Charting Progress to 1.5°C through Certification

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Acknowledgements

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# Key Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BAT</td>
<td>Best available technology</td>
</tr>
<tr>
<td>BF</td>
<td>Blast furnace</td>
</tr>
<tr>
<td>BOF</td>
<td>Basic oxygen furnace</td>
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<tr>
<td>CC</td>
<td>Carbon Cost (scenario)</td>
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<tr>
<td>CCS</td>
<td>Carbon capture and storage</td>
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<tr>
<td>CCUS</td>
<td>Carbon capture, utilisation and storage</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<tr>
<td>CO₂e</td>
<td>Carbon dioxide equivalents</td>
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<tr>
<td>DRI</td>
<td>Direct reduced iron</td>
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<tr>
<td>EAF</td>
<td>Electric arc furnace</td>
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<tr>
<td>H₂</td>
<td>Hydrogen</td>
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<tr>
<td>GHG</td>
<td>Greenhouse gas</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>MOE</td>
<td>Molten oxide electrolysis</td>
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<tr>
<td>MPP</td>
<td>Mission Possible Partnership</td>
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<tr>
<td>NZE</td>
<td>Net Zero Emissions (scenario)</td>
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<tr>
<td>PL</td>
<td>Progress Level</td>
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<tr>
<td>PL1</td>
<td>Progress Level 1: basic threshold</td>
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<td>PL2</td>
<td>Progress Level 2</td>
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<td>PL3</td>
<td>Progress Level 3</td>
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<td>PL4</td>
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Executive Summary
This report draws clear connections, for the first time, between ResponsibleSteel's Decarbonisation Progress Levels and what is required to deliver a 1.5°C-aligned pathway for the global steel sector

- The International Energy Agency's (IEA) Net Zero Emissions (NZE) by 2050 scenario and the Mission Possible Partnership's (MPP) Carbon Cost (CC) scenario are explicitly linked to the ResponsibleSteel Decarbonisation Progress Levels.
- The Progress Levels benchmark every tonne of crude steel made anywhere in the world, with any technology, from the basic threshold (Progress Level 1) through to near-zero emissions (Progress Level 4), and are designed using a scrap-variable approach to reward improvement across all production routes, regardless of technology dependence.
- Consequently, the Progress Levels are an adaptable tool for managing and incentivising a steelmaker's decarbonisation efforts in alignment with the company's Paris-aligned pathway. Here, we move beyond technology-led roadmaps to understand how certification can drive the transformation we need to see across the global steel sector.
- The results provide a framework for steelmakers and steel users to navigate time-bound certification requirements using Progress Levels, and for policy makers and financial institutions to incentivise the investments we need to see for the industrial transformation.

The entire industry needs to shift but radical change at scale takes time

- The analysis demonstrates the importance of immediate action at scale; for the steel industry to achieve its Paris Agreement obligations, every steel plant in the world needs to reach the basic threshold (PL1) by 2030, which is equal to or better than today's average emissions intensity.
- In other words, following a 1.5°C trajectory, today's average steelmaker will become the industry's worst by 2030 if they don't improve their operations.
- Any near-term (5- to 15-year time horizon) delays in technology or energy investments will intensify the sector's long-term (15- to 35-year time horizon) emission reduction requirements.
- The near-term focus must be simultaneous significant transitional improvements (emission reductions of more than 30% compared to the basic threshold), and breakthroughs (emissions reductions of more than 85% compared to the basic threshold) observed across a leading minority of 'first movers'. First movers may well be capable of supplying near-zero emissions steel before 2030, however, the overall output and cumulative emissions savings will be minimal to start with.
- It is essential for all steel plants to commence their decarbonisation journey, regardless of their starting point. Progress will not be linear, but must commence immediately.
Global objectives require regionally nuanced approaches

- Differences in certification in 2030 are most pronounced across regions. Although, in the two decades to 2050 synchronisation (in relative terms) is observed across the regions as near-zero emissions (PL4) steel production in 2050 is a fundamental requirement of a 1.5°C–aligned pathway.
- Regions operate under unique material and energy endowments, fleets of existing assets, industrial–climate policies, and private/public funding. Accordingly, decarbonisation progress will occur at different speeds and the ResponsibleSteel International Production Standard is adaptable for regional variability in not specifying time-bound targets for Progress Level achievement.
- Common but differentiated responsibilities will be key to achieving sector–wide decarbonisation, acknowledging the heterogeneity of not only the speed of the transition, but also technology adoption, energy source dependence, finance requirements and effective policy mechanisms.

