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IIGCC

The Institutional Investors Group on Climate Change

As part of

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Global Investors Driving Business Transition

GLOBAL SECTOR STRATEGIES: INVESTOR INTERVENTIONS TO ACCELERATE NET ZERO STEEL

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ABOUT THIS REPORT

The *Global Sector Strategies: Investor interventions to accelerate net zero steel* report was developed by Institutional Investors Group on Climate Change (IIGCC) as part of the Global Sector Strategies, a new workstream coordinated by the investor networks that deliver Climate Action 100+.

The report aims to help investors accelerate the transition to net zero in the steel sector. Produced by the IIGCC and building on work by the Energy Transitions Commission [1][2], IEA [3][4][5][6][7][8], Material Economics [9][10], McKinsey [11][12], Responsible Steel [13], Rocky Mountain Institute [14], TERI [15] and Transition Pathway Initiative [16] amongst others, it provides an overview of the status of decarbonisation in the steel sector, what is needed to overcome the challenges posed by the transition to net zero and inform investors' engagements with steel companies. More specifically, it identifies:

1. The level of decarbonisation needed in the steel sector, consistent with limiting the rise in global temperature to 1.5°C (referred to as "net zero" in this report).
2. The principal measures that can be taken to reduce emissions in the steel sector.
3. The specific challenges to delivering net zero in the steel sector.
4. The actions steelmakers and others should take to align to net zero.
5. How investors can accelerate progress.

This report has been circulated to Climate Action 100+ investor signatories and steel companies engaged under the *Global Sector Strategies* workstream, to solicit feedback on its conclusions which have been assessed and incorporated. It will now be used as a tool by investor signatories that are actively engaging with steel companies on the Climate Action 100+ focus list, through sector-wide dialogue that encourages collaborative action and individual engagement.

It is important to note that this report represents investors' current understanding on how the steel sector should decarbonise. This understanding will evolve over time and will be reflected in future iterations as dialogue with the companies continues.

IIGCC would like to express its gratitude for the many colleagues at the supporting investor networks that deliver Climate Action 100+ who provided insightful input, edits, and coordinated investor and corporate feedback during the development of this report: Yong Por (AIGCC), Kate Simmonds (IGCC), Laura Hillis (IGCC), Dan Seligman (Ceres), and Marshall Geck (PRI).

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The feedback provided by these individuals does not represent an investment endorsement or recommendation and does not reflect any policies or positions of their firms.

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ABOUT CLIMATE ACTION 100+ AND THE GLOBAL SECTOR STRATEGIES

Climate Action 100+ is an investor-led engagement initiative that strives to ensure the world's largest corporate greenhouse gas emitters take necessary action on climate change. More than 615 investors with $55 trillion in assets collectively under management are engaging 167 focus companies to improve climate governance, curb emissions, align their emissions performance with net zero, and strengthen climate-related financial disclosures. Climate Action 100+ is delivered by five investor networks working with the initiative's investor signatories (AIGCC, Ceres, IGCC, IIGCC and PRI).

In March 2021, Climate Action 100+ published the first company assessments from its Net Zero Company Benchmark [17] ('Benchmark'), which evaluates climate performance and corporate transition plans. Acknowledging that corporate net zero strategies will vary significantly by sector, Climate Action 100+ is developing a series of Global Sector Strategies, to accelerate sectoral decarbonisation.

This marks a new workstream from the Climate Action 100+ initiative which aims to rapidly accelerate the industry transition by identifying key actions for companies, investors and industries overall. Aligned with the Benchmark, the Global Sector Strategies will guide investor engagement being carried out by Climate Action 100+ signatories, mapping out what corporates in a number of carbon intensive industries need to do to build out effective transition plans and decarbonised value chains.

ROLE OF THE INVESTOR NETWORKS

Each Global Sector Strategy is developed by the investor network with the most in-depth strategic understanding of the sector ('lead'), in consultation with the other investor networks that deliver Climate Action 100+ ('supporting').

The lead investor network develops the strategy in consultation with external sector technical experts, signatory investors and focus companies. The supporting investor networks assist by contributing insights to the report and gathering feedback from their investor network members and focus companies.

The reports provide sector-wide actions that investors can request from focus companies for each regional context. Each investor network will play an important role in taking regionally specific actions to their investors, to inform local focus company engagement.

IIGCC led on the development of the Global Sector Strategy for the steel sector. The supporting investor networks – AIGCC, Ceres, IGCC and PRI – have all reviewed and endorsed the recommendations outlined in this report.

ACRONYMS AND DEFINITIONS

$: USD

€: Euro

BAU: Business as usual. This usually refers to a scenario with no significant changes in technology, economics, or policies, so that normal circumstances can be expected to continue unchanged.

BF-BOF: Blast furnace-blast oxygen furnace

Bn: Billion (USD$)

CAGR: Compounded annual growth rate

CCS: Carbon capture and storage

CCUS: Carbon capture utilisation and storage

CCS/CCUS: this term may be used to transmit that there is possibility for either of the technologies to be used in a certain context.

CO_2: Carbon dioxide

DR: Direct reduction

DRI: Direct reduced iron

EAF: Electric arc furnace

EU: European Union

GHG: Greenhouse gases

Gt: Gigatons

H2: Hydrogen

Industry cluster: Groups of similar and related companies in a defined geographic area that share common markets, technologies, worker skill needs, and which are often linked by buyer-seller relationships.

MoU: Memorandum of Understanding

Mt: Million tonnes

PPP/s: Public–private partnership/s

RDD&D: Research, development, demonstration, and deployment

TWh: Terawatt-hours

FOREWORD

As of June 2021, nine steel companies representing ~20% of the world's steel production, including the world's five largest, have committed to net zero greenhouse gas (GHG) emissions by 2050 or earlier. These commitments have been made despite the uncertain development of emerging low carbon technologies and the potentially high cost of deployment. As such, they demonstrate a willingness amongst industry leaders to tackle climate change. This progress is very much welcomed by investors. Nevertheless, achieving net zero GHG emissions by 2050, particularly in the steel sector, remains a big challenge. The remaining 80% of the industry has yet to state a net zero ambition and, as this report clearly highlights, reaching net zero requires a concerted effort from all stakeholders (steelmakers, policy-makers, energy companies, steel customers, suppliers and investors) coupled with significant improvements in technology and its scalability.

Most of the steel companies making these net zero commitments have yet to lay out in detail how they expect to deliver on them. Given many important technologies and processes (such as hydrogen based DRI and CCS/CCUS) are still at an early stage and the pace of their development unclear, this is perhaps understandable. Nevertheless, as this report clearly shows, waiting for the technology to mature and exclusively relying on technology to reach net zero, is not a credible decarbonisation strategy. Absolute emissions from the steel sector have to fall c.30% from current levels by 2030 to stay within a sectoral budget consistent with net zero by 2050 science-based pathways – delaying action significantly increases the risk that the industry exceeds this budget. Furthermore there is no single silver bullet for decarbonising steel: new technology alone will not deliver net zero. Measures such as enhanced material and energy efficiency plus shifting the mix towards scrap production are cost-effective actions that can make a substantial contribution. Plans to make these changes should begin today. Net zero requires steelmakers to pursue multiple actions simultaneously and with urgency.

In the transition to net zero, the interests of all stakeholders need to be accounted for. Steel companies need to take urgent action to decarbonise whilst creating shareholder value and delivering a just transition for their workforce and communities. Striking this delicate balance will not be easy and will require the support of both long-term investors and policy makers. This report also highlights that the support of energy companies and the steel value chain will also be needed. Decarbonisation of steel, arguably more than many other emission intensive sectors, requires not just steelmakers to change but also substantial actions from a wide range of stakeholders.

As investors, we are ready to play our part to accelerate this transition. We recognise it will take time but work must start now. The first step is for steelmakers to set out their commitment to contribute to delivering a net zero society and, in as much detail as they can today, how they intend to deliver. We recognise there may initially be gaps in these plans but stand ready to provide long-term support and funding for credible net zero strategies. We also recognise that steelmakers cannot deliver net zero by themselves; change is required across the value chain and the policy framework in which they operate. We commit to lending our voice to drive the required change amongst this broader eco-system.

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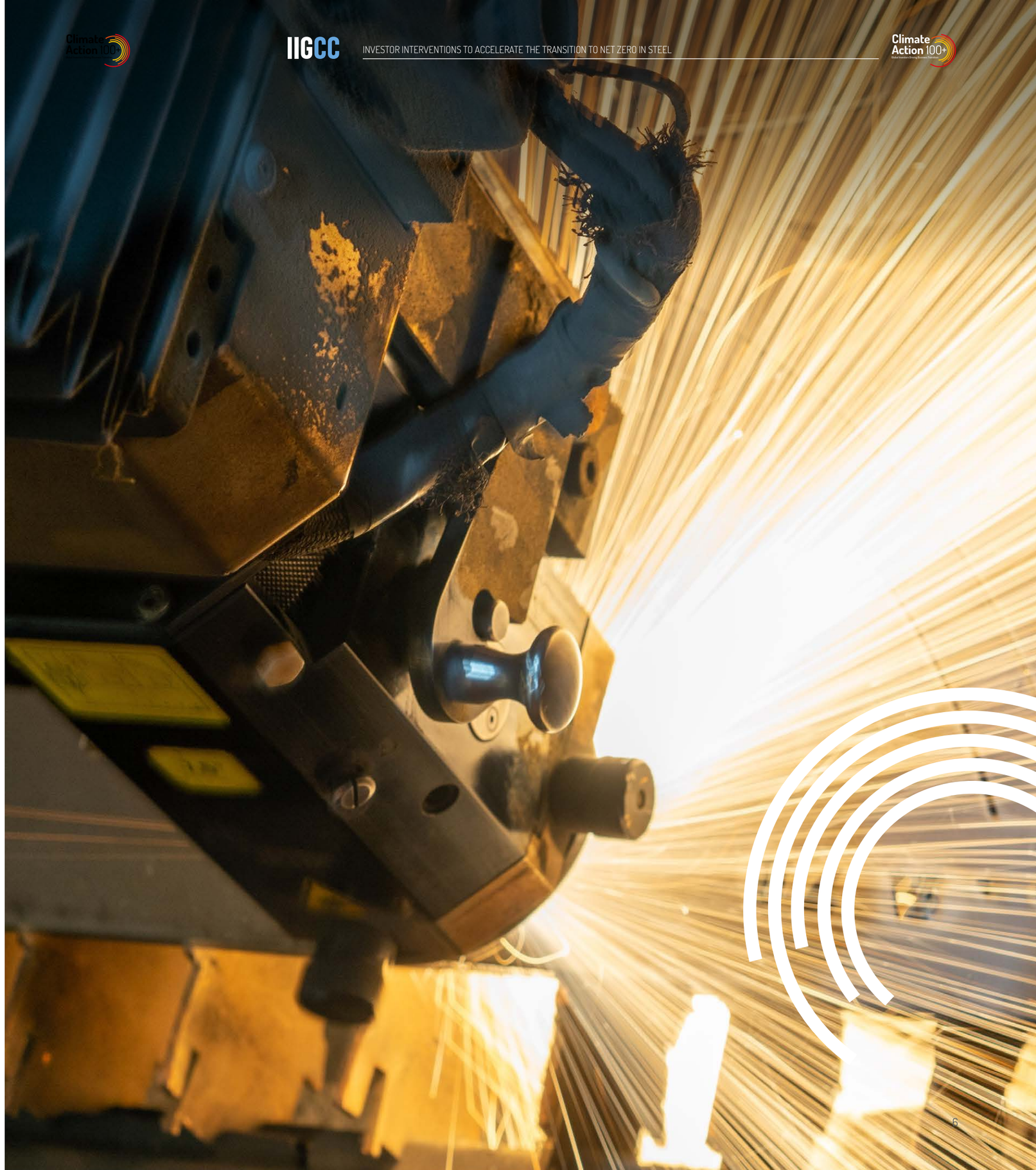

EXECUTIVE SUMMARY

This report aims to help investors accelerate the transition to net zero in the steel sector. It provides an overview of the status of decarbonisation in the steel sector and outlines what is needed to overcome the challenges posed by the transition to net zero by 2050.

These recommendations are based on a review of recent publications on this topic and an analysis of the measures that can be taken to reduce emissions in the steel sector using a simplified emissions model. Five measures appear key:

1) Increasing the proportion of steel produced by the scrap-EAF process
2) Enhancing material efficiency of steel products to limit steel demand growth
3) Further incremental improvements in energy efficiency of existing steel production capacity
4) Invest in low emission DRI-EAF capacity (including hydrogen based) for primary steelmaking
5) Apply CCS/CCUS technology to fossil-based steel production plants where feasible

Increasing the proportion of steel made by the scrap-EAF process (Measure 1) from 23% to 60% by 2050 could reduce annual emissions by 2.4 GtCO2e (51% below an assumed BAU scenario). A relatively large mix change from primary steel production to scrap-EAF already appears likely given the stock of steel approaching end of life is rising. This should result in a significant fall in overall carbon intensity of steel production over the coming decades without a substantial increase in production costs. Enhancing material and energy efficiency (Measures 2 and 3 respectively) could also deliver substantial reductions of emissions across the steel value chain cost-effectively. Investment in new DRI-EAF capacity, which will ultimately be able to utilise low-carbon fuels like green hydrogen, and CCS/CCUS (Measures 4 and 5 respectively) are likely to be needed but require substantial investment.

Many of the most cost-effective decarbonisation measures will require a concerted and co-ordinated response. Delivery needs actions, not just from steelmakers, but from policy makers and stakeholders across the steel value chain. Action in one area will also impact the effectiveness of other measures. All regions will need to take part and the best approach will vary by company and market. China accounts for at least 55% of global steel emissions and should lead the shift to EAF. India is expected to account for over 40% of incremental steel demand between 2018 and 2050 and should avoid locking in emissions by building new BF-BOF capacity if net zero is to remain feasible.

