for lower-cost emissions reduction is exhausted and carbon-intensity thresholds are tightened. In addition, standards – among them the standard being developed by ResponsibleSteel – have been developed to encompass not only carbon-intensity and climate criteria, but also broader environmental, social and governance criteria.

To support the early deployment of breakthrough low-CO_2 technologies in the 2020s, we believe there is value in focusing some demand signals specifically on a narrow definition of low-CO_2 steel, defined by a threshold of tonne of CO_2 per tonne of crude steel. This is technology-agnostic and continues to encourage competition between different breakthrough technology options. The emissions factor considered should be adjusted based on the amount of scrap steel that is used in production. This "sliding scale" methodology is already proposed by ResponsibleSteel: the ResponsibleSteel standard calculates emissions intensity limits as a weighted average between emissions intensity targets for iron-ore based steel and scrap-based steel.

In this report, we therefore define low-CO_2 steel as primary steel which emits less than at least 0.5 tonne of CO_2 per tonne of crude steel. Such a low-CO_2 threshold enables participants to distinguish breakthrough technologies from incremental improvements of ore-based technologies and develop targeted interventions to support them while acknowledging that first-of-a-kind projects might not yet reach complete decarbonisation. This threshold should eventually be tightened, with a potential sliding scale for low-CO_2 steel that would be based on a threshold of, for example, 0.25 tonne of CO_2 per tonne of crude steel for ore-based products to 0 tonne of CO_2 per tonne of crude steel for scrap-based production.

The carbon-intensity thresholds defined in this report could inform bilateral agreements between producers and buyers. They could also be reflected in commonly used standards – and possibly combined with other sustainability criteria. ResponsibleSteel has, for instance, suggested for consultation an ambitious A+++ standard, which could potentially meet the criteria defined in this paper. This standard has, however, not yet been agreed upon.

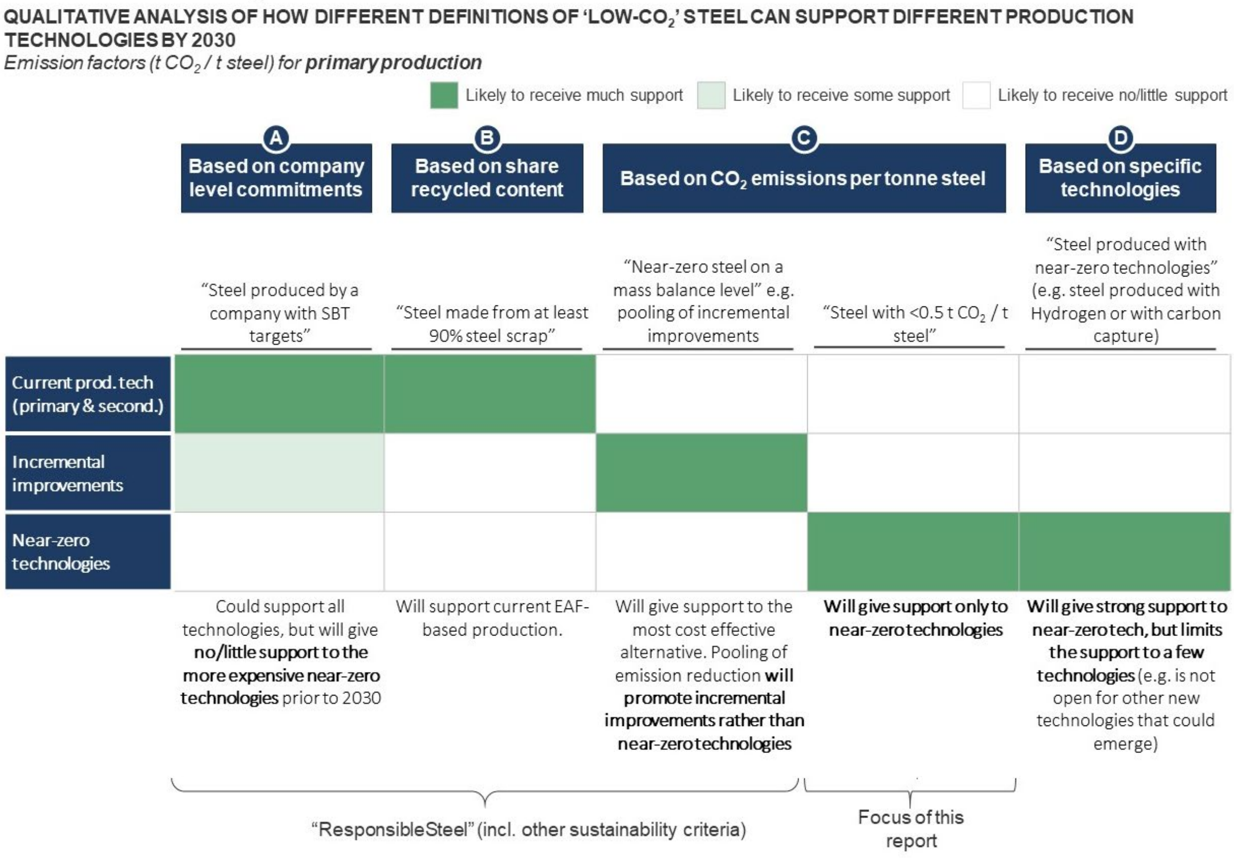


Exhibit 9: Possible definitions of low-CO_2 steel and suggested approach for breakthrough demand signals.

The demand for green products is indeed increasing in several relevant market segments, even if the willingness to pay extra for low-CO_2 steel remains untested.

Market surveys in the construction sector show an expected increase in asset value for green buildings. Consumer surveys in the automotive sector indicate that consumers are prepared to pay more for electric vehicles and that the shift to electric is mainly for environmental reasons.[xxviii] We therefore expect that corporates using low-CO_2 steel may benefit in terms of a higher price, increased market access or increased consumer loyalty as focus shifts over to embodied emissions.

An effective signal from steel buyers to steel producers will therefore entail an acknowledgement of and commitment to pay for this "green premium".

The precision with which the price point is defined between producer and buyer will vary, depending on the nature of the demand signal (as described in further details in Chapter 3).

