MAKING NET-ZERO STEEL POSSIBLE

An industry-backed, 1.5°C-aligned transition strategy

EXECUTIVE SUMMARY / SEPTEMBER 2022

MISSION POSSIBLE PARTNERSHIP

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At current emissions levels, staying within the global carbon budget for 1.5°C might slip out of reach already in this decade. Yet efforts to slow climate change by reducing greenhouse gas (GHG) emissions run into a central challenge: some of the biggest emitters of greenhouse gases into the atmosphere — transportation sectors like aviation, shipping, and trucking, and heavy industries like steel, aluminium, cement/concrete, and chemicals manufacturing — are the hardest to abate. Transitioning these industries to climate-neutral energy sources requires complex, costly, and sometimes immature technologies, as well as direct collaboration across the whole value chain, including companies, suppliers, customers, banks, institutional investors, and governments.

Catalysing these changes is the goal of the Mission Possible Partnership (MPP), an alliance of climate leaders focused on supercharging efforts to decarbonise these industries. Led by the Energy Transitions Commission, the Rocky Mountain Institute, the We Mean Business Coalition, and the World Economic Forum, MPP has as its objective to propel a committed community of CEOs from carbon-intensive industries, together with their financiers, customers, and suppliers, to agree and, more importantly, to act on the essential decisions required for decarbonising heavy industry and transport. MPP will orchestrate high-ambition disruption through net-zero industry platforms for seven of the world's most hard-to-abate sectors: aviation, shipping, trucking, steel, aluminium, cement/concrete, and chemicals.

The foundation of MPP's approach: 7 Sector Transition Strategies

Transitioning heavy industry and transport to net-zero GHG emissions by 2050 — while complying with a 1.5°C target — will require significant changes in how they operate. MPP facilitates this process by developing **Sector Transition Strategies** for all seven hard-to-abate sectors.

A Sector Transition Strategy

is a suite of user-friendly tools (including a report, an online explorer, and an open-source model) aiming to inform decision makers from the public and private sectors about the nature, timing, cost, and scale of actions necessary to deliver net zero within the sector by 2050 and to comply with a 1.5°C target.

The market penetration of viable decarbonisation measures each sector can draw on is modelled in line with industry-specific replacement cycles of existing assets (steel plants or aircraft) and the projected increase in demand.

The objectives of the MPP Sector Transition Strategies are:

1. **To demonstrate industry-backed, 1.5°C-compliant pathways to net zero,** focusing on in-sector decarbonisation and galvanising industry buy-in across the whole value chain.

2. **To be action-oriented with clear 2030 milestones:** By quantifying critical milestones for each sector in terms of its required final energy demand, upstream feedstock resources, and capital investments, MPP wants to lay the foundation for tangible, quantitative recommendations of how these milestones can be achieved through collaboration between industry, policy makers, investors, and customers.

3. **To be transparent and open:** MPP's long-term goal is to fully lay open the internal machinery of the Sector Transition Strategies, that is, to make its Python models open source and all data inputs open access. In addition, MPP is developing online web interfaces that bring the Sector Transition Strategy reports to life: individual users will be able to explore the results of the reports and to customize model input assumptions, explore the impact of individual levers, and dive deeper into regional insights.

4. **To break free from siloed thinking:** The transition of a sector to net zero cannot be planned in isolation since it involves interactions with the broader energy system, (e.g., via competing demands for resources from multiple sectors). All MPP Sector Transition Strategies are based on similar assumptions about the availability and costs of technologies and resources like electricity, hydrogen, or sustainable biomass. By providing a harmonized, cross-sectoral perspective, we intend to inform decision makers with a fair, comparable assessment of transition strategies for all seven sectors.

On the basis of its Sector Transition Strategies, MPP intends to develop practical resources and toolkits to help operationalize industry commitments in line with a 1.5°C target. Among others, the quantitative results of the Sector Transition Strategies will inform the creation of standards, investment principles, policy recommendations, industry collaboration blueprints, and the monitoring of commitments. These will be developed to expedite innovation, investments, and policies to support the transition.

Goals of the MPP Steel Sector Transition Strategy

This report explores potential pathways to reduce emissions from the steel industry. The analysis that follows builds on the first edition of the Steel Sector Transition Strategy (published in October 2021) and the Steel Sector Transition Strategy Model (ST-STSM) upon which it was based. These efforts were informed by the valuable contributions that preceded them, including the Ultra-Low CO_2 Steelmaking (ULCOS) project, the International Energy Agency's *Net Zero by 2050* roadmap, and extensive engagement with Net-Zero Steel Initiative (NZSI) members and steel experts.[i] As in the first edition, the approach taken here is shaped by three main objectives:

1. To provide a detailed reference point for the changes that will be needed over the next 30 years to underpin target-setting across the steel value chain and its financiers.

2. To inform priority actions, trade-offs, and required decisions needed in the 2020s to get to net zero for stakeholders who will shape steel markets, including industry leaders, governments, buyers of carbon-intensive materials, and financial institutions.

3. To underpin a coherent set of commitments to actions from stakeholders across the value chain, which together will unlock investment in zero-carbon solutions.

i ULCOS was a consortium of 48 European companies and organisations from 15 European countries, formed to oversee research and development initiatives that would enable significant CO_2 emissions reductions from steel production.

While the first edition of the Steel Sector Transition Strategy already fulfilled those objectives, the decision was taken to publish an updated version to address five key areas:

A. Inclusion of a 1.5°C-aligned pathway, ensuring that the Steel Sector Transition Strategy mirrored those written for other MPP sectors.

B. An expanded Global Steel Plant Tracker (GSPT) data set, which serves as a key input to the modelling. The updated GSPT covers an additional 32% of tracked capacity compared to the 2021 release.

C. The ability to resolve important regional differences within the global steel industry, addressed by redesigning the ST-STSM to model the industry across 11 unique regions and enable deeper and more granular insight. Previously, the ST-STSM had only been able to model the industry at a global level.

D. The globalised nature of steel markets, taken into account by updating the ST-STSM with a function to model international trade, allowing it to better simulate the reality in which the industry operates.

E. Changes to market fundamentals, such as the jump in fossil fuel prices as a response to the ongoing war in Ukraine.

This updated Steel Sector Transition Strategy includes valuable additions that address these points. However, the key messages of the original edition remain substantially the same. Modifications to the modelling and analysis have understandably caused some details to shift, but the original findings have shown their robustness by remaining directionally unchanged in the face of these modifications.

To promote transparency and collaboration, the model materials and analytics will be made open source and open access, such that the inputs and assumptions are available for enquiry and future iterations may build upon this effort. This open-access approach lends itself to further refinement as data and insights evolve. Critically, it also ensures that the industry can align behind a strategy it considers technically and economically feasible, subject to appropriate value-chain collaboration, finance, and policy support. This open-source approach also enables users to adjust different parameters in the model to reflect the circumstances faced in a particular geography, supporting real-world decision-making.

Industry support for MPP's Steel Transition Strategy

This report constitutes a collective view of participating organisations in the Steel Sector Transition Strategy, foremost the NZSI community. Participants have generally validated the model inputs and architecture and endorse the general thrust of the arguments made in this report, but should not be taken as agreeing with every finding or recommendation. These companies agree on the importance of limiting global warming to 1.5°C, the importance of reaching net-zero GHG emissions in steel by mid-century, and share a broad vision of how a 1.5°C-aligned transition scenario could be achieved. The companies recognize that actions to support this broad vision should be pursued expeditiously.

The fact that this agreement is possible among the industry leaders listed below should give decision makers across the world confidence that it is possible to simultaneously meet rising steel demand, reduce emissions from the sector to net zero by 2050, and comply with a 1.5°C target. It should also provide confidence that the critical actions required in the 2020s to set the sector on the right path are clear and can be pursued without delay, and that the industry is ready to collaborate with its value chain.

Unless otherwise stated, the report is based on publicly available, open access input assumptions and endorsers have not provided commercially sensitive information for technologies under development. While assumptions have been developed through a consensus view of participants, there are significant risks and uncertainties particularly related to cost, performance, and rate of implementation for technologies and actual results may differ materially from those indicated by these forward-looking assumptions.