Existing studies suggest that the current set of responses to reduce emissions in steelmaking is unlikely to deliver emissions reduction consistent with net zero. In particular, there exists little evidence of the concerted action needed from consumers of steel and in the steel value chain to reduce overall demand (Measure 2) or policy programmes that sufficiently support the decarbonisation of steel in the countries that dominate production. Substantial investments in DRI and/or CCS/CCUS may raise production costs, particularly in the near term. In an industry with tight margins, funding this investment – especially without incentives (either from steel consumers or policymakers) to value emissions-free steel – may prove problematic. This report suggests that even with the combination of all these measures, there will still be residual annual emissions in the steel sector of 1.2 GtCO2e in 2050, a 1.0 GtCO2e shortfall against the emissions budget consistent with net zero established by the IEA NZE 2050 scenario [8].

To avoid this shortfall and accelerate progress in the steel industry towards net zero this report advocates the following actions:

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ACTIONS FOR STEEL COMPANIES

1. **Consistent with the Climate Action 100+ Net Zero Company Benchmark Indicators 2-4, set short-, mid-, and long-term decarbonisation targets in-line with the IEA NZE 2050 scenario.** The IEA NZE 2050 scenario data models Scope 1 emissions in the Iron and Steel industry falling 29% by 2030 and 91% by 2050 compared to 2019 levels. Further work is needed to define the exact emissions pathway implied by NZE 2050, however factoring in Scope 2 it is likely to imply that total emissions from steel should fall even faster.

2. **Develop and publish a comprehensive transition plan that is consistent with the Climate Action 100+ Benchmark Indicator 5.** This report recognises that technologies like CCS/CCUS and hydrogen based DRI are still at their early stages and, due to the uncertain pace of development, it will be difficult for steelmakers to provide complete visibility today on how they intend to deliver on their targets. Nevertheless they should be able to say, in broad terms, how they intend to deliver on their net zero ambitions. Companies should specify in their transition plans the main measures they intend to deploy and their expected contribution to both medium- and long-term targets.

3. **Produce reports setting out the opportunities and scale for the company to deploy a) CCS/CCUS and b) Hydrogen based DRI to decarbonise its steel production.** These reports should specify, in as much detail as is practically possible, the role the company currently expects these emerging technologies to play in its overall decarbonisation plan. This should include: the locations (existing or new) where the technology is under consideration, what the company sees as the main barriers (i.e. policy, cost or technology) to deployment and what actions it is taking to address those barriers, how much it is investing in each technology currently and what it expects the overall cost to be, the impact this might have on steel production costs and, finally, what milestones it is setting itself to judge progress. These reports should be published by the end of 2022.

4. **Support the development of international certification standards for "green steel" production and commit to adhere to those standards.** To support customer demand (and justify a premium for) "green" steel, there needs to be confidence in a robust certification scheme such as that being developed by Responsible Steel [13] [14]. Steelmakers should support such efforts and adhere to certification schemes that propose carbon content standards consistent with net zero.

5. **Consistent with Climate Action 100+ Benchmark Indicator 6, commit to aligning its capital expenditure plan with its broader net zero strategy.** Consistent with Actions 2 and 3 steelmakers should set out their plans to invest in low-carbon steelmaking technologies including scrap-EAF, DRI-EAF and CCS/CCUS. Additionally steelmakers should commit not to invest in any new capacity which is not capable (either for technical or economic reasons) of being aligned with their short, medium and long-term science-based decarbonisation targets.

6. **Consistent with Climate Action 100+ Benchmark Indicator 7, specify the policy positions that the company will adopt to accelerate the delivery of its transition plan.** This plan should include:

   a. Its position on carbon pricing mechanisms designed to incentivise investments in low-carbon production technologies in countries/regions where it operates.

   b. Its position on policy/regulations like the EU's carbon border adjustment, that aim to avoid carbon leakage between jurisdictions.

   c. Carbon content requirements for steel in government and/or private procurement contracts [14].

   d. Other government financial and non-financial incentives (e.g. R&D funding) required to support the transition to net zero in the steel industry [14]

7. **Consistent with Climate Action 100+ Benchmark Indicator 9, steel companies should commit to providing a Just Transition.** To meet this commitment, companies should set out, in a board level report, how they intend to manage the wider societal impact of transitioning to net zero and who will be responsible for implementing its just transition strategy.

INDUSTRY-WIDE ACTIONS

8. **In coordination with major steel customers and other value chain participants, convene a cross-sector working group on how material efficiency can be substantially increased across the value chain.** This working group would aim to identify by working through, application by application, where a combination of improvements in manufacturing, end product design/use and recycling have the greatest potential for improving material efficiency and how those improvements can be delivered. The findings, recommendations, and opportunities – including any hurdles that need to be addressed by other stakeholders, including policy makers – should be outlined in a public report.

9. **In coordination with major suppliers, produce a report evaluating the mid- and long-term impacts of the transition to net zero in steel on a) raw materials and b) 100% green energy (hydrogen and electricity).** These reports would enable suppliers to make long term plans to scale back metallurgical coal production, for example, as well as anticipate growth in demand for iron ore pellets required for DRI-based steel production, green hydrogen and green electricity. Thus ensuring that the pace of the transition is not constrained by the lack of availability of resources and infrastructure.

ACTIONS FOR INVESTORS

10. **Identify the largest global purchasers of steel and undertake a systematic engagement process to obtain public commitments from them to buy "green" steel (as established in Action 4).**

11. **Provide capital explicitly to finance the low carbon steelmaking capacity including hydrogen based DRI-EAF, steelmaking from scrap (EAF) and CCS/CCUS deployment.** This will require working alongside other investors and stakeholders such as the Climate Bond Initiative [18] to establish robust standards for steel sector "transition bonds" that define the types of steel projects (and technologies) would fall into the steel "transition" criteria, the appropriate reporting mechanisms and direct covenants.

12. **Support policies consistent with accelerating the transition to net zero.** Investors should support sensible and socially responsible policy that incentivises the steel industry to rapidly reduce emissions and align with net zero. These policy asks can be identified through continued engagement with steel companies, the steel sector, and policymakers, and as they emerge from the company transition plans as requested by Action 6.

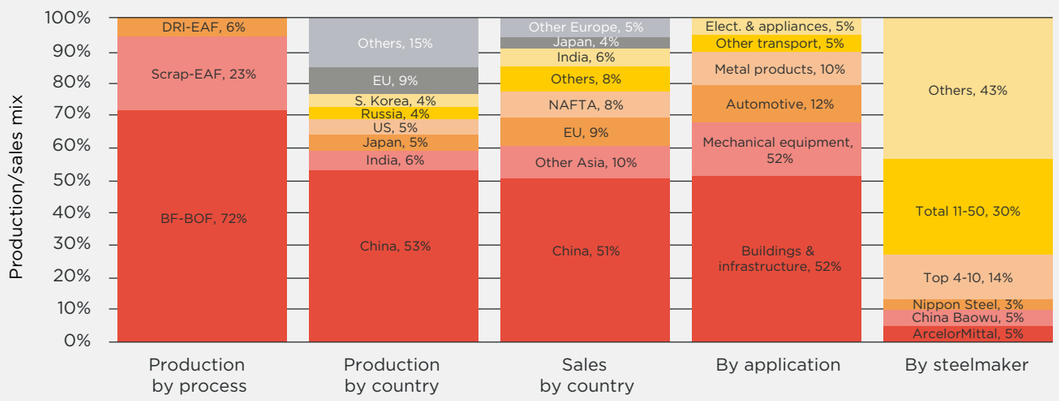
STEEL INDUSTRY BACKGROUND

Steel is a metal alloy formed from iron ore, carbon, and other elements depending on the final properties desired. Its strength and low cost make its use widespread across the construction, transport and industrial sectors. Rising demand from China saw global growth rebound in the early 2000s with the 5-year CAGR peaking at 8.3% in 2007. Growth has been slowing over recent years, averaging just 2% per year between 2014 and 2019. Global production in 2019 was 1,869 million tonnes (Mt) and fell by ~1% in 2020 due to COVID-19 related value chain disruption [19].

Steel is currently produced by two main methods. The ***Blast Furnace and Basic Oxygen Furnace (BF-BOF)*** route (72% of total production) is typically used to make virgin (or 'primary') steel. In this process a high grade (metallurgical) coal is used as both an energy and heat source and as a reduction agent to remove oxygen from the iron ore. Small amounts of other elements are added at the BOF stage to give the steel the desired properties. On average 1.3 tonnes of iron ore and 0.8 tonnes of coal are used to make a tonne of steel, although a limited amount of scrap steel can also be added at the BOF stage. Assuming $170 per tonne of metallurgical coal and $620 per tonne of steel, the cost of metallurgical coal accounts for ~22% of average steel price.

The second method uses an Electric Arc Furnace (EAF), fed by either scrap steel or by Direct Reduced Iron (DRI), also known as "sponge iron". It is estimated that c.500 Mt of steel are recycled every year and that 83% of steel produced is recycled at the end of its life [9]. Feeding this steel "scrap" into the EAF makes "secondary" steel, which currently accounts for 23% of total steel produced. The Direct Reduction (DR) method reduces iron ore in a solid-state form using carbon monoxide and hydrogen, two reducing agents that are currently almost entirely derived from natural gas or coal. The combination of the DRI-EAF methods account for 6% of total steel produced and it is dependent on DR-grade iron ore pellets (typically 67% iron ore or greater). The principal sources of DR-grade pellets are located in South America (Brazil, Chile), Canada, Sweden, Bahrain, Oman and Iran [20].

Figure 1: Steel production mix in 2019 by a) process, b) country, c) sales destination, d) end market, e) steelmaker



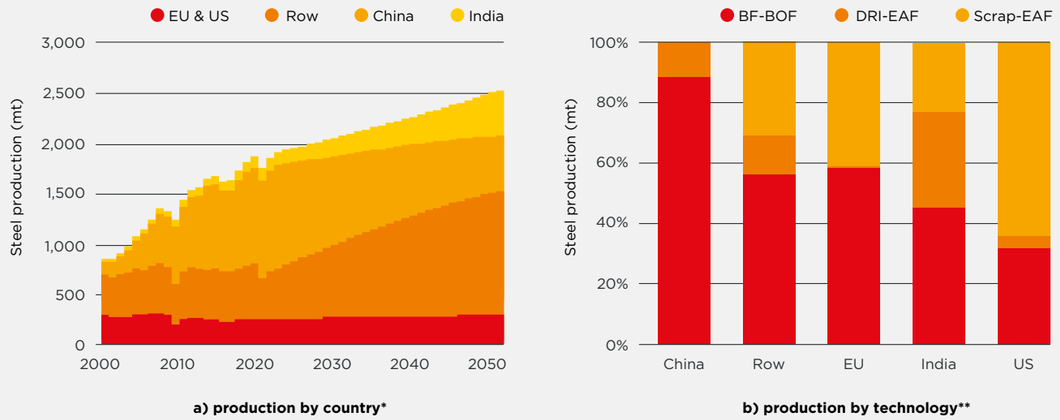
Source: World Steel Association [19].

Steel production has largely expanded in countries with rising domestic demand. Since 2000, 85% of the incremental production has come from China which now accounts for 53% of the global steel production total (see Figure 2a). However, China's stimulus plans after the 2008-9 global financial crisis have led to overcapacity, depressing prices and margins globally [10]; Chinese production is now expected to decline steadily over the long term according to government-backed think tank China Metallurgical Industry Planning and Research Institute [21]. European steel production (9% of the global total) has failed to recover post the 2008-9 global financial crisis and is down 15% since 2007. US production (5% of total) has been steadily declining since 2000. Indian production growth has averaged 8% annually since 2000 and now accounts for 6% of the global total. India is expected to represent over 40% of incremental demand between 2018 and 2050.

Figure 2b highlights how the mix of production methods varies substantially between regions. Scrap fed EAFs account for 41% and 64% of production in Europe and the US respectively, but just 23% in India and 12% in China. While the use of EAF production is slowly rising in all markets, rapid overall growth in the steel sector in China (where EAF is a small part of the mix) has led to its share of global production stagnating. DRI-EAF as a proportion of global production has remained largely constant at 6% and over half this capacity is located in India and Iran.

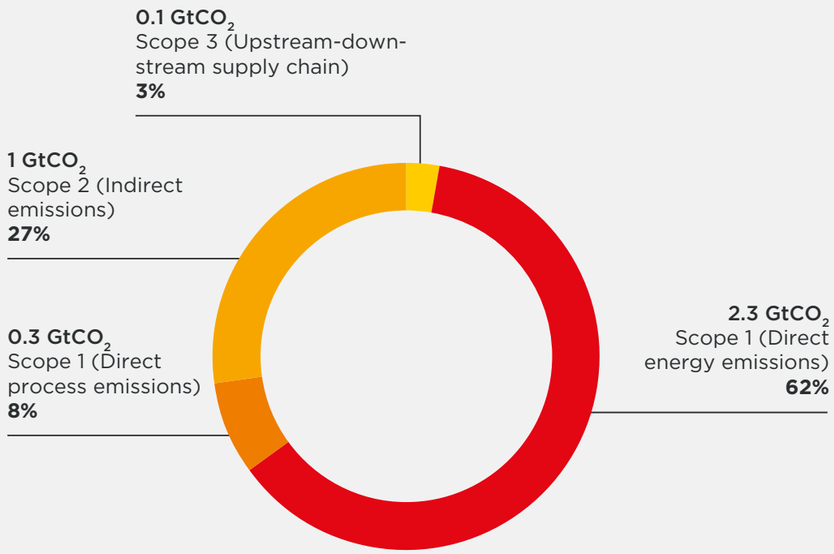
Steelmaking is often seen as a highly strategic industry by national governments, supporting domestic economic development as well as export driven economies (31% of steel is exported from its country of origin [11]). In part because of this, the industry remains highly fragmented, with the three largest global steelmakers (Arcelor Mittal, China Baowu and Nippon Steel) accounting for just 13% of total production and the top ten listed steelmakers just 27%.