Challenge 3: Matching supply and demand in specifications and location

Low-CO_2 steel supply and demand must match not only in terms of volumes but also in terms of geography and steel grades in order for the new trade flow to increase smoothly. The volumes of low-CO_2 steel need to be physically delivered to the buyers, with co-location of steel production and sector-specific manufacturing processes in the same region likely preferred to avoid additional transport costs. Moreover, to enable a buyer to put a low-embodied-carbon product on the market, the steelmaker must be able to

xxviii Automotive: Deloitte (2020) 2020 Global Automotive Consumer Study (Market study including 35,000 consumer responses across 20 global markets). Construction: Dodge Data & Analytics (2018) Results of owner's survey

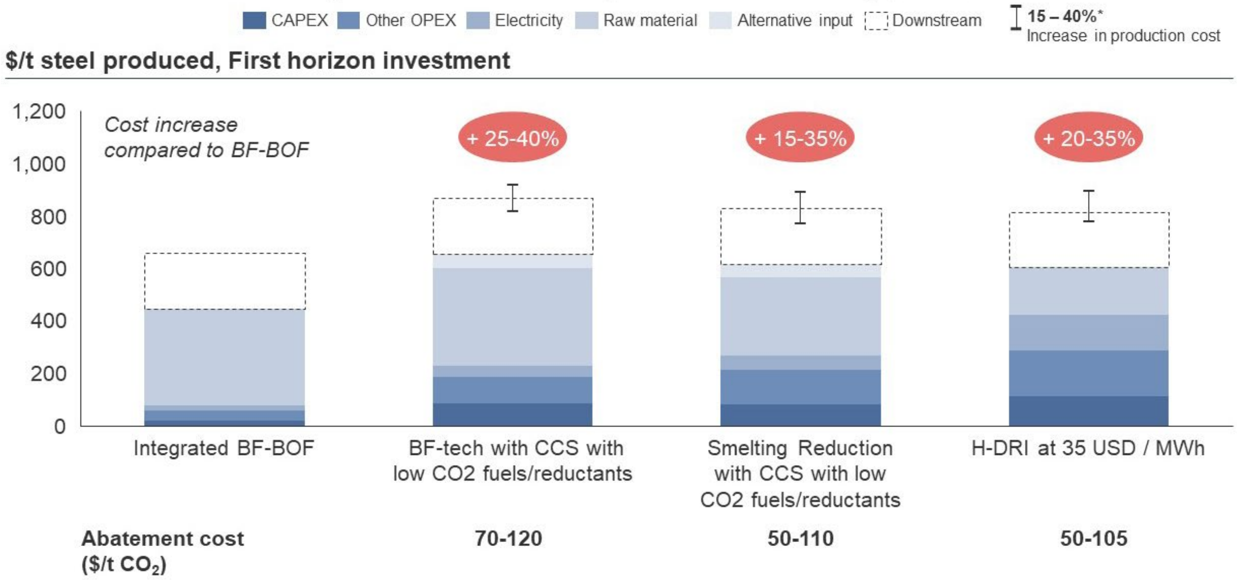


Exhibit 10: Cost of production is higher for low-CO_2 production routes.

Note: These estimates are highly dependent on input costs, geography and local conditions. The main conclusion is the range of the expected cost increase. Price assumptions for a selection of key inputs: Coke $360/t; Coal $85/t, Electricity $70/MWh; Iron ore $75/t; Pellets $125/t; Steel scrap $320/t. Alternative input refers to replacing fossil-fuel based reductants and fuels with bio-coal or hydrogen.

Source: Material Economics & Energy Transitions Commission's analysis based on multiple sources, see endnote.[xxix]

produce the specific steel products its buyer needs. 'Steel' is a homogenous term for products of over 3,500 different grades, with unique physical and environmental properties. This is partly why there is no universally accepted benchmark reference steel price traded on an exchange, as there is for aluminium and other base metals. Moreover, procurement practices differ significantly from one sector to the other – from direct negotiations between mill and consumer to the indirect purchasing of steel contained within a semi-fabricated object.

A steel manufacturer investing in a new production technology must make sure it can provide the types of product that potential low-CO_2 steel buyers will need in the right location. Incumbent producers can choose to continue using existing downstream production capacity to meet their clients' requirements but may find that demand for low-CO_2 steel comes from new rather than old customers, and therefore need to adapt their production accordingly. New entrants face another challenge: they can customise a greenfield plant to match customer groups that are likely to pay a premium but need to develop new commercial relationships with a suitable mix of customers. Value-chain collaboration will likely be essential to facilitate this matching process. In a recent example, the vehicle and machinery producer Volvo Group and the steelmaker SSAB signed a collaboration agreement on research, development, serial production and commercialisation of products to be produced in the HYBRIT project which aims to produce steel through the hydrogen direct reduction route.

xxix Material Economics & Energy Transitions Commission's analysis based on: CFR Qingdao (2018) Iron-ore index (MBIO); Vogl, V., et al. (2018) Assessment of hydrogen direct reduction for fossil-free steelmaking; Fischedick, M., et al. (2014) Techno-economic evaluation of innovative steel production technologies; Metal Consulting International (2018) Electric Arc Furnace Steelmaking Costs viewed May 2021, steelonthenet.com; Metal Consulting International (2018) Basic Oxygen Furnace Route Steelmaking Costs viewed May 2021, steelonthenet.com; Eurofer (2018) Annual Report 2018; BP (2018) Statistical Review of World Energy June 2018; Metal Consulting International (2018) Met Coke Prices – Europe 2014-2018 viewed May 2021, steelonthenet.com; Eurofer (2013) A steel roadmap for a low carbon Europe 2050; Global CCS Institute (2017) Global Costs of Carbon Capture and Storage; Johnsson,F. et al (2020) Marginal Abatement Cost Curve of Industrial CO_2 Capture and Storage; Jackson, S., et al. (2017) Optimization of the Energy Consumption of a Carbon Capture and Sequestration Related Carbon Dioxide Compression Processes; Mandova, H. et al (2018) Possibilities for CO_2 emission reduction using biomass in European integrated steel plants, Biomass and Bioenergy; Van der Stel, J., et al. (2017), Hisarna, an Opportunity for Reducing CO_2 Emissions from Steel Industry; BloombergNEF (2020) Hydrogen Economy Outlook; Slutrapport HYBRIT (2018) Hydrogen Breakthrough Ironmaking Technology Genomförbarhetsstudie Energimyndighetens projektnr; Elementenergy (2018) Cost analysis of future heat infrastructure options; Schmidt, O., et al. (2017) Future cost and performance of water electrolysis: An expert elicitation study; Expert interviews.