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Mission Possible Partnership (MPP)

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% of emissions: aviation, shipping, trucking, steel, aluminium, cement/concrete, and chemicals. Without immediate action, these sectors alone are projected to exceed the world's remaining 1.5°C carbon budget by 2030 in a Business-as-Usual scenario. 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. **www.missionpossiblepartnership.org**

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 organizations – 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. **www.energy-transitions.org**

RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing. **rmi.org**

World Economic Forum

The World Economic Forum is the international organization for public–private cooperation. The Forum engages the foremost political, business, cultural, and other leaders of society to shape global, regional, and industry agendas. Learn more at **www.weforum.org**.

EXECUTIVE SUMMARY

TEN CRITICAL INSIGHTS ON THE PATH TO A NET-ZERO STEEL SECTOR

1. Bringing the iron and steel sector on a path to net-zero emissions by 2050 is technically and economically possible. Achieving it will require deployment of multiple available and emerging technologies.

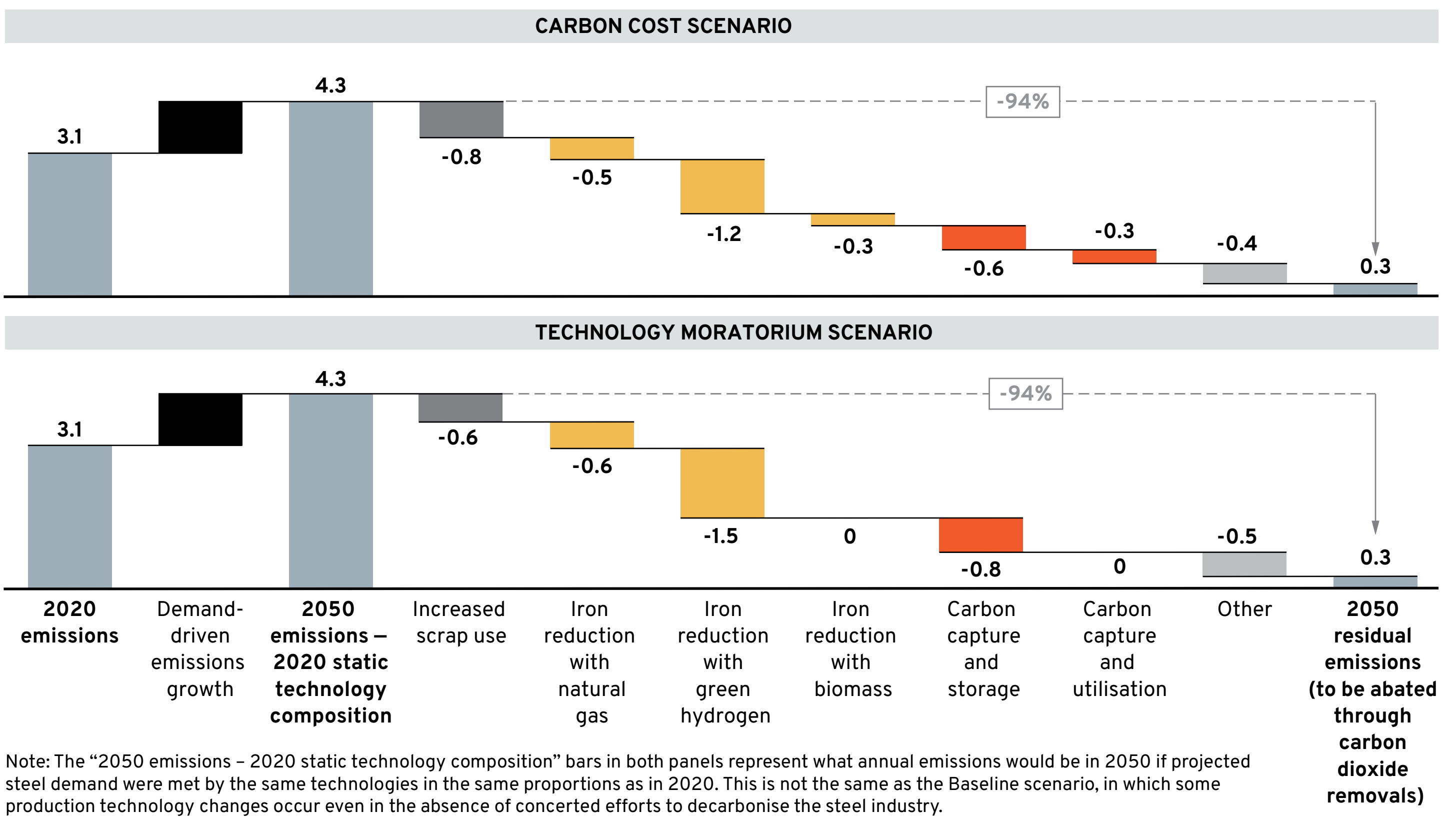
In 2020, the global iron and steel industry was responsible for more than 3.1 gigatonnes of carbon dioxide (Gt CO_2) emissions, about 7% of the total global greenhouse gas (GHG) emissions. In contrast to a Baseline scenario,[ii] two net-zero scenarios show different perspectives to reach net-zero emissions by 2050.

The pace of progress in the 2020s will depend on the extent to which policy and company decisions can bring forward investments in low-emissions steelmaking over the next decade, when the majority of capacity is expected to undergo major investment. The Carbon Cost scenario illustrates how the sector might decarbonise if coordinated action to support low-CO_2 steelmaking takes hold this decade. The Technology Moratorium scenario assumes limited progress this decade, before constraining investments to near-zero-emissions technologies from 2030 onwards. In both scenarios, residual emissions from these technologies remain in 2050 at levels of less than 10% of current emissions and requiring mitigation through carbon dioxide removals (Exhibit A).

EXHIBIT A

Key emissions reduction levers to achieve net zero in the steel industry

Annual emissions (Scope 1 and Scope 2), in Gt CO_2



Note: The "2050 emissions – 2020 static technology composition" bars in both panels represent what annual emissions would be in 2050 if projected steel demand were met by the same technologies in the same proportions as in 2020. This is not the same as the Baseline scenario, in which some production technology changes occur even in the absence of concerted efforts to decarbonise the steel industry.

Source: MPP analysis

ii A Baseline scenario acts as a reference case in which steelmaking assets switch to the technology with the lowest total cost of ownership at each major investment decision, without a net-zero constraint.

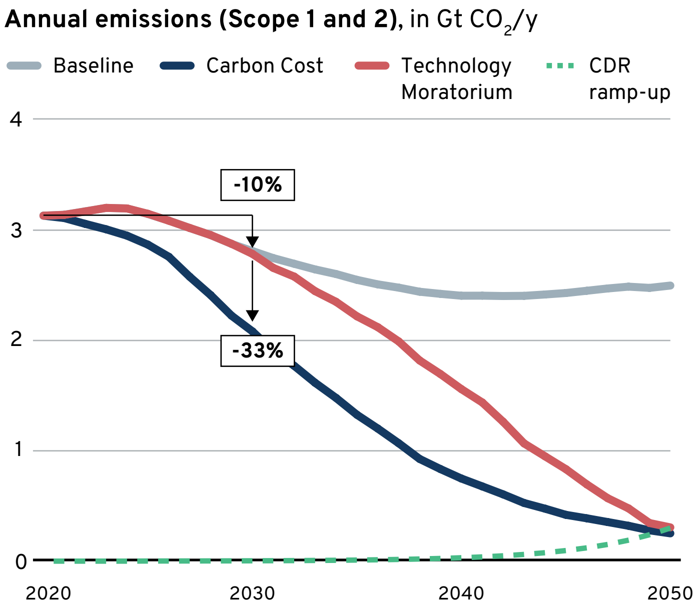
2. Although the pathways of both scenarios reach net zero by 2050, early progress in the 2020s is essential if the steel sector is to stay within its sectoral carbon budget.