Figure 2: a) Steel growth by country and b) production mix by country

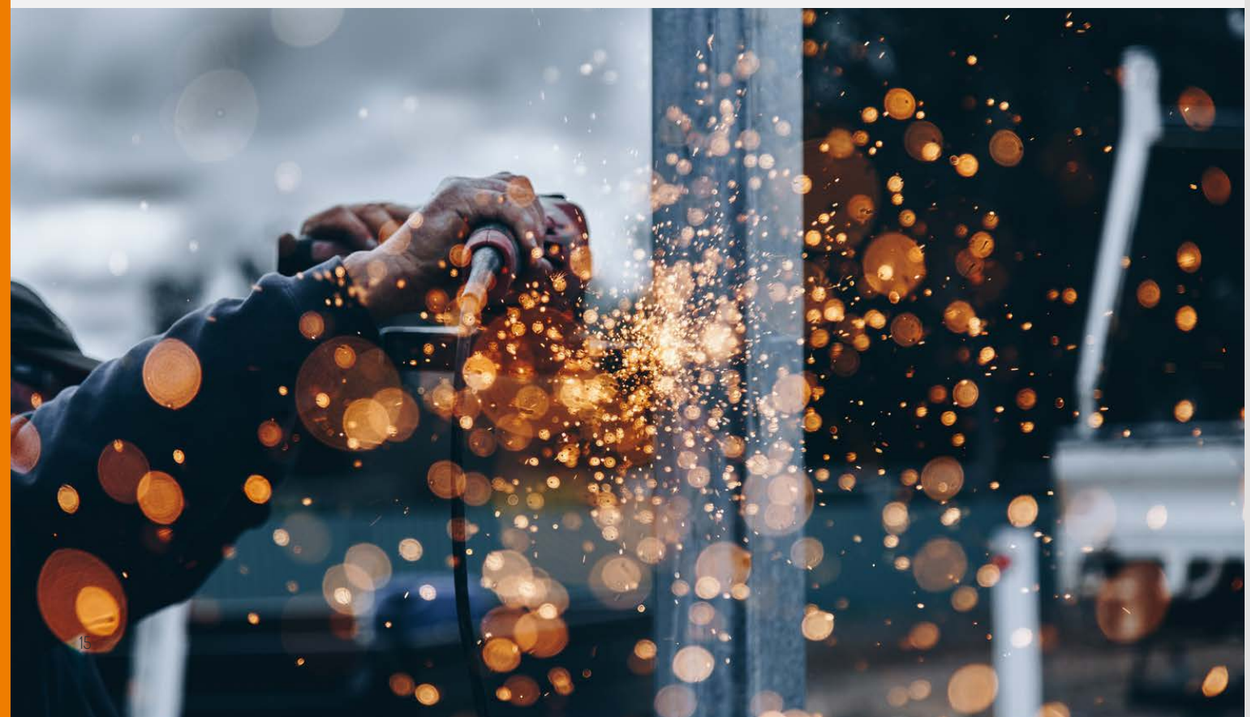


Source: *Historical data from World Steel Association [22] with forecast for China and India based on [23] and [15] respectively.
**Based on World Steel Association data.

Figure 3: Steel industry emissions by scope (% and $GtCO_2$)



Source: Adapted from IEA Iron and Steel, Tracking report. June 2020. Total of 3.7 $GtCO_2$ includes 0.1 $GtCO_2$ of Scope 3 (supply chain)emissions



CLIMATE IMPACT OF THE STEEL INDUSTRY

IMPACT BY PRODUCTION ROUTE

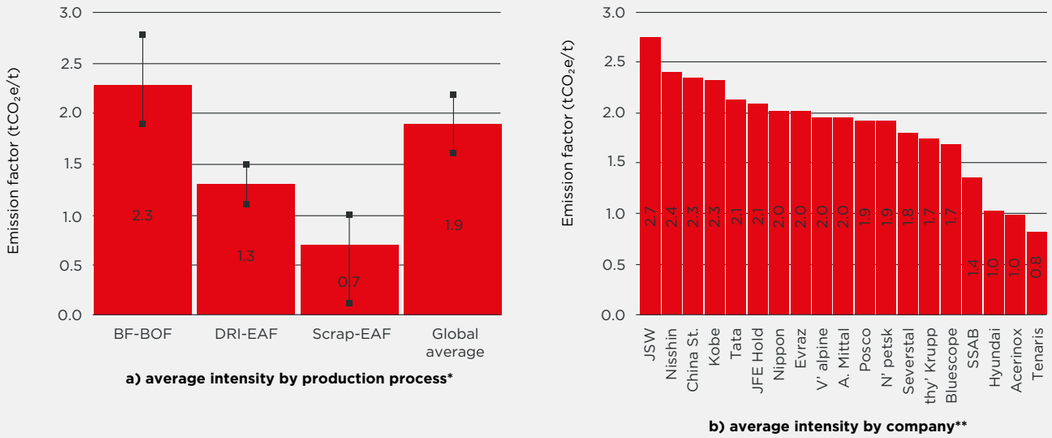
According to the IEA [3], steel production emitted 3.6 $GtCO_2$ in 2019, 9% of total energy sector emissions. Steel's direct (Scope 1) emissions, largely released by the burning of coal, accounted for the largest share (62%) followed by indirect (Scope 2) emissions (27%) from imported and on-site electricity and heat generation. **The BF-BOF process is responsible for c.85% of these emissions with the majority released during the BF stage.** A relatively small part (8%) are from process emissions (Scope 1) in the preparation of coke and the use of lime in the BF-BOF process. Factoring in Scope 3 emissions generated from iron ore extraction and transport (3%) the steel supply chain released 3.7 $GtCO_2$.

Emissions grew at 4% CAGR between 2000 and 2019, in line with steel production. Although energy intensity improved during this period (energy intensity declined by 14%), the overall emission intensity of steel production (t CO_2/t steel) remained relatively unchanged due to the rapid growth in coal-fuelled Chinese BF-BOF production [4].

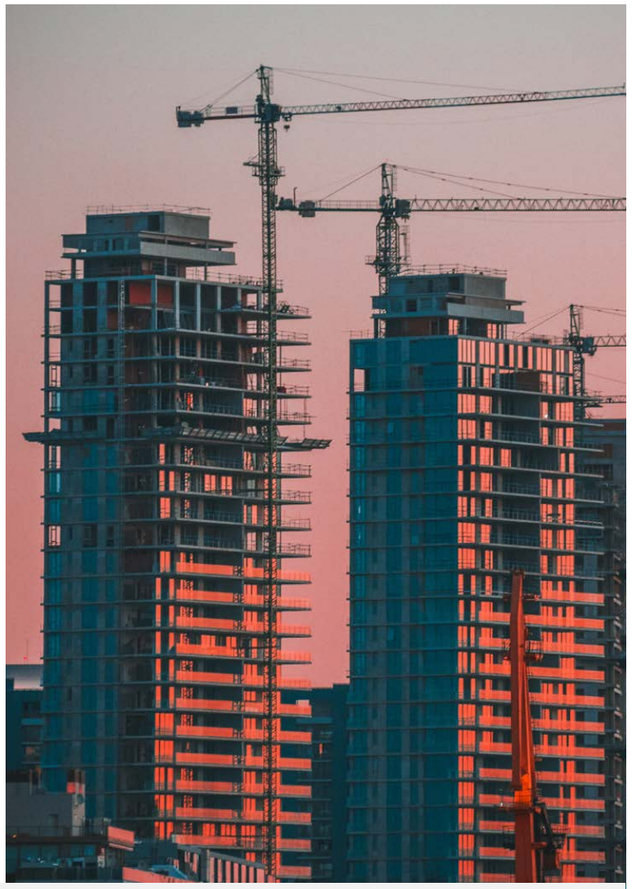
Dividing these emission estimates by total steel production suggests the average (Scope 1 and 2) intensity of steel production is 1.9 $MtCO_2$ per tonne. Different grades of steel, particularly those like stainless steel that have a high proportion of other elements, can have much higher intensities [13]. As Figure 4a highlights, **intensity also varies substantially between production methods.** Coal fuelled BF-BOF production emits 2.3 t CO_2 per tonne of steel while the global average of scrap-EAF is closer to 0.7 tCO_2 per tonne. EAF facilities powered by low-carbon electricity can have substantially lower intensities.

We estimate that China's steel production currently accounts for 2.0 $GtCO_2e$, 55% of global steelmaking emissions and slightly higher than its production share due to its reliance on BF-BOF. Europe accounts for just 0.3 $GtCO_2e$ (7%). **The difference in production mixes is also reflected in the range of emission intensities estimated for listed steelmakers companies.** Tenaris, a mainly EAF-focused steelmaker (using up to 70% of recycled steel), has an emissions intensity of 0.8 tCO_2e per tonne while JSW Steel, a mainly BF-BOF steelmaker, has an emission intensity of 2.6 tCO_2e per tonne.

Figure 4: a) Emission intensity by production method and b) by company



Notes: *2018 global scope 1 & 2 emission intensity factors used in this report based on a variety of sources (see [13]) with data screened to ensure consistency of emission boundary ** Based on publicly reported scope 1 & 2 emissions in 2018 published by TPI [16].

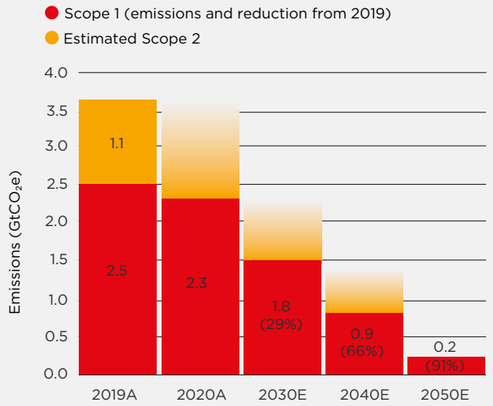


A simple extrapolation of current emissions growth rates (1% per year) without any material or energy efficiency improvements, or any shift away from BF-BOF to EAF or use of CCS/CCUS, suggests emissions from steel could rise to 4.8 $GtCO_2e$ by 2050 in a theoretical Business As Usual (BAU) scenario. While this scenario is increasingly unlikely (some shift away from BF-BOF is almost certain given the rising volume of available scrap) it represents a convenient baseline to judge the impact of decarbonisation measures and the expectations from other scenarios and therefore will be cited in this report as a point of comparison.

The IEA's recent Net Zero by 2050 report [8] models net Scope 1 emissions in the steel sector of 2.5 $GtCO_2e$ in 2019 falling 29% by 2030 and by 91% by 2050 (see Figure 5). **Technologies that are currently available including material and energy efficiency and increasing the share of scrap based production deliver 85% of the emissions reductions by 2030** ((2.5 $GtCO_2e$ – 1.8 $GtCO_2e$)*85% = 0.6 $GtCO_2e$). **Beyond 2030, the majority of emissions reductions come from technologies currently under development including CCS/CCUS and hydrogen based DRI.** Scope 1 emissions captured using CCS/CCUS rises from 0.1 $GtCO_2e$ in 2030 to 0.7 $GtCO_2e$ (i.e. 27% of the 2019 total). Strikingly the IEA NZE 2050 scenario assumes just 6% growth in steel production between 2019 and 2030 (i.e. a 0.2% CAGR).

Further work is needed (by the TPI and others) to translate this data into a benchmark that investors can use to directly assess steelmakers commitments. Scope 2 emissions from the sector (1.1 $GtCO_2e$ in 2019) are likely to need to fall even faster than Scope 1 emissions.

Figure 5: Scope 1 emissions from the Iron and Steel sector in the IEA's NZE 2050 scenario



Source: Adapted by IIGCC from IEA NZE 2050 scenario

CORPORATE CLIMATE AMBITIONS

As of Q2 2021, **nine companies representing ~20% of the global steel production and including the world's five largest producers, had made net zero emissions commitments.** Eight of these companies plan to reach net zero by 2050 with SSAB planning to achieve it by 2045. Seven of the nine had set interim reduction targets and four of those (ArcelorMittal, Nippon, HBIS and ThyssenKrupp) appear to be aligned with IEA's most recent NZE 2050 scenario which specifies a 29% emissions reduction by 2030 compared to 2019 levels [8]. Most of these commitments are from European and Asian companies, reflecting national net zero pledges and existing regulation.

Although steel companies are increasingly setting ambitious net zero commitments, many have yet to explain how they will deliver on these targets. Climate Action 100+ Net-Zero Company Benchmark [17] "Indicator 5" (Decarbonisation strategy) suggest companies include specific actions that they will take to achieve their GHG reduction targets and the measurable impact of those actions within their transition plans (See POSCO Case Study below).