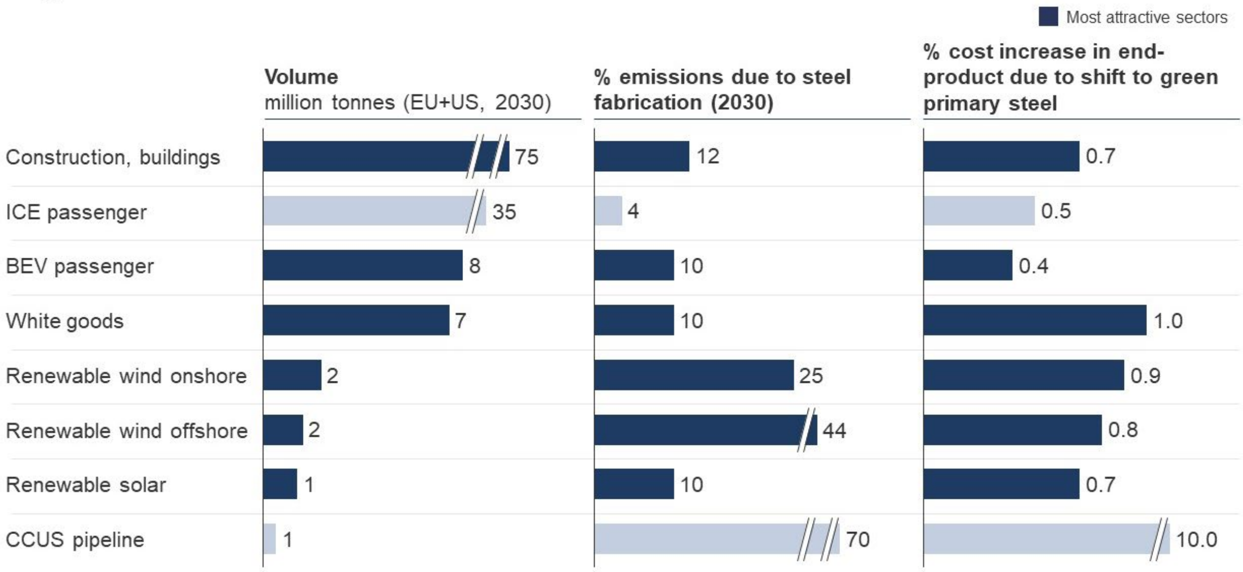


Exhibit 11: A shift to low-CO_2 steel in viable sectors can lead to a significant reduction of emissions at a modest cost to the consumer.

Source: Material Economics & Energy Transitions Commission's analysis based on multiple sources.[xxx]

An alternative to this matching process would be to 'dematerialise' the low-CO_2 steel transaction. The development of a low-CO_2 steel certificate would allow the associated CO_2 abatement to be traded separately from the physical delivery of the product while providing certainty to buyers that the volume of low-CO_2 steel purchased has truly been produced and used somewhere in the steel value chain (similar to renewable energy certificates).

xxx Premium considered for a cost increase in steel of $130/t of steel. Source: Cullen et al (2012) Sustainable Materials with Both Eyes Open; Allwood et al (2012) The flow of steel into the construction sector; BloombergNEF (2020) Elevtric Vehicle Outlook, Siemens Gamesa(n.d.) Environmental Product Declaration SG 8.0-167 DD, Vestas (2017) Life Cycle Assessment of electricity production from an Onshore V136-3.45 MW Wind Plant, IRENA (2020) Power generation costs; IEA ETP (2020) CCUS in clean energy transitions, Steel Construction Institute (n.d.) The free encyclopedia for UK steel construction information. Available at: www.SteelConstruction.info (Accessed May 2021)

Chapter 3

Developing demand signals to bring low-CO_2 steel to market

The previous chapter outlined the need to bring low-CO_2 primary steel to the market at scale and the rationale for steel buyers to proactively support this development. Demand signals, when properly structured, can address the key obstacles that currently slow down investment in breakthrough technologies while allowing buyers to reap the benefits of early access to low-CO_2 material input in a fast-moving market. Multiple ways of signalling demand for low-CO_2 steel can be envisioned – from direct offtake agreements to a more general public statement of intent to address CO_2 emissions in the supply chain. Buyers' commitments that are firm and precise (in volumes, specifications and price points) will generally be more effective to unlock investment in breakthrough technologies – and will likely benefit the companies that issue them more extensively by enabling them to secure access to initial volumes in a scarce market, negotiate potential commercial upsides directly with producers, and achieve greater marketable value. However, the nature of the demand signal that steel consumers can send to producers will depend on the value chain and each stakeholder's position within it.

This chapter describes three possible models of demand signals, before exploring how they could be implemented, taking the examples of the automotive and construction sectors. In practice, corporates may adopt an evolving hybrid approach starting with an indirect demand signal and progressing toward a more direct intervention model.

i. The basic elements of a low-CO_2 steel demand signal

A demand signal for low-CO_2 steel can take three basic forms – direct offtake, a future purchase commitment and an indirect demand signal. These are complementary and steel buyers can engage in a combination of all three; however, some demand sectors are more likely to use more direct signals as they have the pre-requisites in place.

A direct signal involves an actual agreement between a steel buyer and a specific steel supplier, intended to give the steel company the certainty needed to invest in a breakthrough production route and the steel buyer the assurance of access to a particular volume of low-CO_2 steel meeting its specifications.

- Direct demand signals can take the form of bilateral offtake agreements which, in the case of new steel production technologies, define the terms of the transaction several years in advance. This type of agreement is frequently used in the energy sector, where large electricity consumers commit to purchase electricity from a certain plant, through Power Purchase Agreements (PPA), years before it is built. For steel, such a clear and actionable demand signal can likely be sent only by certain companies that directly procure large amounts of steel, such as automotive OEMs, some renewable energy OEMs, and companies in industrial manufacturing.

- In the case of direct steel purchase, procurement teams typically enter direct negotiations with multiple mills, covering aspects including technical specifications of the steel product, price premium, credit terms and logistics. Early procurement of low-CO_2 steel would likely have to be defined as a strategic priority within the company to drive changes in procurement practices. Indeed, as highlighted in earlier sections, low-CO_2 steel will initially have a green premium attached to it, which could deter purchase under normal circumstances. Generic CO_2 emissions reduction criteria could be insufficient to orient procurement toward breakthrough technologies, as there can be CO_2 emissions reductions alternatives in the supply chains with a lower short-term cost, but less strategic upside potential. Only a specific strategic commitment at executive level can incentivise procurement teams to focus on a narrow definition of low-CO_2 steel.

- Direct demand signals can also take the form of a co-investment between a steel manufacturer and a steel buyer in a joint venture. This would represent a higher initial risk, but a greater ability to shape the market and a bigger potential for future upside for steel buyers making an early strategic move into low-CO_2 steel. There have been recent announcements of co-investments in breakthrough steel technologies, including for instance in early 2021 from Scania and BMW. Joint venture models between material producers and buyers have been successfully implemented for other materials and components in the past years, including for aluminium and batteries (Exhibit 13).

A future purchase commitment, on the other hand, is not directed to any specific supplier, but instead indicates a willingness to buy low-CO_2 steel, to the supply market as a whole.