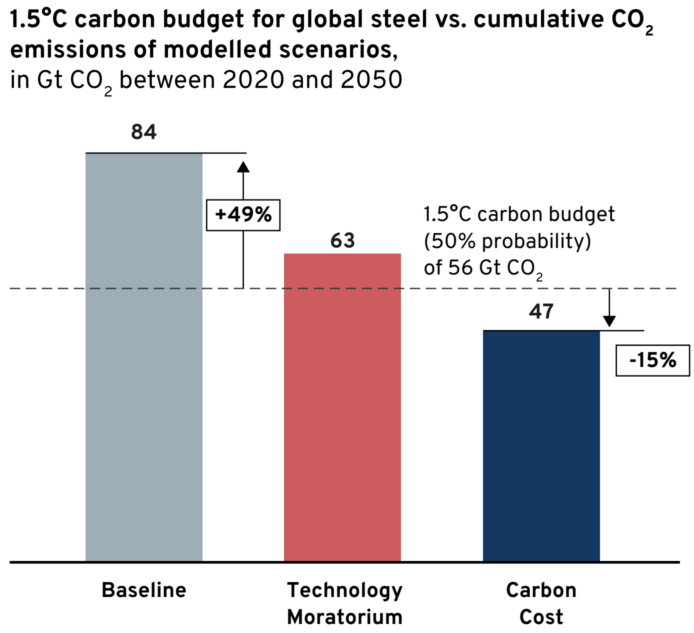
Incremental improvements in existing steelmaking technology and progressive decarbonisation of power grids could deliver 10% emissions reductions in 2030 compared to 2020 at little additional cost. But incentivising early switches to technologies with greater abatement potential could achieve much sharper reductions this decade and radically lower cumulative emissions.

Under the Carbon Cost scenario, up to 1 Gt of annual CO_2 emissions could be avoided in 2030 (a 33% reduction compared to 2020) if carbon pricing globally were to reach around $52 in 2030 or equivalent mechanisms were implemented.[iii] Following this faster trajectory would help ensure the industry remains within a 1.5°C-aligned carbon budget of approximately 56 Gt CO_2, in contrast to the Technology Moratorium scenario in which action is delayed to 2030 (Exhibit B).[iv] This level of decarbonisation would require a major ramp-up in low-CO_2 steelmaking investments in the 2020s, approaching 170 million tonnes (Mt) of annual primary steel production by 2030, equivalent to about 70 near-zero-emissions steel plants.

EXHIBIT B

Annual emissions trajectories and cumulative emissions in the steel industry





Note: The left panel includes the ramp-up of carbon dioxide removals (CDRs) required to abate residual industry emissions by 2050 and ensure the sector reaches net zero.

Source: MPP analysis

iii All costs throughout this report are in US dollars based on an exchange rate of 0.877 EUR per USD.

iv The sectoral 1.5°C carbon budget is calculated as of the beginning of 2020 at a 50% probability of achieving a 1.5°C target. It has been broken down from a global carbon budget provided by the IPCC to individual sectors following an average of the sectoral allocations of BloombergNEF *New Energy Outlook*, the International Energy Agency's *Net Zero by 2050*, and the One Earth Climate Model.

3. Progress in the 2020s has implications for the mix of steelmaking technology in 2050.

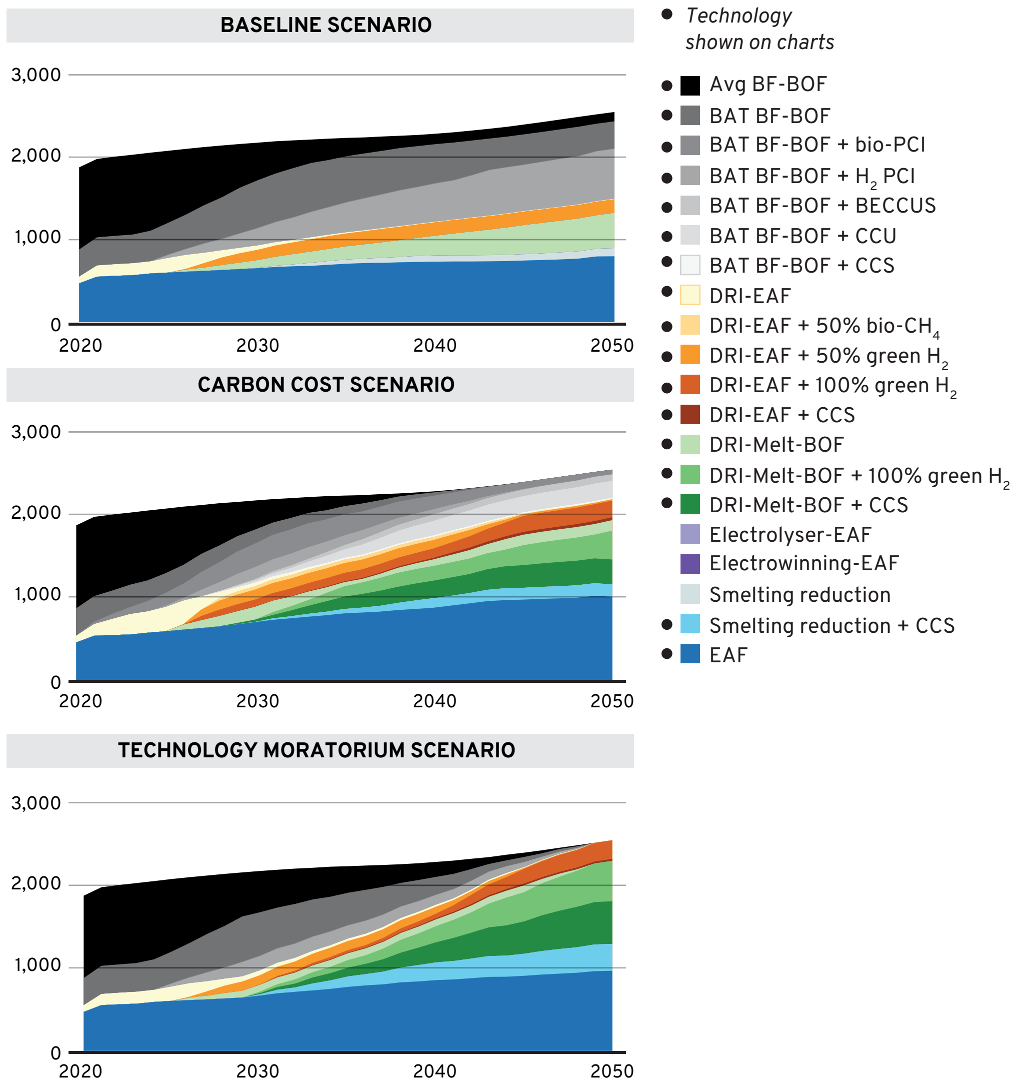
Given the typically 40-year asset life spans of steel plants, investment decisions in the 2020s will shape technology composition into the 2050s. In the Carbon Cost scenario where a cost of carbon is introduced early in the 2020s, the emissions reduction offered by secondary production is leveraged – within the limits of regional scrap availability – in advance of decarbonised primary steelmaking technologies becoming commercially available. This sees scrap-based steelmaking exceed 40% of total production by mid-century.

Additionally, production technologies coupling blast furnaces with bioenergy and carbon capture, utilisation, and storage (BECCUS) become cost-competitive by the late 2020s. This enables blast furnaces to provide 15% of total steelmaking capacity and retain a role in the industry in 2050 and beyond. In the Technology Moratorium scenario, delayed action sees greater uptake of direct reduced iron (DRI)–melter technology as a means to sharply reduce emissions in the 2030s–2040s and make the global industry compatible with a net-zero economy. Crucially, although the path to net zero in 2050 looks different between the two scenarios, early emissions abatement using lower-emissions transitional technologies is needed to deliver a net-zero outcome that is 1.5°C-aligned (Exhibit C).

EXHIBIT C

Evolution of the steel production technology mix

Crude steel production, in Mt



Note: The technology configurations comprise variations on two key processes, ironmaking and steelmaking. Ironmaking routes available today include conventional blast furnaces (BFs) or direct reduced iron (DRI) technologies. Electrolyser and electrowinning are novel ironmaking technologies that are not yet commercially available. These ironmaking technologies are then paired primarily with either a basic oxygen furnace (BOF) or an electric arc furnace (EAF) for steelmaking, both common today. Smelting reduction is an innovative technology that remains in development. Within these overarching routes there are additional subvariations: BF-BOFs can be designated as average or best available technology (BAT), or include the pulverised coal injection (PCI) process supplemented by additional feedstocks. Similarly, DRI technology can be made to work with a BOF by adding a melter (Melt) to the process. Lastly, all fossil fuel–based technologies can be paired with carbon capture, utilisation (CCU), and storage (CCUS) systems, which can derive their inputs from bioenergy (BECCUS). Please see the Glossary for additional details of the different production technology archetypes and their corresponding acronyms.

Source: MPP analysis

4. There is no silver bullet for decarbonising steelmaking, but a greater role for scrap and material efficiency, disruption of the blast furnace, and significant build-out of direct reduced iron–based steelmaking are likely.