The reduction of supply chain emissions is critical to reach near zero

- This report has also analysed how the balance of emission sources would change over time in the 1.5°C–aligned scenarios. The analysis demonstrates that upstream indirect emissions related to material and fuel inputs would become larger shares of the total site–level crude steel emissions intensity even under ambitious assumptions for intersectoral decarbonisation (including the mining sector, H₂ sector, ferroalloys sector).
- Indirect supply chain–related emissions will comprise about one–third of emissions in 2050, an increase from today’s approximately one–quarter share. In addition, even if most direct emissions are eliminated through transformational technology change the industry must not neglect persisting direct emission sources. Some carbon–based inputs, which are required due to the inherent chemistry of steelmaking, present challenges for complete decarbonisation (e.g. carburising agents, lime fluxes, and graphite electrodes) and lack investments to grow near-zero emissions alternatives.
- Whilst decarbonisation of the power sector is far from certain, the energy–intensive steel industry can play a powerful role in stimulating demand for near–zero emissions electricity, and/or developing behind–the–meter renewable energy projects to directly feed the site. Industrial decarbonisation requires steelmakers to be accountable both within and beyond the physical site boundary.
The decarbonisation challenge is heightened under higher steel demand trajectories

- To reach net zero, the steel sector must reduce the emissions intensity of steel production and/or reduce overall steel consumption. In 2050, steel demand is modelled by MPP to reach 2.5 billion tonnes, and by IEA to reach 2 billion tonnes (20% lower), based on different assumptions of material efficiency and circularity patterns.

- The key differences between the certification pathways relate to the near-term achievement of near-zero emissions (PL4), and timing of the phase out of the basic threshold (PL1). In the MPP model, 7% PL4 is achieved in 2035 and all PL1 certification is eliminated by 2040, whereas in the IEA model 1% PL4 is achieved by 2035 and PL1 is more gradually phased out towards 2050.

- Despite these differences, the analysis shows similar decarbonisation trends are required to meet the common ambition. The certification pathways (in relative terms) are not disparate as near-zero emissions in 2050 remains the goal, and substantial emission reductions must occur by 2030.

- In addition, both models agree that the scrap portion of metallic inputs to steelmaking over time will reach about 50% by 2050, from today's 35%. Consequently, whilst steelmakers should enhance circular economy practices to maximise value retention in secondary material flows (within the limits of end-of-life steel availability), energy-intensive ironmaking processes will still be required in 2050 and must be decarbonised.

Ambition and urgency are required to ensure commitments made under the Paris Agreement are achieved

- Steel's industrial decarbonisation will not be easy, but it must be done. In the 26 years from 2024 to 2050, business-as-usual must move from the basic threshold (PL1) to near-zero emissions (PL4).

- To do so, an effective global standard and certification scheme will be instrumental in:
  i. establishing and maintaining equitable guardrails for achieving sustainable steel production,
  ii. providing a lens through which the entire steel value chain can measure and verify decarbonisation progress, and
  iii. enabling lower/much lower/near-zero emissions steel markets to flourish.

- The ResponsibleSteel International Production Standard is ideally positioned as a powerful tool for steelmakers, policymakers, financial institutions, trade organisations, and campaigners, to support genuine decarbonisation of the steel sector at large.
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Introduction
The study

In this report, we set out to devise what time-bound pathways to net zero look like for the steel sector, in terms of ResponsibleSteel's Decarbonisation Progress Levels. We demonstrate what volumes of Certified Steel may be required for a 1.5°C compatible pathway and provide an example of what steelmakers should do to track their own progress.

ResponsibleSteel's International Production Standard1 (referred to as the 'Production Standard') requires that steelmakers have a publicly available Paris-aligned decarbonisation pathway at corporate level, alongside a credible strategy to achieve the emission reduction targets and evidence of effective implementation over time (criterion 10.1).

Simultaneously, steelmakers wanting to sell their products as ResponsibleSteel certified must measure their site-level crude steel GHG emissions intensity (in accordance with criterion 10.4) to determine the appropriate Progress Level (under criterion 10.6). How these elements – pathways and Progress Levels – interact has not yet been demonstrated by ResponsibleSteel nor its members – a gap this Report starts to close.