- This model will likely be used by companies purchasing steel directly to send an early demand signal ahead of evaluating their needs precisely, assessing different supply options and entering direct purchasing agreements with their preferred vendor(s), which will enable them to lock in volumes, specifications and prices.

- Future purchase commitments enable companies that still face significant uncertainty with regards to the scale and characteristics of their future steel demand – for instance, white good producers with rapidly evolving product lines – to call on steel manufacturers to anticipate an increase in future demand for low-CO_2 steel while keeping flexibility in their procurement.

- To be effective in unlocking investment in low-CO_2 steel production, though, those commitments should be made public and ideally aggregated with commitments from other producers, via a buyers' campaign like SteelZero,[xxxi] to create enough confidence on the scale of future markets.

Finally, indirect demand signals can be sent by a much broader pool of organisations that operate across complex value chains to indicate a willingness to decarbonise their supply chains and encourage their suppliers to engage in green steel demand.

- This type of market signal can be sent by a much broader pool of organisations (including both private and public stakeholders) across complex value chains, even if they do not purchase steel directly from steel companies but rather purchase steel-made components from intermediaries.

- As this signal does not provide certainty of offtake to a steelmaker, it is not as firm as a direct signal to underpin the business case for investment. However, this approach can help grow the future market for low-CO_2 steel more rapidly than would be feasible by leveraging direct offtake agreements from major direct steel purchasers only. If significant volumes can be demonstrated (ideally volumes as high or higher than the total production of low-CO_2 steel currently foreseen for 2030), it could give steel producers and their financiers enough confidence in the scale of future markets to unlock investment.

- This confidence will be raised if indirect commitments down the value chain are combined with dialogues with suppliers to encourage a greater number of direct steel buyers even in complex value chains (e.g., equipment manufacturers) to send direct demand signals.

- It will generally be more difficult for a consumer in a fragmented supply chain to impose a narrow definition of low-CO_2 steel on their suppliers unless they have a high purchasing power and/or a particular importance in the value chain. An example of this is Apple's recent directives on the use of secondary metals within its supply chain. However, full transparency on lifecycle emissions across those value chains can help consumers navigate the market and orient their purchases.

Buyers' initiatives – both private-sector initiatives like SteelZero and public-sector initiatives such as the public procurement effort being shaped by the Clean Energy Ministerial – will play an important role in orchestrating indirect demand signals. These initiatives can aggregate dispersed committed volumes to provide a stronger signal to the steel market. Furthermore, they can serve to align stakeholders on a joint definition of low-CO_2 steel which establish a clear goal for breakthrough technology developments. As shown in Box 2, this definition of low-CO_2 steel would be ideally framed as <0.5t CO_2 per tonne of crude steel and trending towards the target level of <0.25t CO_2.

xxxi SteelZero is an initiative run by Climate Group in partnership with Responsible Steel to drive demand to low-CO_2 steel together with companies that purchase large amounts of steel. Corporates joining SteelZero must commit to procure 100% low-CO_2 steel by 2050 and to procure a share of certifies steel by 2030.

	① Direct offtake agreement	② Future purchase commitment	③ Indirect signal
Characteristics	• Bilateral agreement between a steel buyer and a steel producer • Agreement on volumes & prices • Possible joint investment to share risks & upsides	• Public announcement indicating intention to purchase low-CO_2 steel • Ideally with clarity on timing & volumes • Commitment to pay a premium (not jointly defined)	• Commitment to decarbonise supply chain, e.g., with a Science-Based Target or net-zero target • Ideally commitment to encourage low-CO_2 steel purchase through supply chain
Typical example of senders	*Companies with stronger control on supply chain* • Automotive OEMs • Whitegoods • Renewable energy	*All previously mentioned, plus* • Construction companies & developers • Public procurement	*All previously mentioned, plus* • Investors & funds • Building end-users • Trade associations
Advantages	• Higher certainty of demand for supplier • Secured quantities and products for buyer • Suitable to combine with R&D partnership	• Greater flexibility for buyers with low / varying purchase volumes • Lower level of commitment for buyers	• Closer for companies & organisations who do not directly procure steel – i.e. only purchase intermediary products containing steel – in complex value chains
Disadvantages	• Harder to implement by companies who have more volatile volumes and fast changing product portfolios • Detailed matching of supply and demand	• No offtake guarantee for an individual steel manufacturer • Lower certainty on volume or price • Steel manufacturer investment likely higher risk with higher cost of capital	• More difficult to narrow down signal to low-CO_2 steel definition higher up in complex value chains • Less guarantees to steel producers, so weaker investment case
Example	• Kingspan has announced investment in series A of H2 green steel and intention to enter long-term, supply agreement. • Volvo Group has entered a partnership with SSAB regarding steel from the HYBRIT initiative	Construction and energy companies have grouped under SteelZero to commit to 100% purchase of low-CO_2 by 2050 and to intermediate goals by 2030	

Aggregation via public campaign can strengthen signal (② and ③)

higher ← ***Strength of signal at given volume*** → lower

Exhibit 12: There are various options for orchestrating demand signals across value chains for low-CO_2 steel.

	STEEL	BATTERIES	ALUMINIUM	ENERGY
Examples	H2green steel, Kingspan, SCANIA: Equity investment BOSTON METAL: Equity investment HYBRIT, VOLVO: Development and production partnership	northvolt: Joint Venture Panasonic: Joint Venture northvolt: Offtake agreement	EGA: Offtake agreement Alcoa: Offtake agreement Alcoa: Joint Venture	SVEVIND, Hydro Markbygden ETT Windfarm Power Purchase Agreement (PPA)
Why a value chain approach?	Secure future deliveries, develop joint IP and early specifications	Enables OEMs to confidently secure batteries in a market with increased scrutiny on material sourcing	Enables OEMs to confidently secure low-CO_2 aluminium in a CO_2 intensive industry	Renewable Power Purchase Agreements allow generators to get projects funded and built by providing revenue certainty by limiting the exposure to energy price fluctuations
Set-up to send a clear signal?	Equity investment with perspective of future offtake, development partnership, offtake agreement	Direct offtakes and Joint Ventures	Direct offtakes and Joint Ventures	Long-term contract to procure electricity from a specific electricity generation facility - usually renewables and can be both on-site and off-site from the customers

Exhibit 13: Value-chain-based industrial partnerships have already been demonstrated in a number of markets.

Source: Company public announcements and news reports.