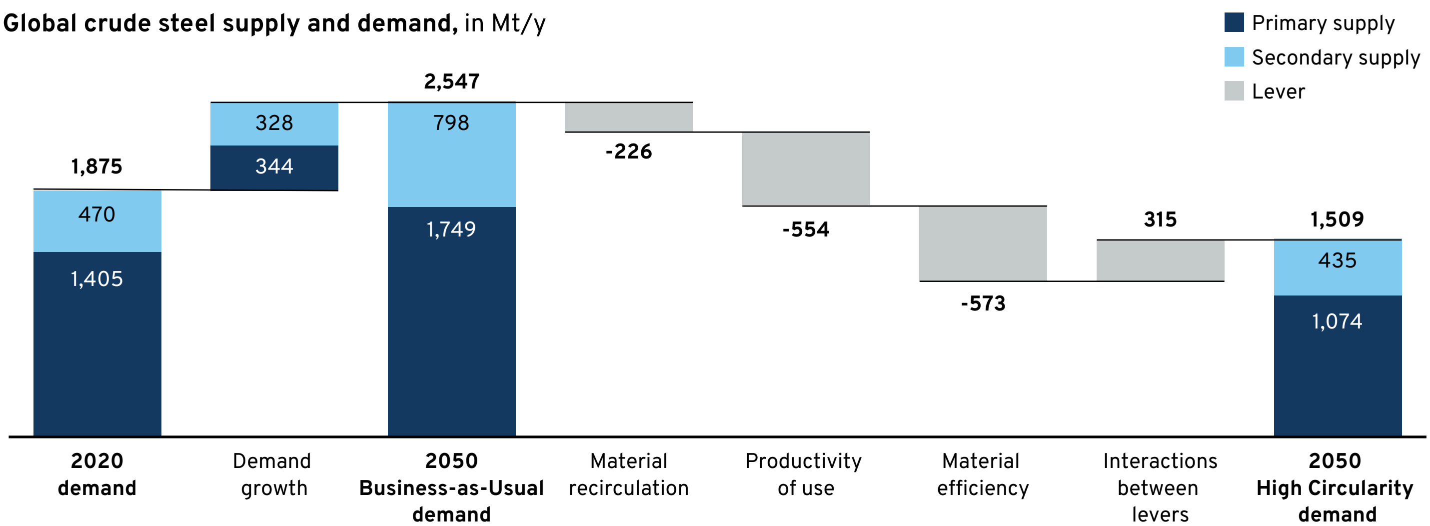
A portfolio of solutions is needed to decarbonise steelmaking because different technologies will be cost-competitive in different locations. Most of today's primary steelmaking is in places that have historically offered affordable access to coal mines, iron ore deposits, and water and rail transport infrastructure. The transition to net zero will add new location contexts. Access to low-cost, low-carbon electricity and hydrogen, bioenergy, carbon capture and storage (CCS) infrastructure and sequestration sites, competitively priced natural gas, and proximity to industrial clusters will shape the technology transition. The exact mix of steelmaking technologies in 2050 will depend on the price dynamics of key commodities, maturity timelines of different technologies, and the evolution of government policy, among other factors. Still, several key trends can be predicted with some confidence:

Scrap-based production, material efficiency, and circularity will play a critical role in decarbonising the industry, but large volumes of primary steel will still be needed to 2050 and beyond.

EXHIBIT D

Key levers to reduce primary steel demand

HIGH CIRCULARITY SCENARIO



Note: The Interactions lever refers to how preceding levers support and rely on one another to achieve the greatest possible impact.

Source: MPP analysis

Steel scrap will play an increasingly important role in decarbonising the sector, both as an input to secondary steelmaking (which relies heavily on electricity and will decarbonise in tandem with the decarbonisation of the power sector) and as an input to primary steelmaking that can help lower the carbon intensity of production.[v] Growth in the global supply of steel scrap, particularly in China, will see its utilisation increase from around 670 Mt/y today to almost 1,180 Mt/y by 2050, replacing iron ore (although the extent of this replacement will likely vary substantially from region to region).

v Primary steel uses iron ore as the main ferrous input, whereas secondary steel is made with mostly steel scrap (i.e., recycled steel).

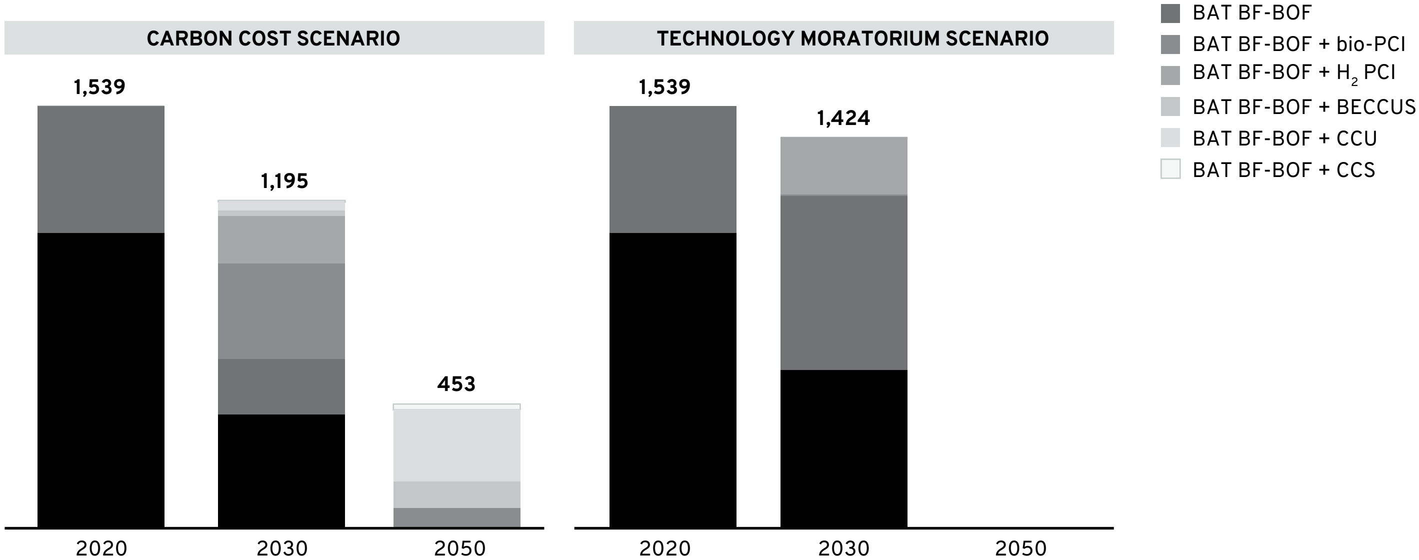
Future demand for primary (ore-based) steel can be further reduced through measures that improve scrap recirculation, productivity of steel use, and material efficiency across steel production and use. Recognising that there are diverging views on future steel demand, our Business-as-Usual (BAU) demand projection foresees an increase from 1,875 Mt in 2020 to more than 2,500 Mt in 2050, driven by demand growth in a number of developing regions. However, if material circularity measures are deployed maximally, they could reduce steel demand by up to 40% by 2050 relative to this projection, avoiding 18 Gt of steel production over the next three decades (Exhibit D). Even with these measures, not all steel demand can be met by recycling scrap, meaning primary steel must also decarbonise to achieve deep decarbonisation in the sector.

Today's dominant steelmaking technology, the blast furnace, is likely to undergo significant disruption, even if carbon capture technology is retrofitted.

EXHIBIT E

Evolution of blast furnace steelmaking capacity

Global blast furnace-based steelmaking capacity, in Mt/y



Source: MPP analysis

Retrofitting existing blast furnace–basic oxygen furnace (BF-BOF) technology with carbon capture, utilisation, and/or storage (CCUS) may not be a competitive long-term strategy (Exhibit E), particularly in regions where hydrogen can be produced at highly competitive costs. As the cost of zero-carbon electricity, and with it hydrogen, declines over the coming decades, DRI-based steelmaking routes using 100% zero-carbon hydrogen will be increasingly cost-competitive compared to fitting blast furnaces with CCUS.

Even in locations with favourable access to CO_2 sequestration sites and industrial clusters for CO_2 utilisation, hydrogen-based steelmaking may still be the more competitive option if zero-carbon hydrogen can be delivered at less than $1.70/kg, depending on the emissions profile of the existing furnace.[vi] In locations where zero-carbon hydrogen remains expensive, other carbon capture–based technology routes may offer more favourable economics than retrofitting blast furnaces. These alternatives include smelting reduction technology with CCS and natural gas–based DRI with CCS in combination with an electric arc furnace (EAF).