Table 1: Net zero emissions commitments by steelmakers

Global Rank (Mt)[1]	Company	Country	Market share (% steel output)	NZ Target[2]	Interim target[2 3]
1	ArcelorMittal	Luxembourg	5.2%	2050	30% by 2030
2	Baowu Steel	China	5.1%	2050	Peak emissions in 2023 & 30% reduction by 2035
3	Nippon Steel	Japan	2.8%	2050	30% by 2030
4	HBIS	China	2.5%	2050	Peak emissions in 2022, 10% reduction in 2025, and 30% by 2030
5	Posco	Korea	2.3%	2050	20% by 2030 and 50% by 2040
13	U.S. Steel	USA	1.4%	2050	-
35	ThyssenKrupp	Germany	0.7%	2050	30% by 2030
49	SSAB	Sweden	0.4%	2045	-
Under top 50	Outokumpu	Finland	0.2%	2050	20% by 2023

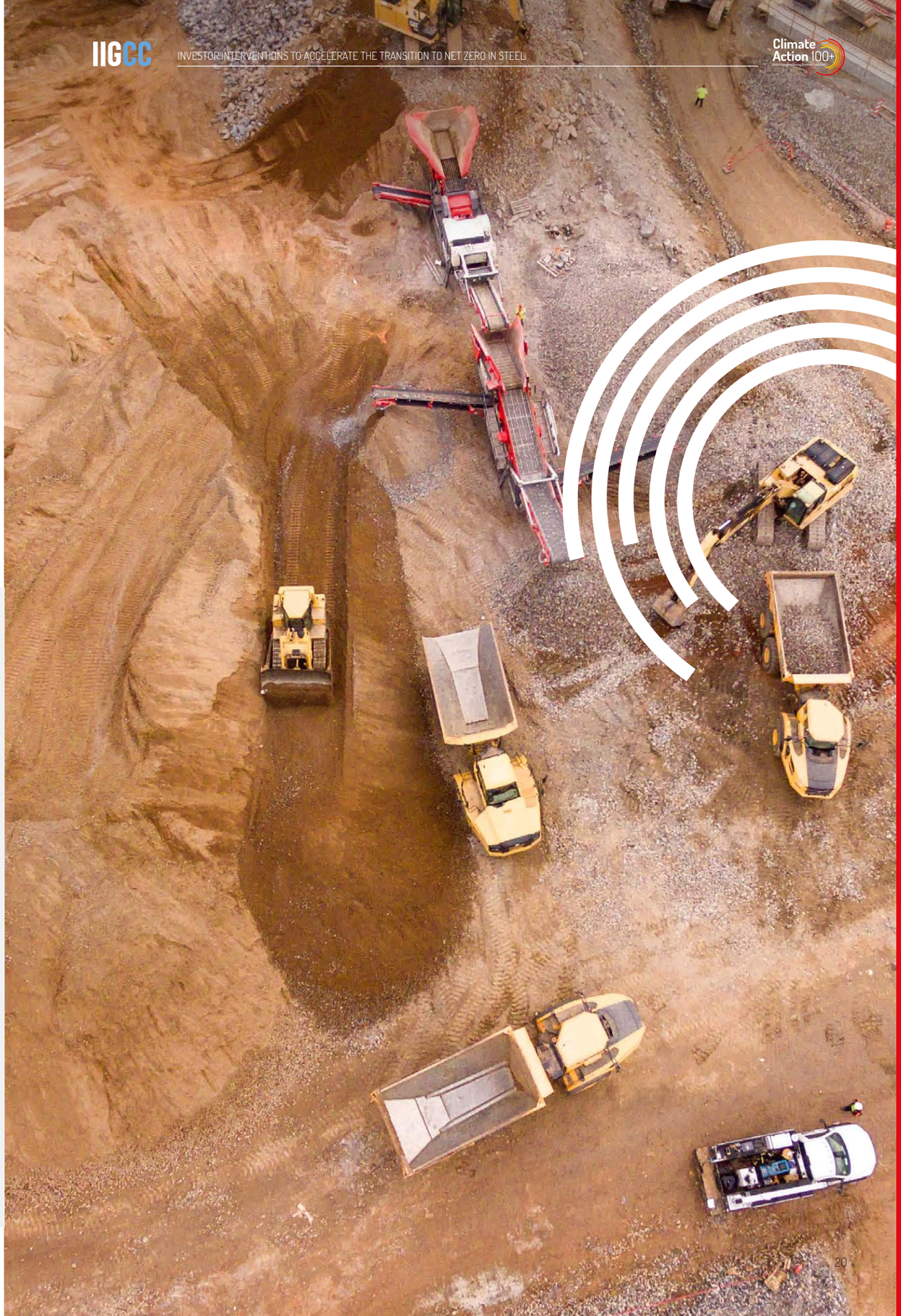
[1] The global ranking is approximate and may unintentionally exclude companies or include outdated steel production. This global ranking is based on steel production (Mt). Production data is based on worldsteel.org

[2] Emissions scopes included in these targets may vary (e.g. Scope 1, Scope 2, Scope 3).

[3] Baselines used to compare the interim targets are unspecified in this table, but some companies do include them.

*The companies considered for this table have net zero commitments globally across all their operations. Partial commitments or commitments from subsidiaries operating in a specific region are not considered.

Source: Company websites and Green Steel Tracker



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Climate Action 100+
CLIMATE IMPACT OF THE STEEL INDUSTRY

CASE STUDY: POSCO DECARBONISATION PLAN: CARBON NEUTRAL BY 2050

1. Introduction: POSCO, the world's fifth largest steel producer, has laid out a structured pathway towards full decarbonisation, as detailed in its inaugural Climate Action Report published in December 2020. Clear mid and long-term emission reduction commitments were made, including for a CO_2 reduction of 20% by 2030, 50% by 2040 and full neutrality* by 2050. In this report, POSCO details a comprehensive technology pathway and its expanded offering of low-carbon products.

2. Phases of the decarbonisation plan -
The broad outline of POSCO's decarbonisation plan is:

Phase 1 – Aims for a 10% CO_2 reduction via digitisation, modernisation, and rationalisation to increase energy efficiency, ranging from reuse of off-gas and off-heat as well as coke dry quenching.

Phase 2 – Aims for a ~35% CO_2 reduction via: a) increased scrap use by developing technology to maximise scrap use and lower hot metal ratios (HMR) up to 70% in the BOF; b) CCUS involving the reuse of captured carbon in the steel production process and raw materials for chemical products and partial hydrogen reduction; and c) injection of hydrogen rich coke oven gas and FINEX off-gas into the BF.

Phase 3 – Aims for a completely carbon-free hydrogen DRI technology on an industrial scale in 10-20 years. Key technological elements are already in demonstration phase in the FINEX process, and the ratio of hydrogen will be gradually increased in two currently operational furnaces with 3.5Mt per annum of capacity. The long-term goal is to produce DRI through HYREX with green hydrogen and operate EAF with renewable energy.

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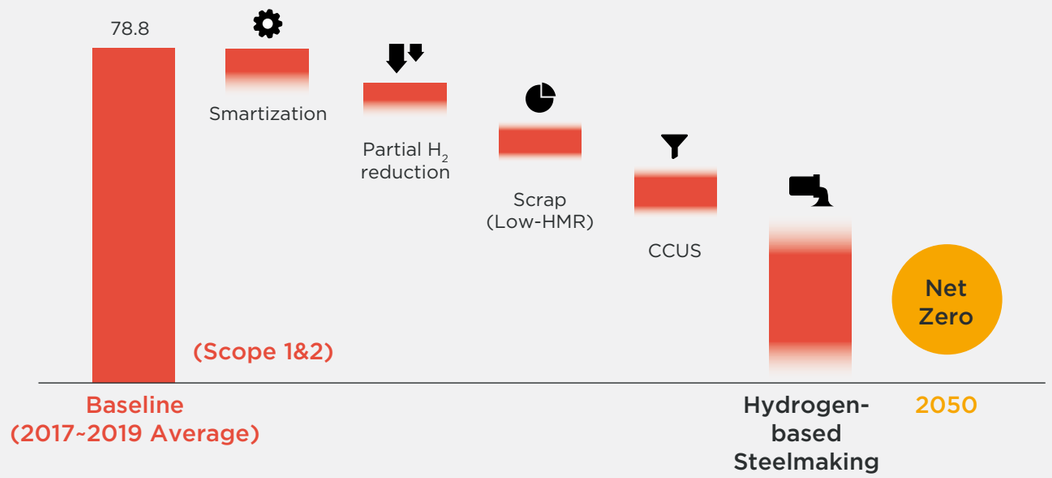
Pathway to achieving the carbon neutral ambition (million tCO_2)



Source: Posco

POSCO is also the only major steel company to have committed to establishing world-scale green hydrogen capacity targeting annual sales of 30 Tr KRW (~$ 26.5Bn). In addition to producing hydrogen, POSCO intends to create a value chain consisting of production, transport, storage and application. POSCO International will participate in domestic and overseas hydrogen projects, POSCO Energy will build hydrogen terminals and POSCO E&C will develop hydrogen urban development projects.

* Neutrality – sometimes this term is not used consistently to mean net zero. In this context, Posco seems to target net zero emissions. Posco does not disclose in its Climate Action Report the share of "green revenues" over its total revenues and its future green revenue targets as recommended by Climate Action 100+ Sub indicator 5.2.

PATHS TO REACH NET ZERO IN THE STEEL SECTOR

This section reviews the measures steel companies and the broader value chain can adopt to reach net zero. It seeks to identify the key measures and quantify their impact using a simplified emissions model (see Figure 6).

The three basic production routes (BF-BOF, DRI-EAF and scrap-EAF) are modelled separately with emissions considered a function of: 1) the level of steel demand **(production),** 2) the **energy efficiency** of production, 3) the **carbon intensity** of the energy consumed and 4) any **captured and stored emissions** (CCS/CCUS). Measures to reduce emissions from steelmaking must act on at least one of these components.

REVIEW OF THE INDIVIDUAL IMPACT OF KEY MEASURES

Measure 1: Increasing the proportion of steel produced by the scrap-EAF process

The proportion of steel made from recycled scrap using an EAF has a big impact on emissions. Aside from being more energy efficient (it requires just 8 GJ per tonne of steel produced vs 22 GJ per tonne for BF-BOF [4]), the emission intensity of the energy used (electricity vs metallurgical coal) is also much lower. Consequently, the emission intensity of scrap-EAF today is just 0.7 tCO_2e per tonne of steel produced, vs 1.9 tCO_2e per tonne for the global average. While scrap-EAF production accounts for 23% of the global total currently, it is likely to substantially grow as a fraction of total production over the next 30 years as the availability of scrap in China rises [23]. However, it could be challenging to increase recycled steel proportion in western markets where this process is well established, and recycling rates are already high. To solve this, engagement with policymakers, customers and scrap processors would be necessary to improve scrap collection schemes and adjust trade policies on steel scrap to ensure an open market [24].

Assuming a hypothetical scenario in which scrap-based EAF rises to 60% of global steel production by 2050, **would reduce annual emissions from steel production by 1.5 $GtCO_2e$, or 32% vs our BAU scenario.** While not an exact comparison, the IEA NZE 2050 scenario estimates the share of steel production using recycled scrap at 46%. In addition, it is expected that electricity generation will continue to decarbonise. Therefore, assuming an 85% reduction in the emission intensity of the grid to 0.4 tCO_2e/MWh (0.1 tCO_2e/GJ), this would further reduce emissions **by 0.9 $GtCO_2e$ or 19% relative to our BAU.**

Measure 2: Enhancing material efficiency to limit steel demand growth

Analysis by Material Economics [2,3] highlights opportunities for greater "material efficiency" in the use of steel in building and manufacturing to limit steel demand without impacting the quality or output of steelmakers' customers. Raising manufacturing yields, enhancing grades, increasing maintenance to improve product longevity, and tightening construction specifications to reduce overbuild could, in aggregate, cut annual steel demand in Europe by 54 Mt (or 28%) by 2050. TERI [15] estimates similar measures could cut Indian steel demand by 25%. The IEA NZE 2050 estimates that material efficiency strategies could halve global steel use in buildings by 2050 relative to today through a combination of measures at the design, construction, use and end-of-life phases but gave no estimate of the potential in other sectors (i.e. buildings and construction account for 50% of total steel demand). Overall, averaging different steel demand reduction estimates from different regions (not including the IEA NZE 2050 estimate) we assume a 22% reduction to global steel production from our 2050 BAU forecast, **reducing emissions by 1.1 $GtCO_2e$ or 23% relative to our BAU.**

Measure 3: Further incremental improvements in energy efficiency of existing steel production capacity

Energy consumption per tonne of steel produced fell by an average of 0.9% per year between 2000 and 2018 and there should be opportunity to enhance energy efficiency further. Energy is a significant cost for steelmakers, so they are already incentivised to reduce its consumption. While steel plants in Europe, US and Japan are believed to be close to maximum efficiency, in other areas there is still room for improvement. For example, Indian facilities currently use 40% more energy than the global average [15].

To improve energy efficiency steel companies should adopt the best available techniques (BAT) developed by organisations like the OCDE, IPCC, EU Commissions JRC and eventually the upcoming revised EU's Industrial Emissions Directive (IED). Regarding specific energy efficiency measures, steel companies could recover the excess heat and gases produced during BF operations and use them to generate electricity for on-site use or sell it back to the grid [1]. McKinsey [11] estimates average global energy efficiency in steel production has scope to improve a further 15-20% on average. Assuming energy intensity of both of the BF-BOF and EAF processes continue to improve at a rate similar to the last decade, annual **emissions would be reduced by 1.2 $GtCO_2e$ or 24% by 2050 relative to our BAU.**

Other approaches to **reducing the emission intensity of BF-BOF** are also being developed. A novel approach called the HIsarna smelting process was developed as part of the ULCOS research programme funded by the European Commission and it is currently being piloted by Tata Steel [5]. It injects iron ore and coal as powders into the "reactor", avoiding the need to produce iron ore agglomerates (pellets and sinter), improving energy efficiency by 20%. In 2018 Tata Steel announced that by also using biomass and scrap as inputs, this process could deliver CO_2e emission reductions of more than 35%. Assuming that 15% of global BF-BOF production adopted this or similar emission reducing technology by 2050, while achieving a conservative 30% reduction in emission intensity, this **would result in an annual 0.2 $GtCO_2e$ reduction relative to our BAU in overall steelmaking emissions.**

Measure 4: Investing in (low emission) DRI-EAF capacity for primary steelmaking

Shifting from BF-BOF to DRI-EAF production would also cut emissions. The DRI method is currently more energy intensive, but it allows for the substituting of metallurgical coal for natural gas, which reduces the overall emissions intensity of the process by c.30-40% [10]. The IEA forecasts DRI-EAF production rising from 100 Mt in 2018 (5% of the total) to c.400 Mt (20% of the total) by 2050 [5]. Pushing this target further, by assuming production from DRI-EAF reaches 631 Mt (25%) by 2050 and exclusively uses natural gas, **would reduce emissions by an annual 0.5 $GtCO_2e$ or 9% relative to our BAU.**

Replacing natural gas with hydrogen (which emits no GHG emissions when burnt) further reduces the emission intensity of the DRI-EAF process. Upgrading a DRI facility that utilises natural gas to instead use hydrogen requires little additional capital. Critically, if renewable electricity is used to produce both the hydrogen ("green hydrogen") and the electricity supplied to the EAF, the emission intensity can be reduced by 95% to just 0.1 tCO_2e per tonne of steel produced, when compared to the current integrated route (BF-BOF) [6]. Production costs also fall as electricity becomes cheaper. Material Economics [10] estimates that producing steel in Europe through the DRI-EAF method with hydrogen would be cheaper than BF-BOF when there is a carbon price of c.$60 per tonne and electricity costs below $47 per MWh. Without a carbon price, electricity would have to be below $15 per MWh to be cheaper than BF-BOF.