To give concrete examples of how direct offtake agreements and future purchase commitments can be set up, we delve into more detail in the automotive and construction sectors below. Those examples present commonalities with other sectors and are meant to inspire action from a range of stakeholders, even outside of those value chains. The white goods sector has strong similarities with the automotive sector (industrial processes with closer relationship with steel manufacturers, relatively stable demand for steel and geographically tied to a manufacturing location), while the renewable energy sector operates more like the construction sector (project-based industries with a distant relationship with steel manufacturers, volatile demand for steel).

ii. How a direct demand signal could be set up: The automotive example

Five design parameters should be considered when developing a direct demand signal to maximise benefits for both steel supplier and buyer:

1) Demonstrable climate benefit of commercial value

2) Offtake to enable investment certainty

3) Premium proportional to production cost increment

4) Optionality to handle uncertainty

5) Nature of the transaction

These design parameters will need to be defined and negotiated in bilateral discussions between a steel buyer and a steel supplier. They should be defined not with a zero-sum mindset, but one seeking mutual benefits. There are several options within each design parameter, and no strict 'one size fits all' solution. They will generally entail a deviation from standard procurement practices and will therefore require buy-in and steering from the companies' leadership.

1) Demonstrable climate benefit of commercial value

The bilateral offtake agreement should set out a narrow definition of low-CO_2 steel. As discussed in Box 2 above, a clear definition of low-CO_2 steel with a low-CO_2 emissions threshold (in the order initially of <0.5 tCO_2 per tonne of primary steel but trending over time to below 0.25 tCO_2) will be more effective to bring forward breakthrough technologies and yield marketing value for the buyer. The exact emissions limit can be the subject of a discussion between supplier and buyer and would ideally be as close to zero as possible. The steel delivered as part of such a contract must bear proof of the CO_2 intensity of the process

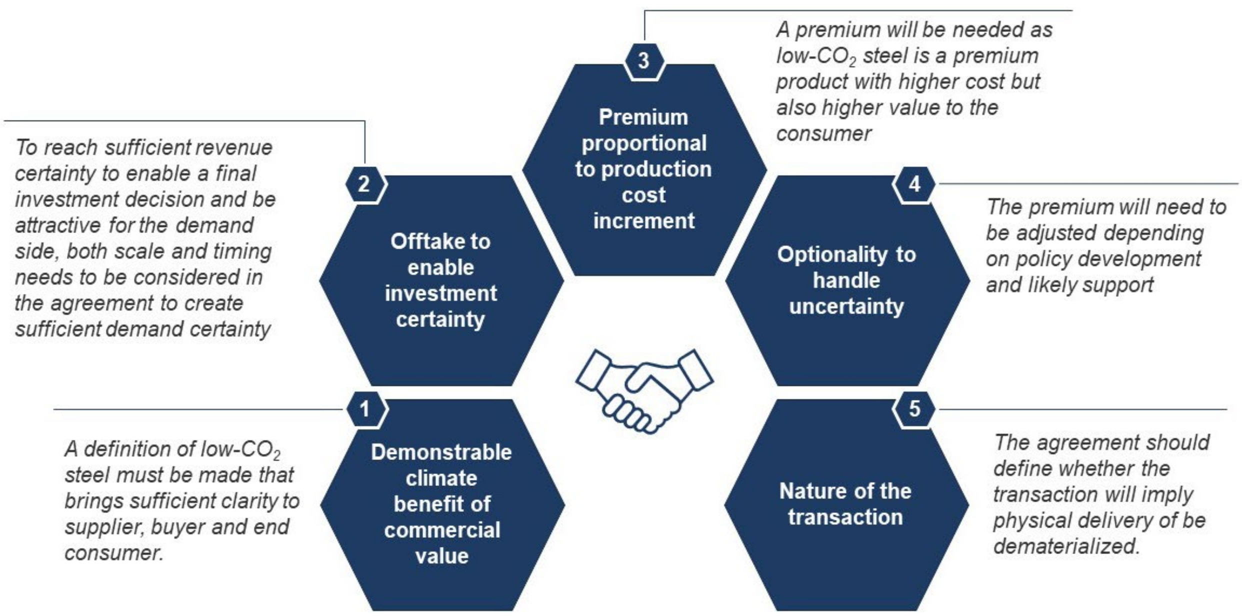


Exhibit 14: Five design parameters for efficient direct demand signal set-ups.

(e.g., through a certificate, an Environmental Product Declaration (EPD) or verification by an appropriate standard setter). Using an industry-defined standard is in principle preferable, if that standard provides a level of certification with a low enough CO_2 threshold to incentivise breakthrough technology developments, as it provides greater clarity and comparability to buyers and end consumers. Moreover, a standard like Responsible Steel[xxxii] would have the additional advantage of including other dimensions of the sustainability agenda (including socioeconomic issues).

In addition, for a steel buyer to be able to market its products as "using carbon-free steel", the steel manufacturer needs to be able to meet the technical specifications for most components in the product. For automotive, the priority is likely to be body-in-white,[xxxiii] as that steel is generally procured directly by the OEM and makes up 40-50% of total steel use in a car. However, the body-in-white in a car can contain up to ten different grades of cold-rolled steel. The steel supplier would also ideally be able to provide appropriate grades required for the other steel-made components of the car.

An additional difficulty arises for products with complex manufacturing processes: automotive OEMs source roughly 70-80% of the steel used in a car indirectly, through their component suppliers. This adds a layer of complexity for the development of an offtake agreement that brings maximum commercial value to the steel buyer: to meet its goal of a truly low-CO_2 car, the OEM would have to work closely not only with the steel manufacturer but also with component makers to direct them to buy low-CO_2 steel. Fortunately, OEMs have a tradition of close collaboration with suppliers and can set requirements on origin of and CO_2 limits on components through 'house standards' for suppliers.

2) Offtake to enable investment certainty

A direct offtake should ideally include a volume commitment giving the steel producer sufficient certainty of future demand to invest in the new production technology. In total, this volume should be sufficiently large to invest in a plant of commercial scale, which can be around 1 million tonnes of steel. The necessary volume commitment for one plant could come from a single company, or a small group of companies, each agreeing bilateral offtake agreements with the same steel producer. The latter option is more likely as few companies would have the capacity to absorb 1 million tonne of low-CO_2 steel a year – this tonnage would equate to the production of at least 2 million cars per year.[xxxiv] Having multiple off-takers also constitutes a risk-sharing mechanism for these low-CO_2 steel projects.

The purchase commitment should have a long, clear timeframe. By agreeing on a future purchase at least 5 years in advance, the steel supplier can make sure that the lead time for investment in the new steel production process is appropriately planned for, the buyer can build the introduction of low-CO_2 steel into its product launch cycle, and supplier and buyer can jointly ensure that all necessary product development and testing is done ahead of time. For steel buyers, marketing benefits might be reaped even before the product launch.