As the Carbon Cost scenario suggests, new roles for the blast furnace may yet emerge in a net-zero economy. Should a bio-based replacement for coke be developed or closed-loop circular carbon value chains be established, the blast furnace may prove to be a cost-efficient source of zero-emissions syngas (short for synthesis gas) for the production of feedstocks for the chemicals industry and/or a valuable source of negative carbon emissions. Significant uncertainty remains over the viability of these technologies, the size of the addressable market for captured CO_2, and the availability of sufficient supplies of sustainable bioresources for the steel sector.

vi Based on levelised cost of steelmaking in 2030 assuming a plant with a production capacity of 2.5 Mt/y and a utilisation factor of 80%.

Direct reduced iron–based steelmaking's share of primary production could grow from 5% today to between 70% and 80% by 2050, with implications for iron ore markets and emissions.

The DRI steelmaking process using natural gas provides an immediate emissions savings of about 1 tonne of CO_2 per tonne of crude steel (t CO_2/t CS) compared to an average BF-BOF of 2.4 t CO_2/t CS. In markets where gas prices are economically competitive for steelmaking, developing brownfield DRI capacity (by converting existing BF-BOFs) can help companies reach 2030 emissions reduction targets. These facilities can be set up to utilise a growing share of green hydrogen as supplies become available or can be fitted with CCUS technology, either of which can deliver near-zero-emissions steelmaking. They can also be 100% powered with gasified biomass, making DRI much more flexible in terms of feedstock than blast furnaces.

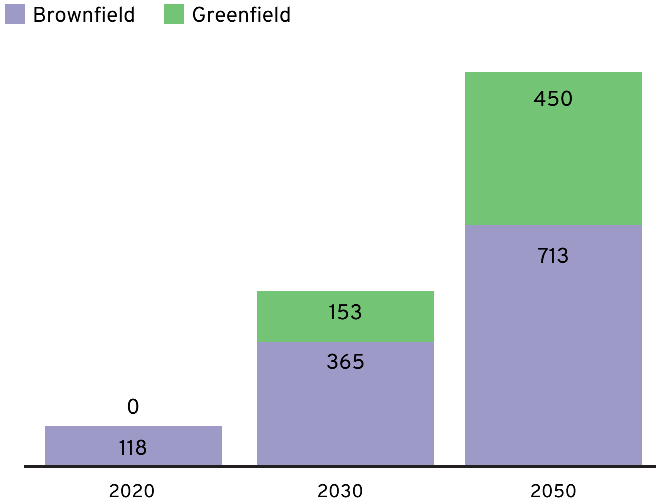
Only 13% of iron ore shipped today is of a suitable grade to use in DRI-EAF steelmaking. If DRI becomes the dominant ironmaking process, as this report suggests (Exhibit F), demand would need to be met through the development of new ore deposits, greater pre-processing of lower-grade ores to achieve sufficient purity, or the development of new melter technologies that enable lower-grade ores to be utilised in DRI-based steelmaking. Given the foreseeable development of new deposits and melter technologies, significant ore processing capacity is likely to be needed. Addressing the scaling of DRI demand will have cross-value-chain implications, creating opportunities and challenges in upstream iron mining activities.

EXHIBIT F

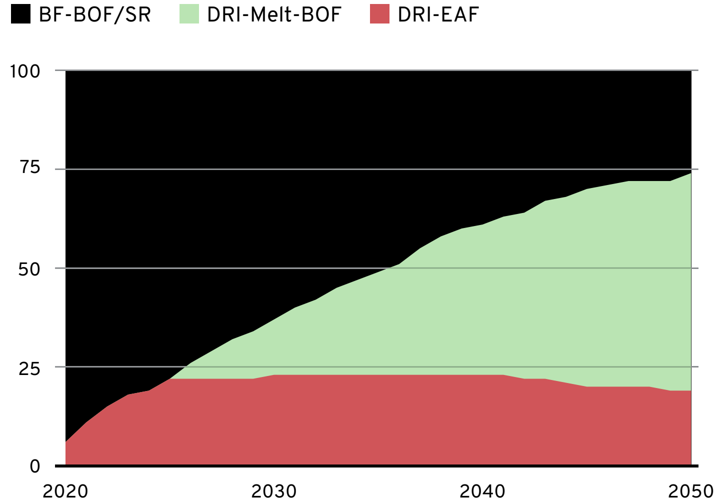
Evolution of DRI steelmaking and iron ore consumption

CARBON COST SCENARIO

Global DRI-based steelmaking capacity, in Mt/y



Global iron ore consumption, percentage



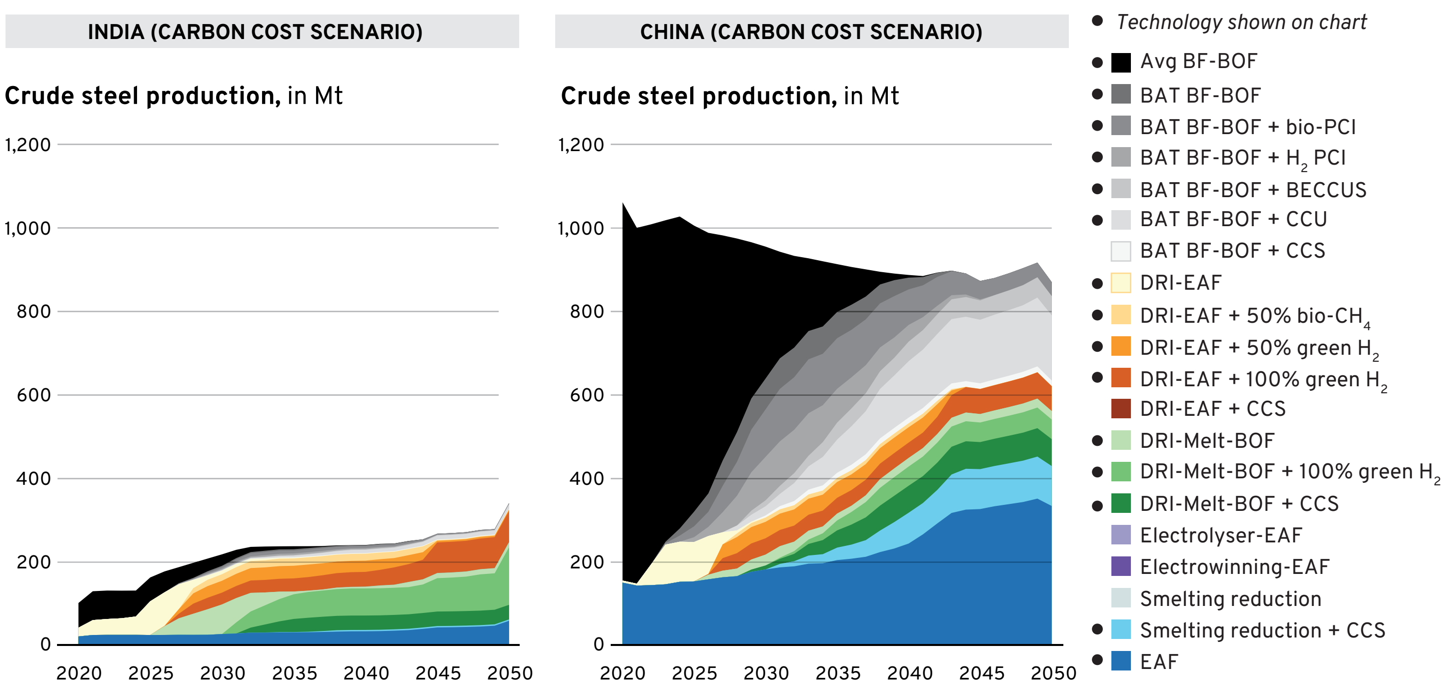
Source: MPP analysis

5. Decarbonisation trajectories for critical steel-producing regions will be shaped by existing assets, energy resource availability, policies, and regional demand for steel. Peak steel demand and increasing scrap availability in China combined with rising demand and increasingly affordable green hydrogen in India will do the most to shape steel sector emissions on a path to 1.5°C.