Applying the previous emission intensity estimates to our model, and assuming that three quarters of DRI-EAF production is fuelled by green hydrogen by 2050 (implying annual demand for 45 Mt of hydrogen), the shift to DRI-EAF could reduce annual emissions by **1.2 $MtCO_2e$ or 23% relative to our BAU.**

Overall, an approach that combines scrap steel recycling and hydrogen-based DRI is currently considered the most viable option and the long-term solution to achieving carbon-neutral steel production [12]. However, the development of DRI-EAF with hydrogen is still in the early stages. For example, HYBRIT (see HYBRIT Case study), a green steel joint venture between the Swedish steelmaker SSAB, Swedish state-owned utility Vattenfall, and miner LKAB, is targeting commercially viable fossil-free steel production from 2026 [25]. Other companies are choosing to use hydrogen directly in blast furnaces rather than through the DRI route. As an example, Thyssenkrupp announced in June 2020 that it is targeting c. 0.05 Mt of zero emission steel production per year (~0.5% of its annual steel production) by using green hydrogen to replace the pulverised coal component of the raw material mix in the blast furnace by 2022 [26].

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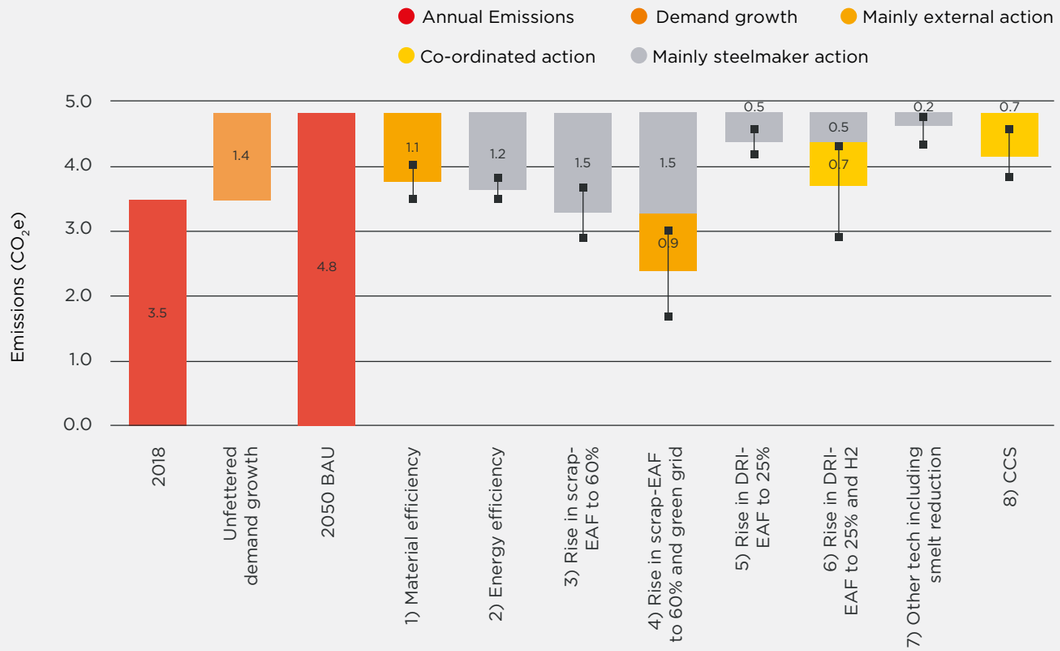
PATHS TO REACH NET ZERO IN THE STEEL SECTOR

Measure 5: Adapt CCS/CCUS technology to fossil-based steel production plants when technically and economically feasible

While initial steps have been taken to implement CCS/CCUS in steelmaking, most projects remain in early adoption or demonstration phase. The first steel CCUS facility was opened in 2016 and it was attached to a natural gas-fuelled DRI facility in the UAE. It has the capacity to capture 0.8 $MtCO_2$ annually which can then be used for enhanced oil recovery [27]. Given the captured CO_2 in effectively spurs oil production, the application of CCUS in this example is considered to be detrimental for climate goals [28]. On the other hand Tata Steel is part of a consortium exploring the feasibility of storing carbon in the North Sea and that aims to capture 7.5 $MtCO_2$ by 2030 (not all from steel or from Tata). The most recent IEA NZE 2050 scenario assumes the capture of 0.7 $GtCO_2$ annually from steelmaking processes by 2050 and c.53% of global primary steel production equipped with CCS/CCUS. In our model, we assume a very similar contribution of CCS/CCUS with an annual emissions reduction of **0.7 $GtCO_2$ or 14% relative to our BAU.**

Figure 6: Individual impact of measures to reduce steelmaking emissions in a BAU scenario in 2050



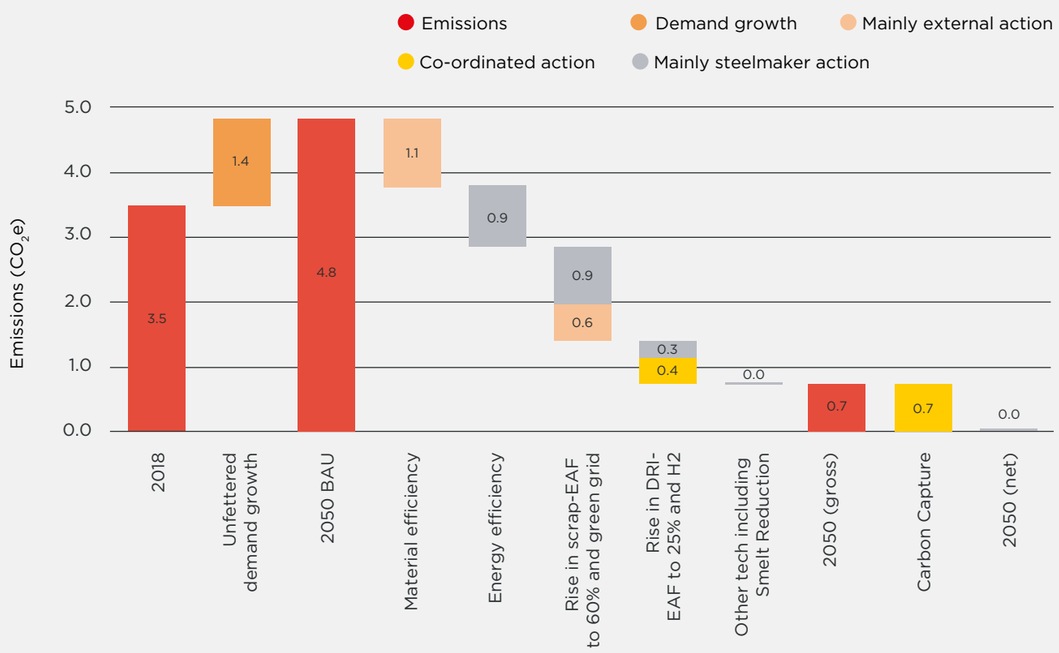
Notes and sources of the simplified model used in this report: BAU assumes no change in current growth rates, production mix, energy efficiency, carbon intensity or CCS. Analysis attempts to assess the impact of each measure (high, low and average case) against this BAU based on information drawn from the following sources: 1) material efficiency from average of sources [2, 3, 7, and 12], 2) energy efficiency assumes continuation of historic trends (0.9% improvement annually), 3) based on source [10] "increasing scrap input beyond 60% would require a concerted push", 4) assumes grid average of 36 gCO_2e/KWh by 2050, 5) assumes DRI rises to 25% of production and 1.3 tCO_2e/t emission factor, 6) assumes DRI rises to 25% of production and 0.4 tCO_2e/t emission factor assuming a 75% penetration of green hydrogen, 7) assumes smelt reduction achieves a 15% penetration and a 30% reduction to BF-BOF intensity and 8) compares to CCS emissions in the IEA's Two degrees scenario [5] of 0.5 $GtCO_2e$.

COMBINING KEY MEASURES TO DELIVER NET ZERO: A MATTER OF COORDINATION

The previous section showed the individual impact of each measure discussed when compared to a business as usual (BAU) scenario in 2050 (see Figure 6). However, they are just a theoretical estimation of the abatement potential of those individual measures. As none of them deliver net zero emissions by themselves, they must be used in combination to decarbonise the sector. Using measures in combination changes their impact on emissions.

Figure 7 shows one possible way these measures could be combined to reach net zero. **The analysis suggests it is feasible to reach net zero provided technology currently in demonstration is scaled up successfully and coordinated action in all regions is taken simultaneously by different actors.** Nevertheless, this scenario highlights the key role of "coordinated" and "mainly external" actions to deliver substantial emissions reductions. Around 58% (or 2.8 $GtCO_2e$) of the total reductions shown in Figure 7 correspond to "coordinated" and "mainly external" actions. For example, enhancing material efficiency requires coordination with construction and automotive supply chains while lower carbon energy (electricity and green hydrogen) is dependent on infrastructure investment from energy companies (see HYBRIT Case study). **As such, a credible transition plan for the steel industry requires a coordinated effort across sectors and value chains.**

Figure 7: How major measures could combine to deliver net zero by 2050



Note: Analysis based on the same assumptions shown in Figure 6

CASE STUDY: THE HYBRIT PROJECT: FOSSIL-FREE STEEL THROUGH CROSS-SECTOR COLLABORATION

HYBRIT FOSSIL-FREE STEEL

1. Introduction: HYBRIT (Hydrogen Breakthrough Ironmaking Technology) is a Swedish project founded in 2016 by a partnership between steel maker SSAB, electric utility Vattenfall, and iron ore miner LKAB to produce fossil-free steel from 2026.

2. Technology route: Using HYBRIT technology, SSAB aims to replace coking coal with fossil-free electricity and hydrogen provided by Vattenfall. Iron ore pellets specially developed by miner LKAB are reduced by hydrogen gas through the DRI process, producing an intermediate product, sponge iron or direct reduced iron (DRI). The sponge iron can be used as hot DRI and melted immediately in an electric arc furnace (EAF) together with recycled scrap. The DRI can also be processed into hot briquetted iron (HBI), which can be stored and shipped to another site. The crude steel from the EAF goes through a similar process as in the blast furnace-based route, i.e. alloying and refining before being cast into slabs, ready for rolling and further heat treatment before shipping to customers.

3. Challenges as stated by the HYBRIT partnership:

- To develop an effective process to use 100% hydrogen at an industrial scale.
- To produce hydrogen in an energy-efficient way so that it is economically justifiable/ commercially viable.
- Financing for the pilot plant – Link to source

4. Target: SSAB will cut its CO_2 emissions in Sweden by 25% as early as 2025, through the conversion of the BF-BOF in Oxelösund, Sweden, to DRI-EAF. Between 2030-2040, the plan is to convert the blast furnaces in Luleå, Sweden and Raahe, Finland to eliminate most of the remaining CO_2 emissions. Their Americas operations will also be able to offer fossil-free steel products starting in 2026. At the same time, SSAB has started the process of phasing out fossil fuels used in rolling mills and heat treatment plants throughout the company, to reach the goal of becoming a totally fossil-free steelmaker by 2045.

5. Timeline/Phases of HYBRIT project

2016 - 2017

Pre-feasibility study

2016
- Pre-feasibility study with support from Swedish Energy Agency
- 4-year R&D project with support from Swedish Energy Agency

2017
A joint venture company between SSAB, LKAB, and Vattenfall

2018 - 2024

Feasibility study pilot plant trials

Feb 2018
Decision for pilot phase

2019-2021
Fossil-free pellets trial

2019-2021
Hydrogen storage

2020-2024
Hydrogen-based reduction and smelting trials

2025 - 2045

Commercial volume plant trials and transformation

2025
- Transformation from BF to EAF at SSAB Oxelösund
- HYBRIT demo plant

2026
SSAB fossil-free steel on market

2030-2040
Transformation - BFs to EAFs at SSAB Raahe & SSAB Luleå

2045
SSAB fossil-free as a steel company

Source: SSAB

DECARBONISATION TECHNOLOGIES: STATUS AND FUTURE PROSPECTS

As stated by the IEA in its TRL analysis [7] and NZE 2050 scenario [8], the low carbon steel production technologies expected to be commercially available in between **2020 and 2025**[1] are:

- Scrap-EAF process
- DRI based on natural gas with CCS/CCUS
- DRI based on blends of natural gas-hydrogen with hydrogen content up to ~30%
- Blast furnace-CCUS to convert off-gasses to fuels. However, the energy used by the CCS/CCUS system, the scale of the demand for synthetic fuels in the short and mid-term, and the fate of the CO_2 contained in the resulting fuels remain unclear [7].

Between **2025 and 2030**, the following additional low carbon production technologies are expected to become available:

- Blast furnace-CCUS to convert off-gases to chemicals
- Smelting reduction combined with CCUS
- Blast furnaces using moderate levels of electrolytic hydrogen in natural gas blending

Beyond 2030, the additional production technologies are expected to become commercially available:

- Blast furnace based on off-gas hydrogen enrichment and/or CO_2 removal for use or storage
- Blast furnace based on high levels of electrolytic hydrogen in natural gas blending
- Blast furnace based on electrolytic hydrogen
- DRI using natural gas with high levels of electrolytic hydrogen blending
- DRI based solely on electrolytic hydrogen
- Hydrogen-based smelting reduction (hydrogen plasma reduction)
- Direct electrification of primary steelmaking though iron ore electrolysis (this technology is not included in IEA's SDS scenario due to its comparatively low TRL)

For more detail on these technologies and the existing projects where these are applied, please see Table 3, page 29.

[1] This list excludes non-scalable steel routes like charcoal-based (biochar) blast furnaces due to mechanical and sustainability limitations [7].