The purchase commitment should ideally last at least seven years from the start of production. For OEMs, this corresponds to a normal model cycle timeframe. For steel producers, it corresponds to the possible duration of a long-term bank loan. Lenders to breakthrough steel mills will consider the offtake agreements as a key de-risking mechanism ahead of a financing agreement. After entering such a bilateral offtake agreement, the automotive OEM will therefore need to give up the flexibility in pitching several suppliers against each other for a certain period but will be able to maximise the commercial opportunity related to strategic purchasing of low-CO_2 steel.

3) Premium proportional to production cost increment

To underpin investment in breakthrough technologies that will be costlier than the high-carbon alternative, at least initially, the agreement between producer and supplier should include a premium price. As an example, for the automotive industry, the introduction of low-CO_2 steel will likely represent an additional cost – or "green premium" – on a vehicle's bill of materials

xxxii Responsible Steel is an organization developing new standards and certification on responsible and sustainable steel. Responsible Steel standards are developed in close collaboration with industry and environmental, social and governance issues, including climate action.
xxxiii Body-in-white (BiW) is the name given when all the components of a car—barring moving parts or chassis subassemblies—have been welded together but not yet painted.
xxxiv On average ~1 tonne primary steel needs to be procured for a medium sized car, assuming 50% to be low-CO_2 primary steel. Based on WorldAutoSteel (2017) UCSB Energy & GHG Model v 5.0

of around \$100-\$250 per finished car. At the consumer level, this would represent less than 1% of the Manufacturer Suggested Retail Price of a typical compact battery electric vehicle.

There are several options for producers and buyers formulating such a premium in a contract. The price could be agreed on a fixed long-term basis, based on a steel index with an agreed green premium on top, or it could entail a "cost-plus" model with an open book approach. Price linked to a steel index with a green premium on top could be an attractive model for both buyers and suppliers. Prices on high-end steel products can already be based on a market price for a basic product (such as hot-rolled coil), with a premium depending on the quality and content of the final product (alloys, coatings, etc.). This model ensures that the price paid by the buyer is somewhat linked to the price that their (non-green) competitors pay. This could, however, result in an increased risk for the steel producers, which would face a different cost base than competitors operating based on conventional technology. As explained below, optionality can help mitigate that risk.

4) Optionality to handle uncertainty

The pricing mechanism agreed between supplier and buyer could be complemented with a price adjustment based on important input parameters (e.g., electricity and hydrogen costs, available policy support). This would both enable the steel supplier to hedge against increases in input prices and the steel buyer to benefit from any upside (for instance if public financial support schemes were put in place after the initial purchase agreement was established). The parties can agree on a way to divide both potential risks and benefits. Given that price and premium negotiation will take place several years ahead of the actual steel purchases, a higher level of uncertainty on future input costs would justify such optionality. As mentioned above, a direct demand signal can also be combined with the buyer taking an equity stake in the low-CO_2 steel venture, which would entail greater exposure to both potential risks and likely upsides.

5) Nature of the transaction

The nature of the transaction between producer and buyer should be defined in the contract. The transaction could take two forms: physical delivery of the low-CO_2 steel to the customer or dematerialisation of the transaction, with a low-CO_2 steel certificate being sold to the buyer irrespective of physical transactions. For most buyers, physical delivery is likely to be more attractive: it ensures that the material used in their product is low-carbon and facilitates marketing. However, stakeholders with a strong interest in the decarbonisation of the steel industry, in particular public policymakers, could be open to dematerialised transactions. These would enable them to encourage emissions reduction in steel, by leveraging public procurement of infrastructure projects, without being constrained by the geographical limits of a physical transaction.

iii. How a future purchase commitment could be set up: The construction example

Future purchase commitments can de-risk investment decisions for steel producers. Many steel users, in particular those operating in fragmented value chains purchasing steel indirectly and with relatively low or variable purchase volumes, would be unable to deliver a direct demand signal as described in the previous section. **What a future purchase commitment would lack in specificity, it can make up for in scale.** It enables a demand signal for low-CO_2 steel to come from a potentially much bigger pool of steel users, including stakeholders down the value chain that are several steps removed from the steel purchase stage (such as corporates owning or renting newly built office buildings). The nature of the signal sent by corporates to the steel market may evolve – from an indirect statement of intent to secure low-CO_2 steel into a direct bilateral offtake as clarity of the mechanics of a supply chain is achieved.

The construction sector offers such an example. As the biggest market for steel globally, it could offer a significant volume of transaction of low-CO_2 steel. However, it is a fragmented market with long supply chains, where a direct demand signal is unlikely to emerge. From the moment that steel is melted at the mill to the point it reaches the end-consumer (the developer or owner of the building), steel can be transacted many times: from the mill to stockholders, then to steel fabricator who welds the pieces and components, to a subcontractor that works for the main contractor who finally delivers the building to the developer. The structure is often designed, and the steel specified, by an external consultant, following design guides from a public or non-profit organisation. In most cases, the ability to extract a commercial value from low-CO_2 steel sits with the developer, whereas the purchasing decisions sit with the contractor, influenced by specifications from external consultants, engineers, and architects. As a result, few players would hold both major steel purchase volumes and the ability to shape the market by imposing the use of costlier low-carbon materials on downstream players. Stakeholders up in the value chain might be most incentivised to use "green materials" (public procurement departments, leading global corporates owning or renting buildings, etc.), but rarely purchase steel directly to manufacturers and do not alone represent a sufficient volume to create a strong demand signal.

However, combined action from a critical mass of stakeholders across the construction value chain could send a powerful demand signal by demonstrating the existence of a significant market for low-CO_2 steel. Many stakeholders could send the signal to their supply chains that they value low-CO_2 steel (Exhibit 15).

- **In this value chain, public procurement can play a major role in creating markets for innovative products.** Governments committed to climate targets have a strong interest in helping the steel industry decarbonise, while also ensuring that production and jobs remain local. As major buyers of buildings and infrastructure, national and local governments alike can incentivise the use of lower-carbon materials by adapting their public procurement criteria accordingly and encouraging similar practices from public organisations that depend on them (such as transport authorities). Some governments have already taken initiatives to address steel emissions in their procurement practices (for instance, California through its Buy Clean programme, or the Swedish Transport Administration – Exhibit 16). However, most of these initiatives incentivise energy efficiency improvement, incremental emissions reductions, and increased use of recycled steel; we are not aware of public procurement policies targeted to incentivise investment in breakthrough steel technologies. Such practices could take the form of commitments on quantities of low-CO_2 steel purchased for specific construction projects. To represent a relevant volume for steel producers, though, commitments from several public sector organisations would have to be aggregated. The Swedish Transport Administration example in Exhibit 16, even though not singling out low-CO_2 primary steel, have set a CO_2 price in tenders that is sufficiently high to incentivise low-CO_2 primary steel (compare to the CO_2 price corresponding to the green premium described in Chapter II). This is a method that individual organisations can use to send a strong indirect signal as it signals there is a willingness to pay a green premium and thus a market for early low-CO_2 steel.