The technology and emissions pathway to a net-zero steel sector for each major steel-producing region will vary markedly. The technology composition and overall trajectory will be shaped by factors that affect the timing of investment decisions (such as regional demand shifts, the age of existing assets, or political decisions on whether to make or import steel) as well as those that affect the competitiveness of the different technology options available at those decision points (such as the infrastructure of existing assets, the availability of scrap steel, or local energy resources). Two trends will do most to shape a 1.5°C-aligned GHG trajectory of the sector (Exhibit G). China, leveraging an expanding domestic supply of scrap steel, invests heavily in secondary steelmaking capacity, which could account for almost 40% of domestic production by 2050. In India, rising demand and lower scrap availability will likely result in scale-up in primary capacity to meet burgeoning domestic demand. Low hydrogen prices in India mean that the majority of this primary capacity is centred on DRI technology utilising hydrogen.

EXHIBIT G

Regional evolution of the steel production technology mix



Source: MPP analysis

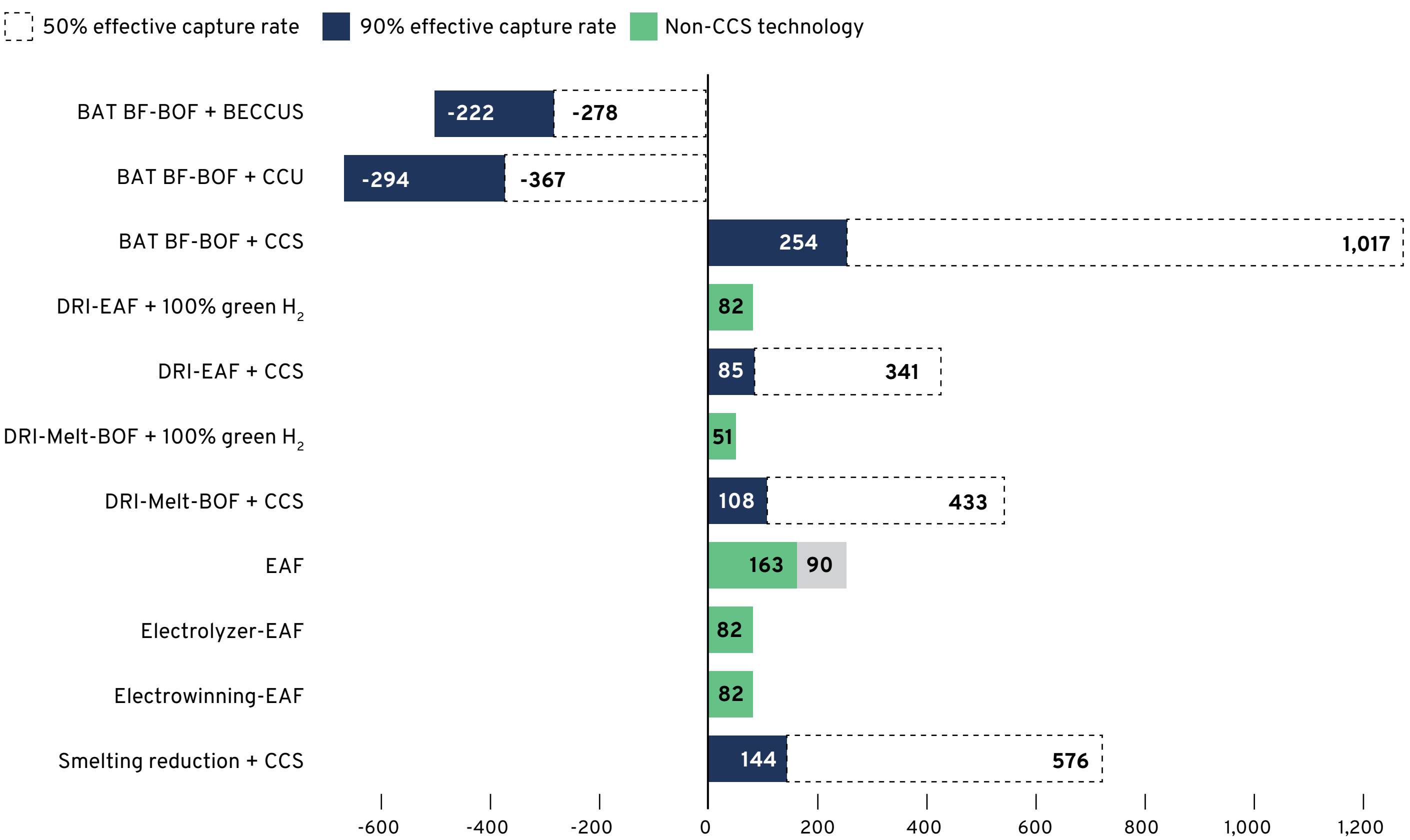
6. Almost all technologies will have residual emissions, which will need to be addressed to achieve net zero by 2050.

Except for technology archetypes that combine bioenergy resources with CCUS and deliver negative emissions, all near-zero-carbon production technologies will have residual emissions (Exhibit H). As a result, even if global power grids fully decarbonise, there will still be up to 0.3 Gt of residual CO_2 emissions from the steel sector (equivalent to ~10% of the steel sector's emissions today) in 2050. This is primarily due to expected uncaptured carbon dioxide from carbon capture technology (assuming a 90% effective capture rate) and electrode degradation in EAFs. The industry's remaining Scope 3 emissions, particularly in upstream feedstock production such as methane from coal mining and gas production, should also not be neglected. These will need to be managed by the industry and Scope 1 residuals alone may add a significant cost ($60 billion) annually from 2050 based on a $200/t$CO_2$ price for direct air carbon capture. Pricing these emissions into decision-making and developing further technology solutions to lower residuals will be key to minimising the cost of achieving net zero by 2050.

EXHIBIT H

Residual emissions of net-zero-compatible steelmaking technologies

Residual Scope 1 Emissions in 2050, in kg CO_2/t CS



Note: The range of residual emissions from EAF production depends on the presence of natural gas in the preheating and finishing steps. Both the BAT BF-BOF + CCU and BAT BF-BOF + BECCUS archetypes achieve negative emissions through bioenergy use.

Source: MPP analysis

7. Commercialisation and deployment of technologies to achieve net zero will require major investment inside and outside the steel industry, totalling $170–$200 billion annually.

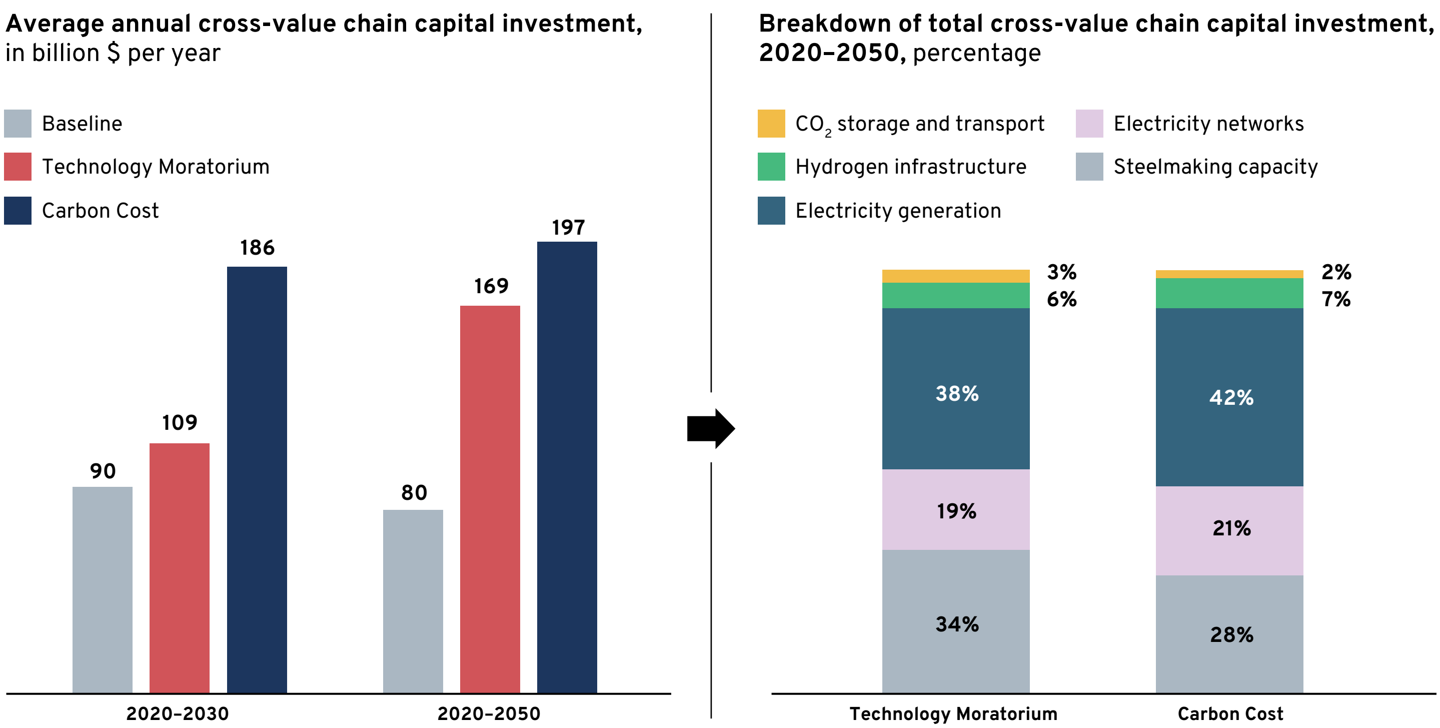
Even without major transformation, the steel sector is projected to need approximately $47 billion in investment annually to meet growing demand over the next 30 years and maintain existing sites. Transitioning the global steel asset base to net-zero-compliant technologies will require an additional $8–$11 billion investment annually — equal to $235–$335 billion of additional investment cumulatively by 2050. Initiatives to focus greater flows of capital towards those companies that align with a net-zero pathway will help accelerate these shifts.