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PATHS TO REACH NET ZERO IN THE STEEL SECTOR

BARRIERS TO DELIVERING NET ZERO

The preceding section demonstrated that it is technically feasible for the steel sector to reach net zero by 2050, but that achieving this goal will require simultaneous action across all regions and include stakeholders external to the steel sector itself. It will also require a combination of investment, technological progress, further reductions in green electricity prices, and considerable policy support.

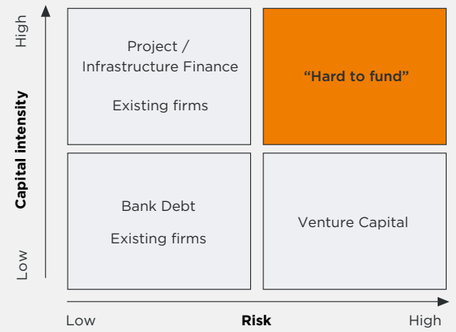
The following is a summary of the barriers that must be overcome by the industry to make net zero by 2050 a reality:

Barrier 1: Capital cost of new production processes

One of the biggest issues facing steelmakers is securing the funding to invest in low carbon production. **Whilst the capital expenditures of energy efficiency measures can have relatively short payback periods, the more profound changes needed to deliver deep decarbonisation typically require much greater investment, involve higher technology risks, and take longer to pay back.** Modest and volatile cashflows make it difficult for steelmakers to make these investments at the pace required. Hence many of the steel projects using emerging decarbonisation technologies could be categorised in the blue square of Figure 8 as "Hard to fund". As an example, shifting primary production to a (natural gas or hydrogen based) DRI-EAF facility is a multi-billion dollar investment. Market leader ArcelorMittal recently estimated that the cost of reaching net zero across its European operations would be $65bn [29]. This includes $41bn to be spent on DRI upgrades and $24bn on "smart carbon" solutions (e.g. green electricity, bioenergy and CCS/CCUS), but it excluded the $18-236bn investment costs associated with new energy infrastructure to be built by others in order to supply renewable energy. This amount dwarfs ArcelorMittal's annual free cashflow of $2.4bn in 2019.

However, analysis completed by Material Economics [10] suggests the capital cost of transition will be much lower. It estimates that the incremental capital costs (i.e. on top of the current investment levels) required by the European steel industry between 2020 and 2050 are in the range of $14-37bn. Its circular economy scenario, which models substantial demand side reductions and supply side increase of scrap-EAF production rising to 70%, is the lowest cost strategy. However, it also estimates the capital cost of low-carbon routes like hydrogen-based DRI or smelt-reduction with CCS/CCUS to be triple that of existing non-abated BF-BOF capacity.

Figure 8: Funding high risk, high capital intensity projects



Source: Adapted from Energy Transitions Commission, Mission possible platform, World Economic Forum, Net zero steel initiative workshop. Financing the transition to net zero steel in the 2020s. Adapted originally from Ghosh and Nanda, "Venture Capital Investment in the Clean Energy Sector", Harvard Business School WP, 2010 [2]

The wide range in cost estimates for decarbonising European steel exemplifies the difficulties in estimating the total amount of capital required to reach net zero globally. Taking the global scenario depicted in Figure 6, where DRI-EAF production rises from 100 Mt currently to 492 Mt in 2050, and applying a capital cost of $1,684 per tonne of capacity, the total capex required for DRI globally might be at least $650bn and the incremental spending (i.e. the outlay above the cost of BF-BOF capacity) might be more than $400bn (excluding any additional investment needed in energy infrastructure). In addition, investment in CCS/CCUS will also be needed. Assuming the industry needs to capture 0.7 $GtCO_2e$ annually and applying an estimated capital cost of $400 per tCO_2e, suggests that at least a $250bn will be needed for CCS/CCUS capex.

Barrier 2: Increasing capex will lead to more expensive steel

Increased capex will also feed into steel production costs. In addition to higher depreciation charges, the shift to electricity and gas (hydrogen or natural) may push up costs. Material Economics suggests that DRI-EAF will push up the levelised cost per tonne of steel by 6-18%. Other estimates are substantially higher: ETC suggests HYBRIT raises costs by 20-30% [1] while the IEA [3] suggests the costs of a 100% hydrogen based DRI-EAF in 2035 could be 60-70% higher than the BF-BOF route.

Given modest margins it is not clear that steelmakers can bear these incremental costs and remain profitable competing on the same terms as low-cost, high-carbon production. **Steelmakers could attempt to pass the additional costs onto customers by charging a premium for certified "green" steel, once a standard and certification scheme is developed and widely adopted.** An example is the standard already developed by Responsible Steel [13]. The premium needed to absorb the costs would, however, be a small proportion of the total cost of the end product (i.e. 2% of the cost of average car) and, with sufficient industry support, this might be good marketing for the product manufacturer. However, steelmaker's customers have their own margins to protect and there would be a strong incentive to buy cheaper (emission intensive) steel. The impacts of voluntary purchasing schemes in driving change in other sectors are seen as modest, at best. Therefore, any passing on of costs to customers must be accompanied by policy support that does not allow the lower carbon steel to be undercut by lower cost, higher carbon steel.

Barrier 3: Lack of policy support impacts the competitiveness of emerging technologies

Carbon pricing is one way of levelling the playing field while increasing the competitiveness of emerging zero-emissions steel technologies. For example, through a combination of the EU ETS[2], and the wider policy framework and research funding, the EU has been relatively successful in encouraging European steelmakers to reduce carbon intensity in the last fifteen years (European average 1.3 tCO_2e/t vs global average of 1.9 tCO_2e/t). But in order to protect and encourage further investment, the European Commission is also set to introduce a carbon border adjustment mechanism (CBAM) that would apply a tariff based on the amount of carbon emitted to produce a product [30]. The combination of these measures would give both the EU and foreign steelmakers looking to export to the EU an incentive to reduce emission intensity and a long-term stable outlook to confidently invest in key emerging technologies. However, in markets where CO_2 is not adequately priced, emerging technologies like those based on hydrogen would be relatively disadvantaged to gain market share.

Higher carbon taxes and falling green electricity prices make hydrogen-based production more attractive. McKinsey estimates that at a CO_2 price of $73/t and an electricity price of $22 per MWh, conventional (BF-BOF) steel production becomes more expensive than hydrogen-based DRI-EAF [12].

In general, steelmakers outside the EU have faced limited pressure from policymakers to reduce emissions. **However recent "net zero emissions" pledges by steel producing countries like China, Japan, and Korea (countries that account for 62% of global steel production) may lead to stricter carbon regulations.** For example, major steel producing countries like China have laid out the regulatory framework for a national carbon emissions market. While the newly established Chinese emissions market only covers power generators currently, the National Development and Reform Commission (NDRC) did announce plans in 2016 to include the steel sector. As a result, 228 Chinese steel companies, accounting for about 610 Mt of crude steel production capacity at the end of 2020, had committed to transforming their operations to "ultra-low emissions" [31].

Barrier 4: Long asset lives will lock-in high-carbon steel production

Blast furnaces are typically depreciated over 20-30 years, but their useful lives can be substantially longer. To avoid locking in high carbon production and raising the transition costs further due to forced closures (or stranded assets), it is argued that no new unabated BF-BOF capacity should be built. Furthermore, according to a study by the Rocky Mountain Institute, to adhere to a 1.5°C pathway, requires either avoiding the construction of or closing down about ten blast furnace steel mills per year [14]. However, it will still take a long time before all the existing capacity is due for retirement. For this reason, the adaptation of existing BF-BOF assets to CCS/CCUS, hydrogen or other low-emissions routes remains an industry priority.

In the context of thin margins and limited capital, investment in new (more expensive) low carbon production before existing capacity has reached the end of its operational life is often hard to justify. The slow turnover of assets will make it difficult to scale up low-carbon technologies and will slow the pace of the transition without the appropriate economic incentives and policy environment. According to the IEA NZE 2050 scenario, **governments should have a strategy in place for incorporating near-zero emissions technologies into the next series of capacity additions and replacements for steel plants by 2024 in advanced economies and 2026 in emerging and developing economies. This should include decisions about whether to pursue CCUS, hydrogen or a combination of both [8].**

Switching to gas (natural or hydrogen) fuelled DRI or investing in EAF may be neither feasible or a strategic priority for countries that have access to plentiful cheap coal and strong demand for steel. Concurrently, bringing gas to steelmaking facilities, adapting CCS/CCUS, or bolstering and decarbonising the grid will require substantial infrastructure spending; investment that will require government support [8] and is outside the direct control of the steel industry. As an example of this, ArcelorMittal [32] announced in 2021 plans to develop a green hydrogen DRI-EAF project in Sestao, Spain, a project that, according to the company "would not be possible without the support and partnership of the Spanish government".

Barrier 5: The potential for steelmakers (and others) to use CCS/CCUS as a pathway to net zero remains unclear

The CCS/CCUS technology is at an early stage of application [3], particularly in the steel industry, and its economics remain uncertain. The steel production route where CCS/CCUS usage has been commercially tested is DRI-EAF which only accounts for 6% of current global production.

Estimates from GCCSI [33] suggest that the current levelised cost of CCS/CCUS in steel production ranges between $65-77 per tonne and would fall over time; however, not all steel facilities are located near suitable storage sites and thus would incur additional transportation costs. For CCS/CCUS to be successful there needs to be significant investment in infrastructure for both the transport and the storage of CO_2. As a result, carbon capture is likely to start off in "industry clusters" as a way for industries to share cost of transport and storage [2].

In addition to the storage and transport barriers, existing BF-BOF facilities typically have multiple emission sources and CO_2 needs to be separated from the mix of exhaust gases. These issues raise the cost of CCS/CCUS in steelmaking and limit the share of emissions that can be captured. In parallel, the market potential to use the carbon captured in applications like synthetic fuels still needs to be adequately assessed. The most recent IEA NZE 2050 scenario vaguely estimates that only 5% of the global CO_2 captured in 2050 will be used to produce synthetic fuels [8]. For these reasons, **further studies on the feasibility of CCS/CCUS in steelmaking would be required to assess its viability as a long-term decarbonisation strategy.**

Barrier 6: Steelmakers will struggle to absorb the costs of the renewable electricity and green hydrogen infrastructure underpinning their low-carbon transition

The energy requirements underpinning the production of low-carbon and green steel are daunting; the most recent IEA NZE 2050 scenario estimates that steel production will require 54 Mt of hydrogen annually[3] by 2050, or approximately 45% of today's total hydrogen production (120 Mt). Assuming[4] that 60% of that hydrogen will be green and have a system efficiency of ~45 kWh/Kg H2 in its production, the electricity required by the steel sector would be around 1,490 TWh annually, more than India's entire electricity production in 2019.

[2] EU emissions trading system: https://ec.europa.eu/clima/policies/ets_en

[3] This compares to the model created for this report which estimates 2050's hydrogen demand in steel at 45Mt annually.

[4] The breakdown of green, blue and grey hydrogen applied to specifically the steel sector is not disclosed by IEA NZE 2050 scenario, although green hydrogen production is assumed to be 60% globally in the scenario.

Furthermore, the IEA NZE 2050 scenario assumes that an estimated 295 GW of on-site hydrogen electrolyser capacity will be required at steel plants, with uncertain implications for existing plants in locations where access to renewable sources of electricity or water is limited. Using IRENA's [34] estimate of the capital cost of electrolysers ($200/kW[5]), 295 GW of on-site electrolyser capacity would cost $59bn, without considering other additional infrastructure costs. In parallel, an undetermined amount of renewable electricity to power the EAF and EAF-DRI plants will be required. **Overall, the costs to deliver the additional electricity and electrolyser capacity will be difficult to absorb by the steel sector on top of the transformative capital investments required to build low-carbon and net zero production routes.** Consortiums, public–private partnerships, industrial clusters, joint ventures, cross-sector partnerships, and off-take agreements will be needed to develop this underpinning energy infrastructure.

Barrier 7: Scrap and DR-pellet availability could slow the pace of Scrap-EAF and DRI-EAF expansion

Increasing the use and availability of scrap steel to enable the shift to EAF run by green electricity looks to be the single largest measure to reduce emissions, yet raising the use of scrap to or even beyond 60% of the global production mix will be a challenge[6]. Scrap availability depends on the stock of steel currently reaching its end of useful life. Therefore, steel production from EAFs is determined not just by the recycling rate today, but by production volumes between 10 and 50 years ago that forms the stock of steel in the built environment. While primary steel production growth appears to be slowing in developed nations, steel stocks in India and Africa are only 1 tonne per capita, substantially below the 12 to 13 tonnes that developed economies have stabilised at [1]. Similarly, and despite China's rapid expansion of production over the last 20 years, its stock is only just over 5 tonnes per capita.

Improving material efficiency to limit or reduce demand is a highly economic and efficient way to offset growth and cut emissions. However, it requires detailed, complex, coordinated actions across multiple value chains. For example, the shift to autonomous or shared ownership models in the automotive sector has the potential to reduce demand here by a third but may take many years to gain mass adoption. **Measures to curtail demand growth are likely the best lever to increase the proportion of steel produced by scrap-EAF and increase the proportion to above 60%.** However, actions to reduce long term demand in this way are unlikely to be in steelmakers' interests.

In parallel, **demand for steel manufactured from the scrap-EAF process is potentially limited because scrap often contains 'tramp elements'**, such as copper, which are difficult to remove and affects the quality of the end product. As a result, certain applications (e.g. automotive) that require particularly high steel grades are not able to use scrap-EAF output. In some cases this issue can be addressed by blending scrap with DR pellets to bring the end product's properties back to the desired levels [12].

In parallel, many steel companies see the ability to scale up supply of DR pellets as a potential constraint to growing DRI-EAF production. However, analysis by IIMA [35] suggests that expected higher DR-pellets production at existing assets and a wave of upcoming DR production projects, will be able to address this constraint at least until 2025.

While there are feasible solutions to many of these issues, the uncertainty around the implementation of collaborative, cross-sector mechanisms and infrastructure, suggests steel sector emissions only falling to 1.2 $GtCO_2e$ by 2050, a 1.0 $GtCO_2e$ above the annual emissions budget consistent with net zero established by the IEA (see Figure 9).