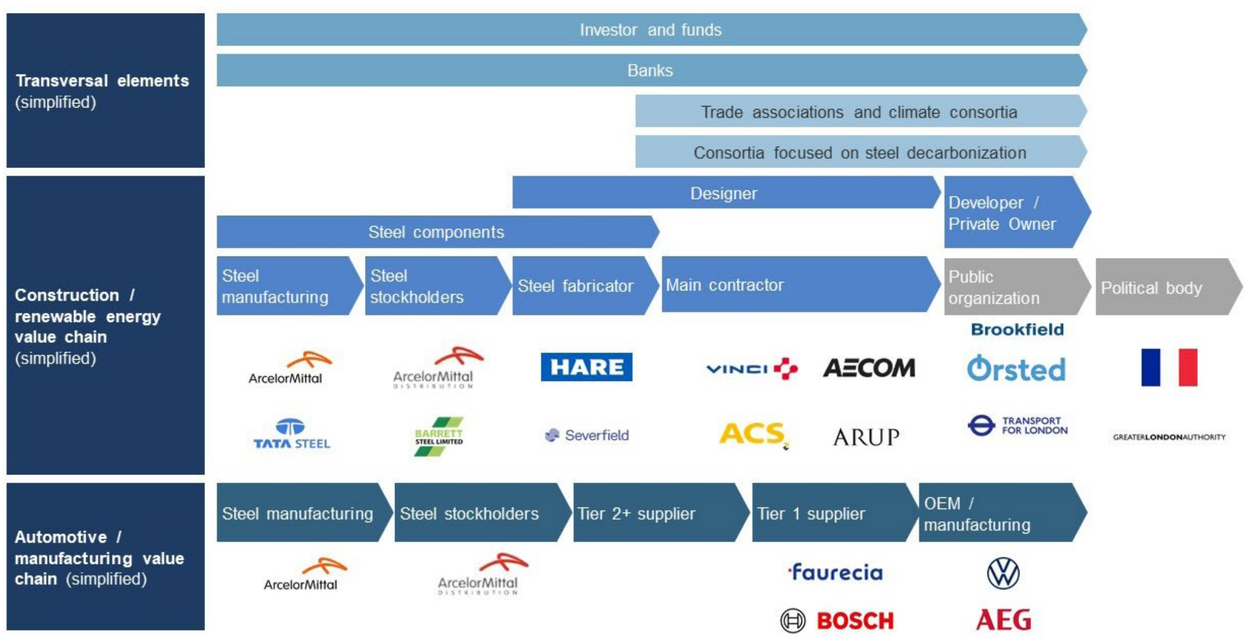


Exhibit 15: Demand signal can come from across the entire construction value chain.

TRAFIKVERKET SWEDISH TRANSPORT ADMINISTRATION The Swedish Transport Administration (STA) is a government agency responsible for long-term infrastructure planning for road, rail, shipping and aviation. This is based on interviews with climate specialists at Trafikverket and aims to portray the plan on how the emissions reduction targets will be implemented.		
	Clearly defined emission reduction targets	STA has set out emissions reduction goals for their projects: 15% reduction by 2020, 30% by 2025 and 50% by 2030, compared to 2015. These goals have been communicated to contractors and suppliers.
	Control over construction materials utilized	STA has control over the specifications on Technically Approved Material (which includes a large fraction of steel products used in public railway). This means that contractors must utilize these specific materials that comply with all requirements set by STA, including climate requirements.
	Bonus and penalty system on meeting targets	Each tonne of CO_2e avoided by a contractor beyond the emission reduction requirement is rewarded with 1000 (+/-500) SEK/t CO_2e (~100 EUR/t CO_2e) up to a certain level, while a penalty twice the level of the bonus is applied if the requirement is not met.
	Flexibility to revise targets for increased ambition	Although STA engages in long term deals with suppliers (sometimes longer than 20 years), there is a review of the material specifications every 3-5 years. This means new requirements can be worked into the contract to address more ambitious targets.
	Climate benefit proven through EPDs	STA requires EPDs for project specific materials. This always apply for concrete, cement, reinforcement steel and construction steel.

Environmental Product Declaration (EPD)

Exhibit 16: The Swedish Transport Administration has built strong incentives into their procurement process.

Source: The infrastructure sector climate transition, Trafikverket (2021) and Expert Interviews.

- **In parallel, developers, designers, contractors, and subcontractors can also commit to lowering their embodied emissions – and, if they are big enough to shape contractual relationships, to purchase certain volumes of low-CO_2 steel produced via breakthrough technology routes.**

  - **Developers, in particular, are key decision-makers,** as they set the brief for designers and the tender for contracts and can therefore operationalise commitments by setting design requirements and/or tender incentives. The tender incentives can initially be in the form of a price on CO_2. This would offer flexibility to bidders, as those without access to low-CO_2 steel could still apply, and would incentivise emissions reductions in steel production; but, it would not provide targeted support to breakthrough production routes. However, requirements on the share of low-CO_2 steel in total use could also be envisioned if they were announced with enough notice for bidders to anticipate those new requirements in their own purchasing practices.

  - **Contractors, designers, and steel fabricators are less likely to have the power to set precise low-CO_2 purchase requirements for the projects they are involved with,** but they can advertise more general climate commitments (many have already done as part of the SteelZero initiative). They can also play a key role in creating the necessary tools and capabilities to provide traceability of CO_2 emissions across a complex supply chain and facilitate green procurement practices, and in establishing sectoral decarbonisation roadmaps that can inform both steel producers upstream and developers downstream about the potential pace and scale of low-CO_2 purchase in the value chain.