The scale of investment needed in accompanying infrastructure could ultimately dwarf the needs of steel plants themselves (Exhibit I). Hydrogen use in the steel sector could grow to 52–75 Mt/y by 2050, eventually all coming from low-carbon energy sources. Electricity demands, both to generate sufficient volumes of green hydrogen and to meet the needs of an increasingly electrified asset base, could increase to 5,700–6,700 terawatt-hours per year (TWh/y) by mid-century.

In areas where competitively priced zero-carbon electricity is not available, carbon capture facilities will need to scale rapidly because storage for 550–750 Mt/y of CO_2 may be needed before 2050. In total, a net-zero steel sector will require cumulative investment between $5.2 and $6.1 trillion, with more than two-thirds of investment falling outside the steel plants.

EXHIBIT I

Summary and breakdown of the total investment involved in the net-zero steel transition



Source: MPP analysis

8. Lower- and near-zero-emissions primary steel will cost more. Public policies and value-chain coordination will be needed to address this premium, especially in the 2020s.

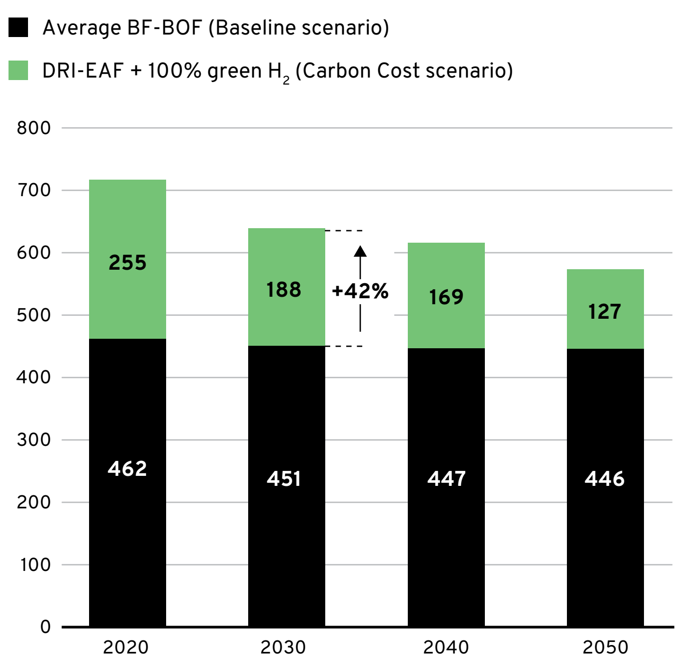
By 2050, the average cost of steelmaking (excluding capital charges) in a deeply decarbonised world could still be 15% higher than in a world without concerted efforts to decarbonise the steel industry. However, the impact of this on the final consumer would be comparatively smaller, given that intermediate steel products often account for only a portion of the cost of many of the final goods or services in which they are used (Exhibit J). If these costs were passed through to end-use markets and consumers, they would likely represent a premium lower than the prevailing market price volatility for basic materials. Moreover, this premium would reduce over time as near-zero-emissions technologies experience economies of scale and lower technology risk, making them increasingly competitive with conventional processes.

The cost difference between high- and low-emissions steelmaking will need to be bridged in the 2020s and 2030s. Measures to address this in the short term could include carbon contracts for difference, green public procurement, and bilateral off-take agreements between steel producers and steel buyers. In the medium term, these initial measures may need to be strengthened with market-based and non-market-based measures, including carbon taxes, emissions trading systems, and emissions performance standards for products. Such measures would be more effective if introduced with coordination across steel-producing regions (recognising differences between individual regions), but the steel sector lacks a global regulator through which discussions on the international challenges of decarbonising the industry can take place. Creating such a forum will be an important first step for coordinated global action.

EXHIBIT J

Impact of near-zero-emissions primary steelmaking on production costs and final consumer goods

Global average levelised cost of steelmaking, in $/t CS



Price difference of consumer goods produced with near-zero-emissions hydrogen steel vs. conventional primary steel, %

Consumer good	2030	2040	2050
Passenger car	+0.5%	+0.4%	+0.3%
Building	+2.1%	+1.9%	+1.4%
White good	+1.5%	+1.4%	+1.0%

Note: To provide a more illustrative comparison, the figures for average BF–BOF exclude any sort of carbon pricing, which would raise its production costs as a carbon intensive technology and further narrow the gap to near–zero-emissions alternatives.

Source: MPP analysis; ETC and Material Economics, **https://www.energy-transitions.org/publications/steeling-demand/**; McKinsey & Company and ETC, **https://www.mckinsey.com/business-functions/sustainability/our-insights/net-zero-steel-in-building-and-construction-the-way-forward**

9. The transition to net zero will have significant resource implications, with large increases in required hydrogen, electricity, and natural gas inputs, but a stark decline in coal.

Hydrogen: This analysis suggests production technologies using 100% green hydrogen could be responsible for 35%–45% of primary steel production in 2050, driving the consumption of zero-emissions hydrogen to 52–75 Mt/y (between 7% and 15% of potential global demand) by mid-century (Exhibit K).[vii] Supporting the growth of hydrogen-based steelmaking could help drive down the cost of green hydrogen production, unlocking its use in a wide range of other industrial applications where direct electrification is challenging.

Electricity: The 5,700–6,700 TWh/y of clean electricity the global steel sector would require by mid-century would be more than double the total power production of European Union member states in 2020. Delivering a resilient, secure supply of these enormous amounts of clean power represents a critical factor in unlocking decarbonisation for the steel industry and will require an extensive build-out of the necessary infrastructure. Given the high level of planning necessary for this infrastructure, for both transmission and distribution networks as well as generation assets, preparation must begin now.

Natural Gas: In addition to the growth of hydrogen, the uptake of DRI technology brought on by steel decarbonisation also sees a significant increase in the use of natural gas, with consumption more than tripling current levels in both net-zero scenarios. Procurement of certified low-methane-emissions natural gas will be important to credibly demonstrate a reduction in supply chain emissions where this fuel is used. This is particularly salient for the Carbon Cost scenario, where faster adoption of DRI technology precipitates a sharper increase in the use of natural gas over the next decade and a half. In both net-zero scenarios, CCUS plays an important role in ensuring that continued natural gas consumption is consistent with the sector's decarbonisation goals.