[5] IRENA assumes this capital cost for electrolyser systems over 10 MW. The capital cost of smaller, modular electrolyser systems for steel plants could be higher but this is not estimated in this calculation.

[6] The IEA in its most recent NZE 2050 scenario estimates the share of recycled scrap as a share of global steel input at 46%.

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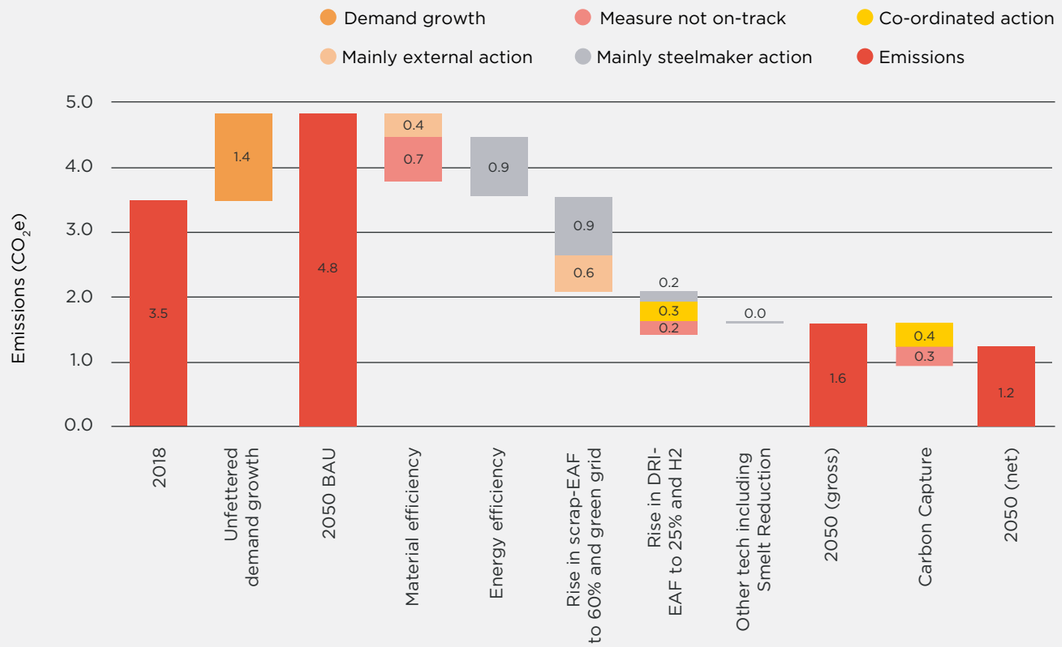
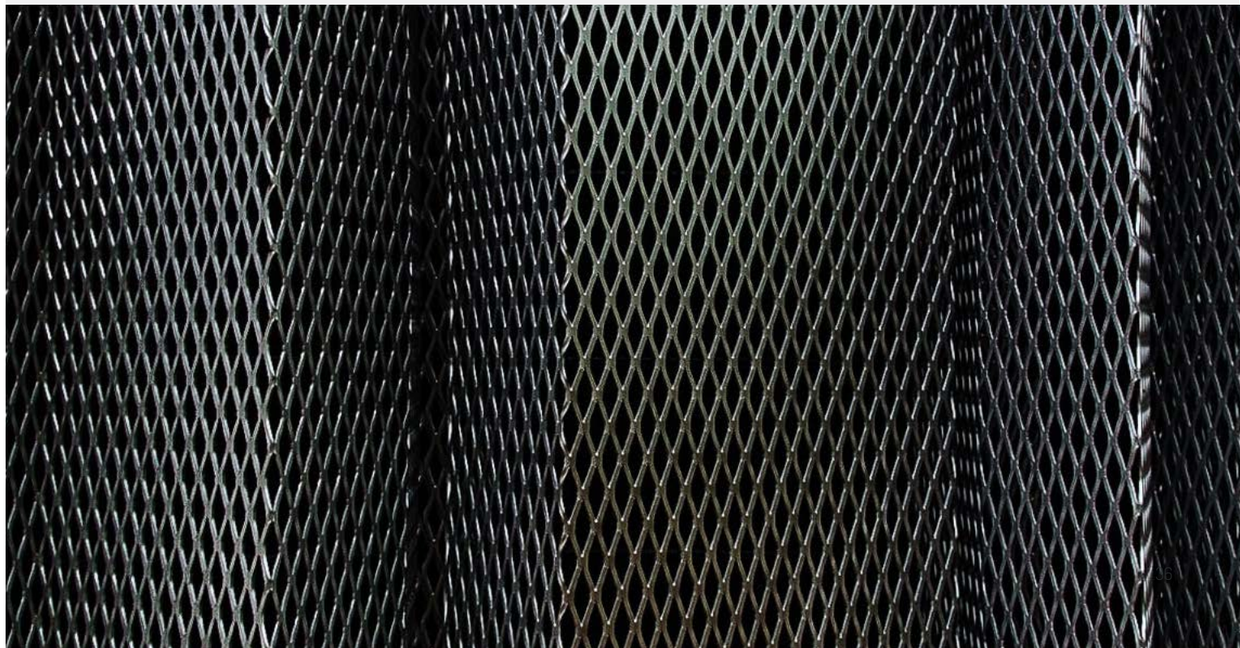
BARRIERS TO DELIVERING NET ZERO

Figure 9: Further actions are needed to deliver net zero in steel by 2050



Note: Analysis based on the same assumptions shown in Figure 6 and Figure 7 but shows (in red) where further actions are needed to deliver net zero in the steel sector. Most of the outstanding actions are at least partially dependent on players outside the steel sector. For example, enhancing material efficiency will be driven by changing customer behaviour, the switch to DRI-EAF will be driven by the availability of low cost green electricity and hydrogen.



WHAT IS NEEDED TO OVERCOME THESE BARRIERS?

Reviewing the barriers to progress suggests that while it is technically feasible to decarbonise steel by 2050, multiple actions will need to be pursued simultaneously and with urgency. Measures that are in the direct interests and control of steelmakers **such as improving energy efficiency, embracing green electricity or shifting to scrap-EAF look likely to be adopted and will make big inroads into overall intensity** provided that capital, renewable electricity, steel scrap, and DRI feedstocks are available.

The substantial investments needed to shift to DRI-EAF production and/or increase CCS/CCUS capacity are likely to require external capital and raise production costs, certainly in the near term. **These additional costs are likely to need to be shared across value chain participants or receive public support,** especially to fund the supporting infrastructure to produce and transport renewable electricity, hydrogen, or the resulting carbon emissions. Consortiums, public–private partnerships, industrial clusters, joint ventures, cross-sector partnerships, and off-take agreements are possible solutions to overcome these costs. Several examples of these cross-sector or private-public alliances are underway to develop CCS/CCUS (UK's CCS strategy, Norway's CLIMIT Programme) and hydrogen projects notably in the European Union, South Korea, and Australia.

Many of the steelmakers providing feedback for this report have highlighted the pre-eminent role of policy in incentivising decarbonisation. Given the long-term investment horizons, a stable and supportive policy environment is cited as key to incentivising investment. We particularly see carbon taxes as a key policy to accelerate the shift to low carbon steel production routes. However carbon taxes are unlikely to be harmonised, raising the issue of unequal competition between regions. One way to adjust this is a carbon border adjustment tax such as the one proposed by the EU. This is seen by its proponents as a key way of levelling the playing field and incentivising companies looking to export to Europe to reduce the carbon content of its products.

Addressing the implications of the uncertain development path of emerging technologies like CCS/CCUS-based production, hydrogen-based production or even direct metal electrolysis (Categorised by IEA under TRL 4 – Small prototype), is not straightforward. As this report highlights, the adoption of technologies can have significant impacts on the effectiveness of other decarbonisation actions. However the potential effectiveness of these technologies is likely to vary substantially by company (according to market, product focus, existing asset mix and geography) and companies can begin work today to clarify the potential role it sees for them in its decarbonisation trajectory alongside other actions. **Investors will be able to allocate capital to companies with credible plans and projects making verifiable progress.**

Measures that are outside the direct control of steelmakers and require action across the value chain look more difficult to achieve. Overcoming recycling challenges will have to be a collective effort. Steel companies should engage with policymakers and recycling processors to establish and support initiatives across the steel value chain to increase scrap availability. Similarly, to control the presence of "tramp elements" like copper in recycled scrap, steelmakers could engage with scrap processors, value chain participants (e.g. steel end users) and researchers to create new processing systems and recycling standards. Academic studies suggest that quantities of copper arising from conventional scrap preparation can be managed in the global steel system until 2050, although further technical and policy interventions along the value chain are needed to close product loops [36].

CONCLUSIONS

This report aims to help investors accelerate the transition to net zero in the steel sector. It provides an overview of the status of decarbonisation in the steel sector and outlines what is needed to overcome the challenges posed by the transition to net zero by 2050. These recommendations are based on a review of recent publications on this topic and analysis of the measures that can be taken to reduce emissions in the steel sector using a simplified emissions model. Five measures appear key:

1) **Lifting the proportion of steel produced by the scrap-EAF process.** Increasingly fed by low cost and low carbon electricity, a shift to 60% production from scrap could cut overall emissions by 2.4 $GtCO_2e$ annually (51%) vs the BAU - without substantially increasing production costs ("Measure 1").

2) **Measures taken by steel customers and other value chain participants to enhance "material efficiency" in their product use can reduce steel demand** and hence emissions by 1.1 $GtCO_2e$ (23%) compared to BAU without impacting the end-use markets ("Measure 2"). By slowing demand growth, the proportion of steel produced by scrap-EAF processes increases substantially reducing the need for new (and expensive) low-carbon primary steelmaking capacity (DRI-EAF) and/or CCS/CCUS.

3) **Further incremental improvements in the energy efficiency of existing steel production capacity by adopting Best Available Techniques (BAT)** can reduce emissions by 1.2 $GtCO_2e$ (24%) annually vs a BAU scenario. These measures are often self-funding with short pay pack periods ("Measure 3").

4) **Investment in DRI-EAF capacity is needed to decarbonise primary steel production.** Assuming production from DRI-EAF reaches 631 Mt (25%) by 2050 and exclusively uses natural gas, would reduce emissions by an annual 0.5 $GtCO_2e$ or 9% relative to our BAU ("Measure 4"). These facilities must be converted to green hydrogen as it becomes available and cost effective. Assuming that three quarters of the DRI-EAF production is fuelled by green hydrogen by 2050, the shift to DRI-EAF could reduce annual emissions by 1.2 $MtCO_2e$ (23%) relative to our BAU. ("Measure 4").

5) **Investment in CCS/CCUS is likely to be needed to cut emissions from remaining emission intensive capacity.** In our model, we assume that CCS/CCUS achieves an emissions reduction of 0.7 $GtCO_2$ (14%) relative to our BAU ("Measure 5"). However, CCS/CCUS may not be economic nor feasible in all locations.

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RECOMMENDATIONS FOR ACTION

Existing studies suggest that the current set of responses to reduce emissions in steelmaking is unlikely to deliver emissions reduction consistent with net zero. In addition, there exists little evidence of the concerted action needed from consumers of steel and the steel value chain to reduce overall demand (Measure 2) or support for policies to decarbonise steel in the countries that currently dominate production. Substantial investments in DRI and/or CCS/CCUS may raise production costs, particularly in the near term. In an industry with tight margins, funding this investment – especially without incentivising (either from steel consumers or policymakers) emissions free steel – may prove problematic. This report suggests that the combination of all these issues will result in residual annual emissions of 1.2 $GtCO_2e$ in 2050, a 1.0 $GtCO_2e$ above the annual emissions budget consistent with net zero established by the IEA [8].

To avoid this shortfall and accelerate progress in the steel industry towards net zero this report advocates the following actions:

ACTIONS FOR STEEL COMPANIES

1. **Consistent with the Climate Action 100+ Net zero Company Benchmark Indicators 2-4, set short-, mid-, and long-term decarbonisation targets in-line with the IEA NZE 2050 scenario.** The IEA NZE 2050 scenario data models Scope 1 emissions in the Iron and Steel industry falling 29% by 2030 and 91% by 2050 compared to 2019 levels. Further work is needed to define the exact emissions pathway implied by NZE 2050, however factoring in Scope 2 it is likely to imply that total emissions from steel should fall even faster.

2. **Develop and publish a comprehensive transition plan that is consistent with the Climate Action 100+ Net zero Company Benchmark Indicator 5.** This report recognises that technologies like CCS/CCUS and hydrogen based DRI are still at their early stages and, due to the uncertain pace of development, it will be difficult for steelmakers to provide complete visibility today on how they intend to deliver on their targets. Nevertheless they should be able to say, in broad terms, how they intend to deliver on their net zero ambitions. Companies should specify in their transition plans the main measures they intend to deploy and their expected contribution to both medium- and long-term targets.

3. **Produce reports setting out the opportunities and scale for the company to deploy a) CCS/CCUS and b) Hydrogen based DRI to decarbonise its steel production.** These reports should specify, in as much detail as is practically possible, the role the company currently expects these emerging technologies to play in its overall decarbonisation plan. This should include: the locations (existing or new) where the technology is under consideration, what the company sees as the main barriers (i.e. policy, cost or technology) to deployment and what actions it is taking to address those barriers, how much it is investing in each technology currently and what it expects the overall cost to be, the impact this might have on steel production costs and, finally, what milestones it is setting itself to judge progress. These reports should be published by the end of 2022.

4. **Support the development of international certification standards for "green steel" production and commit to adhere to those standards.** To support customer demand (and justify a premium for) "green" steel, there needs to be confidence in a robust certification scheme such as that being developed by Responsible Steel [13] [14]. Steelmakers should support such efforts and adhere to certification schemes that propose carbon content standards consistent with net zero.

5. **Consistent with Climate Action 100+ Benchmark Indicator 6, commit to aligning its capital expenditure plan with its broader net zero strategy.** Consistent with Actions 2 and 3 steelmakers should set out their plans to invest in low-carbon steelmaking technologies including scrap-EAF, DRI-EAF and CCS/CCUS. Additionally steelmakers should commit not to invest in any new capacity which is not capable (either for technical or economic reasons) of being aligned with their short, medium and long-term science-based decarbonisation targets.