To increase the effectiveness of the future purchase agreement, coordination within value chains would be recommended. Industry consortia, private buyers' clubs or green public procurement campaigns would usefully aggregate demand for low-CO_2 steel and provide a headline number to the steel sector. They could also establish an agreement across the value chain on a single definition of low-CO_2 steel and influence voluntary standards like LEED[xxxv] and BREEAM[xxxvi] to include incentives for low-CO_2 steel. LEED and BREEAMare voluntary green building standards that certify buildings in grades based on varied sustainability criteria. In the past, incentives for the usage of natural materials in LEED v4 was, for instance, a major lever for the adoption of cross-laminated timber (CLT) and glue-laminated timber (Glulam) in construction.

xxxv Leadership in Energy and Environmental Design
xxxvi Building Research Establishment Environmental Assessment Method

Chapter 4

A call for action

As the need to deeply decarbonise becomes increasingly pressing for both steel producers and steel users, both sets of stakeholders will look for solutions to reduce their CO_2 emissions in the short term and prepare for deeper cuts in the 2030s and 2040s. Primary low-CO_2 (and eventually carbon-free) steel production will be essential for all stakeholders to reach voluntary and regulatory climate targets by 2030 and beyond. This challenge represents a significant business opportunity and the next 5 years are a critical window to invest, given the lead time of technology development. Early movers among producers and buyers, stand to benefit from proactiveness. Steel buyers in particular will be able to secure access to a scarce high-value commodity, seize the commercial opportunity of a “green premium market” before competitors catch up and pre-empt regulatory changes thereby avoiding potentially costly disruptions in supply chains. However, as the technologies are not yet available and remain higher-cost than the high-carbon alternative, action is needed. Direct offtake agreements and future purchase commitments are critical to provide the confidence needed to unlock the flow of investment and technology.

Based on interviews and exchanges with stakeholders across the steel-using value chains, we believe that a small number of critical steps must be taken in the next few years to realise the commercial opportunity that low-CO_2 steel represents:

i. Two critical actions for steel buyers

- **For large, direct steel buyers: Engage in bilateral value-chain cooperation initiatives,** using the significant predictable demand to unlock upstream investments and accelerating the transition to zero. This report has described the expected commercial benefits for early movers in the demand sectors who can secure the first (scarce) volumes of low-CO_2 steel ahead of their competitors. Seizing those opportunities requires a transformation of procurement practices, from a criteria-based sourcing exercise to a strategic supply chain development approach. This approach will enable corporates to develop an innovative “green value proposition” for customers and shape the longer-term competitive edge of the company. In many cases, this strategic direction needs to come from executive management to procurement teams that would otherwise struggle to address breakthrough low-CO_2 steel purchase through existing practices. This strategic direction can be communicated broadly to steelmakers and be the basis for direct offtake agreements.

- **For steel buyers not engaged in direct bilateral negotiations: Engage in the buyers’ club initiatives that will be set up for low-CO_2 steel (e.g., SteelZero), and commit to as large volumes as possible.** Steel users in complex value chains will require access to low-CO_2 steel production to meet voluntary and regulatory embodied emissions targets. They will struggle to access low-CO_2 steel without some form of coordination with other stakeholders to send a sufficiently strong signal in terms of volumes, and to establish a consistent mechanism for tracing embodied CO_2 emissions and to standardise procurement practices. Aggregating demand in this fashion will increase the volumes demanded from the steel industry and hence support the business case of the necessary investment. Individual indirect steel buyers can also send a strong unilateral signal through supply chains by demonstrating a willingness to pay the green premium.

ii. Two critical actions for steel producers

- **Engage with high volume customers to develop the necessary value-chain collaboration.** Better understanding of the context, challenges and opportunities across key value chains and a clear articulation of what steelmakers need to see from the demand side to bring investments forward in time are required first steps for demand signals to be developed. Through long-term strategic fact-based discussions, the joint benefit of a new way of procuring steel can be established.

- **Define, in conjunction with customers, the specifications required to underpin investment in breakthrough low-CO_2 steel.** To be effective in unlocking investment in breakthrough technologies that can reach near-zero-emissions, demand signals need to be designed to specifically support projects with high emissions reductions potential – rather than just incremental emissions reductions. Many climate targets from downstream players are at risk of being too broad to create demand for low-CO_2 steel. Agreeing on a joint definition of such a stringent CO_2 emissions threshold – possibly via the definition of a new standard level within the existing ResponsibleSteel framework – would facilitate the implementation of appropriate demand signals.

iii. Four critical actions for policymakers & public organisations[xxxvii]

- **Continue to provide a supportive R&D environment to foster innovation in the steel sector.** Disruption of the steel industry on the scale required to produce the low-CO_2 steel volumes required in pathways such as the recent net-zero by 2050 IEA report[xxxviii] will require innovation derived from both public and private R&D efforts.

- **Use public procurement to create early markets for low-CO_2 steel between 2025 and 2030.** National governments, local governments and public agencies represent a significant share of total demand in key sectors like the construction sector. Existing commitments to reduce lifecycle emissions of public works and buildings will be insufficient to unlock investment in the required steel breakthrough technologies. The public sector can play a critical role in providing demand at a premium price for the very first volumes of low-CO_2 steel by committing to purchase certain volumes of primary steel with narrow carbon-intensity specifications between 2025 and 2030. Alternatively, applying a CO_2 price in tenders that would be sufficiently high to incentivise breakthrough primary steel in that narrow carbon-intensity band. COP26 offers an opportunity for a major "green steel procurement" campaign to be announced, bringing forward and aggregating commitments from governments and public agencies across several regions of the world.

- **Decrease the risk for first-mover bilateral agreements on low-CO_2 steel.** We have in this paper described models to set up bilateral offtake agreements. These will entail handling considerable risks that come with making early commitments and will be challenging to negotiate. Policy can help by assuming a portion of that risk. Two clear such actions would be to: 1) Give CAPEX support that would correspond to the public innovation value of bringing these technologies to commercialisation. 2) Decrease the OPEX risk in taking a forward position (what happens when commodity prices such as CO_2 prices, etc. fluctuate) by introducing Carbon Contracts for Difference.

- **Set lifecycle emissions standards for key steel-using products, with ambitious targets from 2030 onward.** Although voluntary demand signals will be essential to bring breakthrough technologies to market by 2030, the scale-up of low- and eventually zero-carbon primary steel production in the 2030s will depend on the creation of a much wider market for low-carbon materials. Lifecycle emissions regulations on just a few steel-using value chains, in particular, the automotive, construction and white good value chains – for which energy efficiency standards already exist and could be expanded relatively easily – will likely be a key instrument to fast-track deployment of low-carbon materials.

iv. One critical action for civil society

- **Customers advocating and opting, where possible, for products containing low-CO_2 steel over comparable products would serve to send a clear signal across the steel value chain.** Increasing awareness among end-consumers of the benefits of low-CO_2 steel and of the embodied emissions in buildings, vehicles, white goods, etc. could increase demand for products differentiated based on the emissions of the contained steel. This will serve to increase the investment rationale for breakthrough technologies.

xxxvii A broader set of policy interventions is required to drive the decarbonisation of the steel industry at an appropriate pace to meet the climate objectives set in the Paris Agreement. Those will be addressed in a separate brief from the Net-Zero Steel Initiative. This paper focuses exclusively on how policymakers can create higher volumes of demand for low-CO_2 steel.

xxxviii IEA (2021) Net-zero by 2050 – a Roadmap for the Global Energy Sector

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