Bioenergy: Bioresources such as biochar, biogas, and biomass have a limited but valuable role to play in the steel sector's transition. Early action in the Carbon Cost scenario sees the use of bioresources within existing technology processes becoming cost-competitive, unlocking early emissions reductions of up to 40%–60% per tonne of crude steel compared to natural gas and coal. This early action sees the steel sector's bioresource use peak at 2.4 exajoules per year (EJ/y) in the 2030s, equivalent to less than 5% of global sustainable supply.[viii]

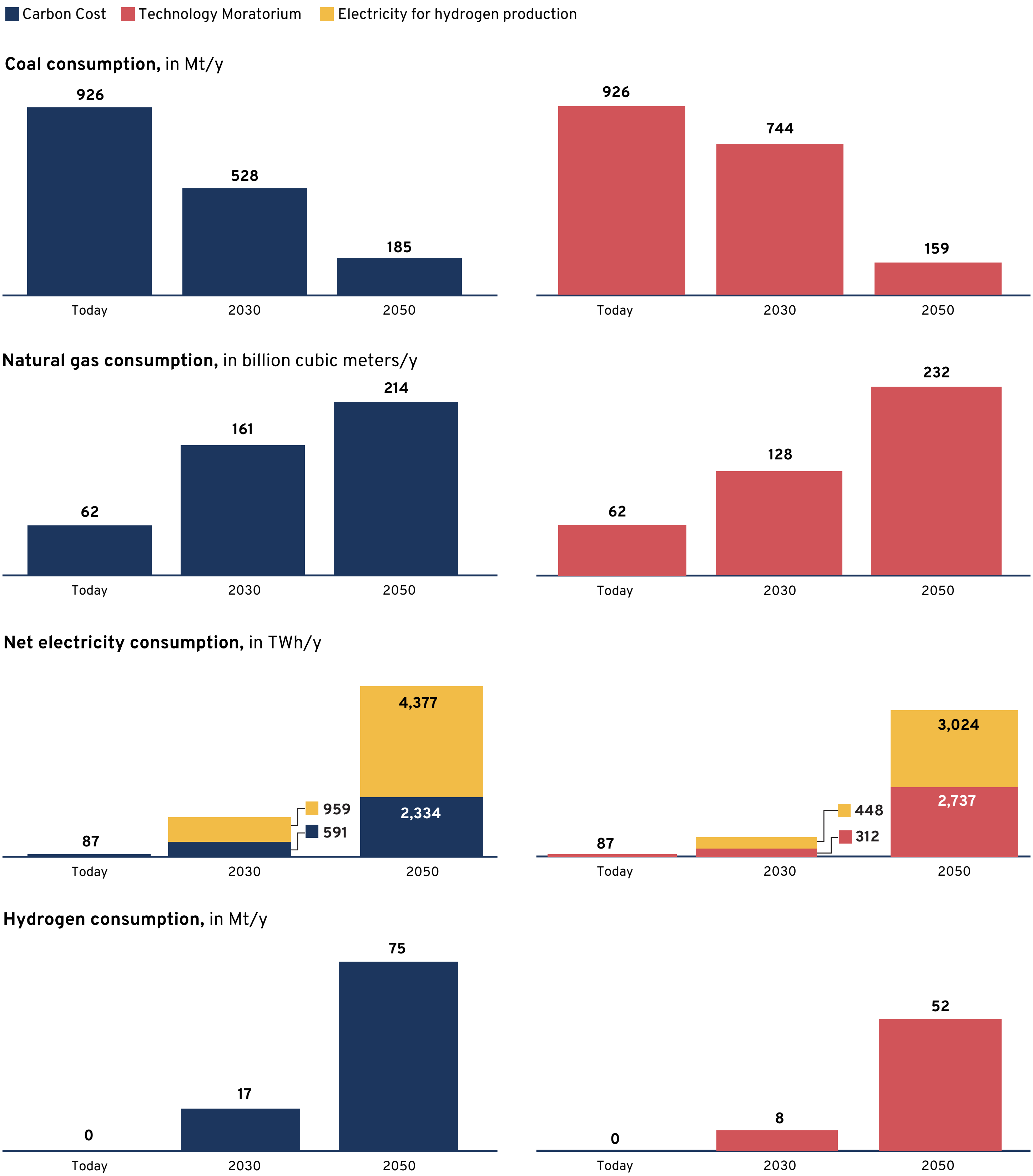
Coal: The replacement of blast furnaces with DRI-based steelmaking and smelting reduction techniques, which do not require metallurgical coal to reduce iron ore into molten iron, will trigger a major decline in demand for metallurgical coal. Use of thermal coal follows a similar trajectory, though its continued role in smelting reduction technology paired with CCUS sees it decline less sharply. Consequently, total coal consumption by the steel sector is expected to fall by more than 80% by 2050.

vii Energy Transitions Commission (ETC), *Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy*, April 2021, **https://www.energy-transitions.org/publications/making-clean-hydrogen-possible/**.

viii Energy Transitions Commission (ETC), *Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach*, July 2021, **https://www.energy-transitions.org/publications/bioresources-within-a-net-zero-emissions-economy/**.

EXHIBIT K

Energy consumption shifts driven by the net-zero steel transition



Source: MPP analysis

10. The key action this decade is to expand the pipeline of near-zero-emissions primary steelmaking. To accomplish this, policymakers need to create a level playing field and support a first wave of projects, industry needs to ramp up supply of and demand for near-zero primary steel, and finance must direct capital towards near-zero-emissions projects.

A narrow but clear window of opportunity is opening. Large swathes of existing steelmaking capacity will need major reinvestment decisions in the coming years and there is a risk of capacity-maintaining investment in high-emissions technology or delayed investment. The business case for low- and near-zero-emissions steel projects now represents the critical challenge that must be overcome.

Policymakers should urgently establish an international forum to debate and resolve the issue of how to create a level playing field and create markets for low-emissions steel production. In parallel, they must develop mechanisms to support deployment of near-zero-emissions industrial technologies and associated infrastructure (Exhibit L).

Industry must progress from the demonstration phase to final investment decisions for industrial-scale projects that will enter operation in the late 2020s. A redrawing of the steel value chain and supplier networks will require new partnerships to be forged. The demand side must also play a part in helping to pull those projects to market through premiums and signalling demand for material volumes of low-emissions steel.

Banks, institutional investors, and public-sector financial institutions must take a more hands-on approach to help manage the project and enterprise risk and direct capital towards first-mover projects and away from carbon-intensive investments. Widespread implementation of climate-aligned investment principles will be an important first step.

EXHIBIT L

Key actions in the 2020s to bring the iron and steel sector on a path to net-zero emissions by 2050

POLICY

Multilateral solutions

- **Level playing field**: Establish an international forum/alliance to debate and resolve the issue of how to create a level playing field and create markets for low- and near-zero-emissions steel production
- **Definitions:** Develop stable and ambitious trade- and transaction-grade standards for low-emissions steel production

National/regional supply incentives

- **Regulatory reforms:** Accelerate and improve permitting procedure for steel and supporting infrastructure
- **Investment:** Combine concessional, blended finance, credit and loan guarantees, and CAPEX grants for first-of-a-kind (FoaK) commercial-scale projects
- **Infrastructure:** Coordinate plans and strategies for necessary infrastructure and raw materials

National/regional demand incentives

- **Demand creation:** Extend green public procurement to support industrial strategy and lead market creation

INDUSTRY

Supply side

- **Projects:** Plan and deploy +70 near-zero-emissions primary steel mills by 2030
- **Target setting:** Set robust emissions reduction targets that are aligned with the goal of limiting global temperature rise to 1.5°C
- **Industry consortia:** Forge new partnerships across the steel value chain and upstream energy system
- **Common policy position:** Set out a joint high-ambition position to policymakers that reflects the role of international steel producers with assets in multiple geographies

Demand side

- **Green premiums:** Agree to long-term off-take with a green premium that is proportional to production cost increment and associated risks for both supplier and buyer

FINANCE

Capital allocation

- **Capital allocation:** Provide sufficient capital to enable at least $100 billion of additional investment in low-emissions steelmaking (and supporting infrastructure) each year until 2030
- **Business case innovation:** Co-develop strategies to manage the market, credit, liquidity, operational, and policy risks for FoaK projects

Climate alignment

- **Investment principles:** Implement 1.5ºC-aligned investment principles and plan and support a moratorium of non-climate-aligned steel investment from 2030

Source: MPP analysis

CONCLUSION

Bringing the iron and steel sector on a 1.5°C-aligned path to net zero is possible. It would require substantial annual investments in the order of $200 billion/y, of which more than two-thirds would fall outside the steel industry and into electricity, hydrogen, and CO_2 infrastructure, with large-scale implications across the wider value chain.

A course towards 1.5°C and net zero will require new levels of partnership between policymakers, industry leaders, and financial institutions. Early action in this decade is required to unlock technological innovation and economies of scale and to enable large-scale GHG emissions reductions in the 2030s and 2040s.

In a joint effort by actors across the value chain, we can make this mission possible.

MISSION POSSIBLE PARTNERSHIP

The Mission Possible Partnership is an alliance of climate leaders focused on supercharging efforts to decarbonise some of the world's highest-emitting industries in the next 10 years.