6. **Consistent with Climate Action 100+ Benchmark Indicator 7, specify the policy positions that the company will adopt to accelerate the delivery of its transition plan.** This plan should include:

   a. Its position on carbon pricing mechanisms designed to incentivise investments in low-carbon production technologies in countries/regions where it operates.

   b. Its position on policy/regulations like the EU's carbon border adjustment, that aim to avoid carbon leakage between jurisdictions.

   c. Carbon content requirements for steel in government and/or private procurement contracts [14].

   d. Other government financial and non-financial incentives (e.g. R&D funding) required to support the transition to net zero in the steel industry [14].

7. **Consistent with Climate Action 100+ Benchmark Indicator 9, steel companies should commit to providing a Just Transition.** To meet this commitment, companies should set out, in a board level report, how they intend to manage the wider societal impact of transitioning to net zero and who will be responsible for implementing its just transition strategy.

INDUSTRY-WIDE ACTIONS

8. **In coordination with major steel customers and other value chain participants, convene a cross-sector working group on how material efficiency can be substantially increased across the value chain.** This working group would aim to identify by working through, application by application, where a combination of improvements in manufacturing, end product design/use and recycling have the greatest potential for improving material efficiency and how those improvements can be delivered. The findings, recommendations, and opportunities – including any hurdles that need to be addressed by other stakeholders, including policy makers – should be outlined in a public report.

9. **In coordination with major suppliers, produce a report evaluating the mid- and long-term impacts of the transition to net zero in steel on a) raw materials and b) 100% green energy (hydrogen and electricity).** These reports would enable suppliers to make long term plans to scale back metallurgical coal production, for example, as well as anticipate growth in demand for iron ore pellets required for DRI-based steel production, green hydrogen and green electricity. Thus ensuring that the pace of the transition is not constrained by the lack of availability of resources and infrastructure.

ACTIONS FOR INVESTORS

10. **Identify the largest global purchasers of steel and undertake a systematic engagement process to obtain public commitments from them to buy "green" steel (as established in Action 4).**

11. **Provide capital explicitly to finance the low carbon steelmaking capacity including hydrogen based DRI-EAF, steelmaking from scrap (EAF) and CCS/CCUS deployment.** This will require working alongside other investors and stakeholders such as the Climate Bond Initiative [18] to establish robust standards for steel sector "transition bonds" that define the types of steel projects (and technologies) would fall into the steel "transition" criteria, the appropriate reporting mechanisms and direct covenants.

12. **Support policies consistent with accelerating the transition to net zero.** Investors should support sensible and socially responsible policy that incentivises the steel industry to rapidly reduce emissions and align with net zero. These policy asks can be identified through continued engagement with steel companies, the steel sector, and policymakers, and as they emerge from the company transition plans as requested by Action 6.

RECOMMENDATIONS FOR INVESTOR INTERVENTION

APPENDIX

Table 2: Technology Readiness Level (TRL) description table

CONCEPT	1	**Initial idea** Basic principles have been defined
	2	**Application formulated** Concept and application of solution have been formulated
	3	**Concept needs validation** Solution needs to be prototyped and applied
SMALL PROTOTYPE	4	**Early prototype** Prototype proven in test conditions
LARGE PROTOTYPE	5	**Large prototype** Components proven in conditions to be deployed
	6	**Concept needs validation** Prototype proven at scale in conditions to be deployed
DEMONSTRATION	7	**Pre-commercial demonstration** Solution working in expected conditions
	8	**First-of-a-kind commercial** Commercial demonstration, full scale deployment in final form
EARLY ADOPTION	9	**Commercial operation in relevant environment** Solution is commercially available, needs evolutionary improvement to stay competitive
	10	**Integration needed at scale** Solution is commercial and competitive but needs further integration efforts
MATURE	11	**Proof of stability reached** Predictable growth

Source: IEA Energy Technology Perspectives 2020. All rights reserved [3].

Table 3: Low & zero-emissions steel technologies by year of commercial availability

Year available	Technology	Application	Description	TRL (Technology readiness level)	Importance for emissions abatement	Number of existing projects and developer/company name
Today	CCS/CCUS	DRI	DRI Natural gas-based with CCS	9 - Early Adoption	Very High	(3) ADNOC, Ternium (2 plants), Orinoco Iron Finmet
Today	CCS/CCUS	Blast furnace	Converting off-gases to fuels	8 - Demonstration	Medium	(3) LanzaTech, Steelanol/Carbalyst project by ArcelorMittal-LanzaTech, FReSMe
2025	CCS/CCUS	Blast furnace	Converting off-gases to chemicals	7 - Demonstration	Medium	(2) Carbon2Chem project by Thyssenkurpp, Carbon4PUR
2028	CCS/CCUS	Smelting reduction	Smelting reduction with CCSU. Off-gas hydrogen enrichment and/or	7 - Demonstration	Very High	(2) Hisama by Tata steel, FIMEX by Primetals
2030	CCS/CCUS	Blast furnace	CO_2 removal for use/storage	5 - Large prototype	Very High	(6) COURSE 50, ULCOS, ArcelorMittal in Dunkirk, IGAR, ROGESA, STEPWISE

Year available	Technology	Application	Description	TRL (Technology readiness level)	Importance for emissions abatement	Number of existing projects and developer/company name
2025	Hydrogen	Blast furnace	Electrolytic H_2 blending	7 - Demonstration	Medium	(1) Thyssenkrupp
2025	Hydrogen	Ancillary processes	H_2 for high temperature heat	5 - Large prototype	High	(2) Ovako-Linde, CELSA-Stratkraft-Mo
2030	Hydrogen	DRI	Natural gas-based with high levels of electrolytic H_2 blending	7 - Demonstration	High	(3) Tenova, SALCOS project by Salzgitter steelworks, Thyssenkrupp
2030	Hydrogen	DRI	Based only on electrolytic H_2	5 - Large prototype	Very High	(3) HYBRIT, ArcelorMittal, Thyssenkrupp
-	Hydrogen	Smelting reduction	H_2 plasma reduction	4 - Small prototype	Medium	(2) SuSteel by K1MET-Primetals, University of Utah pilot

Year available	Technology	Application	Description	TRL (Technology readiness level)	Importance for emissions abatement	Number of existing projects and developer/company name
-	Direct electrification	Electrolysis	Low-temperature electrolysis	4 - Small prototype	Medium	(1) Siderwin project (based on ULCOWIN, ULCOS programmes)
-	Direct electrification	Electrolysis	High-temperature molten oxide electrolysis	4 - Small prototype	Medium	(2) MIDEIO (ULCOS), Boston Metal (MIT)

Year available	Technology	Application	Description	TRL (Technology readiness level)	Importance for emissions abatement	Number of existing projects and developer/company name
Today	Bioenergy	Blast furnace	Charcoal	10 - Early Adoption	Medium	(Many) Projects primarily in Brazil
2025	Bioenergy	Blast furnace	Torrefied biomass	7 - Demonstration	Medium	(1) The Torero partnership by ArcelorMittal

Note: For CCS/CCUS technologies the specified TRL refers to the whole CCS/CCUS value chain applied within the iron and steel sector (whichever has the higher TRL), rather than the TRL of the CCS/CCUS technology only.

Source: Adapted from IEA, Iron and Steel Technology Roadmap Towards more sustainable steelmaking (Part of ETP 2020) [7]

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APPENDIX

REFERENCES

[1] Energy Transitions Commission, Mission Possible: reaching net zero carbon emissions from harder to abate sectors by mid-century. Sectoral focus: Steel

[2] Energy Transitions Commission, Mission possible platform, World Economic Forum, Net zero steel initiative workshop. Financing the transition to net zero steel in the 2020s.

[3] IEA, Energy Technology Perspectives 2020. https://webstore.iea.org/download/direct/4165

[4] IEA, Iron and Steel, Tracking report – June 2020. https://www.iea.org/reports/iron-and-steel#resources

[5] IEA, Energy Technology Perspectives 2017

[6] IEA, The Future of Hydrogen. Seizing today's opportunities. 2019

[7] IEA, Iron and Steel Technology Roadmap Towards more sustainable steelmaking (Part of ETP 2020) https://www.iea.org/reports/iron-and-steel

[8] IEA, Net Zero by 2050: A Roadmap for the Global Energy Sector. https://www.iea.org/reports/net-zero-by-2050

[9] Material Economics, The Circular Economy a Powerful Force for Climate Mitigation Transformative innovation for prosperous and low-carbon industry.

[10] Material Economics, Industrial Transformation 2050 Pathways to Net zero Emissions from EU Heavy Industry

[11] McKinsey & Company, Decarbonization of industrial sectors: the next frontier. 2018

[12] McKinsey & Company, Decarbonization challenge for steel https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

[13] Responsible Steel. Responsible Steel Proposals and Consultation Questions on GHG Emission Requirements for the Certification of Steel Products. Draft 1.0. September 2020. https://www.responsiblesteel.org/wp-content uploads/2020/09/ResponsibleSteel-GHG-Requirements-for-Steel-Product-Certification-for-Consultation-Draft-1-0.pdf

[14] Rocky Mountain Institute, The disruptive potential of green steel https://rmi.org/wp-content/uploads/2019/09/green-steel-insight-brief.pdf

[15] Will Hall, Thomas Spencer, Sachin Kumar. 2020. Towards a Low Carbon Steel Sector: Overview of the Changing Market, Technology and Policy Context for Indian Steel. New Delhi: The Energy and Resources Institute (TERI).

[16] Transition Pathway Initiative (TPI). Carbon Performance in steel https://www.transitionpathwayinitiative.org/tpi/sectors/steel

[17] Climate Action 100+, "Climate Action 100+ Net zero Company Benchmark," December 2020. [Online]. Available: https://www.climateaction100.org/wp-content/uploads/2020/12/Net-Zero-Benchmark-Indicators-12.15.20.pdf.

[18] Climate Bonds Initiative (CBI). Climate Bonds White Paper Financing credible transitions: How to ensure the transition label has impact. September 2020. https://www.climatebonds.net/files/reports/cbi_fincredtransitions_final.pdf

[19] World Steel Association 2020. World Steel in Figures https://www.worldsteel.org/en/dam/jcr:13cda8f8-ba77-4a45-97d2-1fc5e88d5bf3/November%25202020%2520crude%2520steel%2520production%2520table.pdf

[20] Midrex, DR-Grade Iron Ore Pellets – A Supply Overview https://www.midrex.com/tech-article/dr-grade-iron-ore-pellets-a-supply-overview/

[21] S&P Global, Steel sector is key to reducing China's carbon emissions https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/steel-sector-is-key-to-reducing-china-s-carbon-emissions-61634240

[22] World Steel Association. Steel Statistical Yearbooks 2000-2019 https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html

[23] Climate Action Tracker. Manufacturing a low-carbon society: how can we reduce emissions from cement and steel? October 2017

[24] New China steel scrap standards to be issued by end-2020 - Xinhua https://www.reuters.com/article/china-steel-scrap-idUKL4N2H51NP

[25] SSAB, First in fossil-free steel. Using HYBRIT Technology. https://www.ssab.com/company/sustainability/sustainable-operations/hybrit

[26] Reuters business news. Exclusive: RWE, Thyssenkrupp plan hydrogen production venture article https://uk.reuters.com/article/thyssenkrupp-rwe-hydrogen/exclusive-rwe-thyssenkrupp-plan-hydrogen-production-venture-idUKL8N2DN2K5

[27] Global CCS Institute, Global Status of CCS, 2019. https://www.globalccsinstitute.com/wp-content/uploads/2019/12/GCC_GLOBAL_STATUS_REPORT_2019.pdf

[28] Center for International Environmental Law. FUEL TO THE FIRE, How Geoengineering Threatens to Entrench Fossil Fuels and Accelerate the Climate Crisis https://www.ciel.org/wp-content/uploads/2019/02/CIEL_FUEL-TO-THE-FIRE_How-Geoengineering-Threatens-to-Entrench-Fossil-Fuels-and-Accelerate-the-Climate-Crisis_February-2019.pdf

[29] Arcelor Mittal. ArcelorMittal Europe sets out path to net zero by 2050, with pioneering technologies at the forefront of the company's roadmap for carbon-neutral steelmaking, June 2020 https://corporate.arcelormittal.com/media/press-releases/arcelormittal-europe-sets-out-path-to-net-zero-by-2050-with-pioneering-technologies-at-the-forefront-of-the-company-s-roadmap-for-carbon-neutral-steelmaking

[30] Commission launches public consultations on energy taxation and a carbon border adjustment mechanism https://ec.europa.eu/taxation_customs/news/commission-launches-public-consultations-energy-taxation-and-carbon-border-adjustment-mechanism_en

[31] Caixin, China's Steel Industry Argues It's Forging a Low-Emission Future https://www.caixinglobal.com/2020-11-02/chinas-steel-industry-argues-its-forging-a-low-emission-future-101622082.html

[32] ArcelorMittal Sestao to become the world's first full-scale zero carbon-emissions steel plant https://corporate.arcelormittal.com/media/press-releases/arcelormittal-sestao-to-become-the-world-s-first-full-scale-zero-carbon-emissions-steel-plant

[33] Global CCS Institute. Global costs of carbon capture and Storage 2017 update. https://www.globalccsinstitute.com/archive/hub/publications/201688/global-ccs-cost-updatev4.pdf

[34] IRENA. Green hydrogen cost reduction scaling up electrolysers to meet the 1.5°c climate goal. 2020 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[35] Fastmarkets MB, MEIS 2020: Oversupply possible for DR pellet market in mid term https://www.metalbulletin.com/Article/3967296/MEIS-2020-Oversupply-possible-for-DR-pellet-market-in-mid-term.html

[36] Katrin E. Daehn, André Cabrera Serrenho, and Julian M. Allwood. 2017. How Will Copper Contamination Constrain Future Global Steel Recycling? Department of Engineering, University of Cambridge.

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