The study builds upon two existing scenarios of 1.5°C-aligned pathways to net zero2 for the global steel industry: the International Energy Agency's (IEA) Net Zero Emissions (NZE) scenario derived from the Global Energy and Climate (GEC) model3, and the Mission Possible Partnership's (MPP) Carbon Cost (CC) scenario derived from the Steel Sector Transition Strategy Model (ST–STSM)4. Both represent trajectories to net zero 2050 but differ in their forecasts of technology adoption, steel consumption and scrap availability, offering valuable insights into the sectoral transition.

Multiple 1.5°C-aligned pathways have purposely been selected to demonstrate technological, temporal, and spatial variability. The models are normative (i.e. designed to achieve specific outcomes) and intended to inform, not predict, possible industrial change over the next three decades. The pathways are contingent on technology maturity, natural resource availability (e.g. iron ore and renewable energy), secondary material flows (i.e. scrap), policy incentives, available financing mechanisms, intersectoral decarbonisation (e.g. the mining and power sectors), as well as numerous other social, environmental, and economic factors. The resultant pathways for 1.5°C-aligned ResponsibleSteel Certification represent attainable means of reaching net zero by 2050 whilst ensuring that cumulative emissions do not breach carbon budget constraints established in the IEA and MPP scenarios. Details on the process for analysis are provided in the following section (Methodology Overview) and Appendix A (Methodology Details).

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1 ResponsibleSteel. (2024). ResponsibleSteel International Production Standard V2.1. https://www.responsiblesteel.org/standards
2 Net zero and near zero are distinct. Net zero is an outcome in which the total GHGs emitted to the atmosphere are offset by the permanent removal and storage of carbon from the atmosphere. Near zero recognises the reduction of the actual process-related emissions and upstream emissions without any offsetting.
The steel sector's time-bound transition

Under the internationally binding 2015 Paris Agreement, signatories have committed to maintain global average temperatures well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C, recognising that this would significantly reduce the risks and impacts of climate change. The Agreement has been signed and ratified by 195 of 198 parties (excludes Iran, Libya, and Yemen) of the United Nations Framework Convention on Climate Change (UNFCC). Since then, commitments have been set globally by both governments and corporates to reduce iron and steel sectoral emissions to net zero within the next 3 decades, from 3.7 Gt CO₂ per annum in 2023 (a conservative estimate considering direct and indirect energy–related emissions only) which is roughly equivalent to 10% of global energy–related CO₂ emissions⁶,⁷,⁸.

MPP estimates the global steel sector’s 30-year carbon budget (from 2020 to 2050) to be 56 Gt CO₂e (considering direct and indirect energy–related emissions only), inferred from the total global budget estimate of 500 Gt CO₂e from the Intergovernmental Panel on Climate Change (IPCC) for a 55% likelihood of keeping global warming to 1.5°C⁹. Although not published, the IEA’s budget under the NZE for the steel sector is similarly estimated to be around 55 Gt CO₂e¹⁰. The assessed pathways ensure net zero emissions are achieved globally by 2050, an outcome considered necessary by the IPCC to remain consistent with 1.5°C. Of the steel sector’s budget, approximately one–quarter has already been drained in the last four years. If the industry continues business–as–usual, the entire budget will be expended by the late 2030s. Change of the magnitude required necessitates an urgent, strategic, and well–funded transition, for which credible standards initiatives form important guardrails and act as facilitators of change.

The role of standards and certification in the decarbonisation landscape

A global perspective is imperative for the steel sector, with its globalised supply chain and high volumes of international trade. Universally applicable and adopted emission accounting methodologies and thresholds for lower/near–zero emissions steel will help to streamline benchmarking, funnel support towards sites achieving genuine decarbonisation, ease trade barriers, reduce administrative burdens, and enhance traceability across the value chain. Although the premise of alignment of rules applied across the spectrum of standards and methodologies is widely agreed upon (see Box 1), significant challenges exist for achieving such. Emissions intensity–based classification systems (and the methodologies that underpin them) are strongly linked to global market competition and trade tensions. For example, the EU

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and US have still not reached a conclusion for a Global Arrangement on Sustainable Steel and Aluminium\textsuperscript{11} which set out in 2021 to align import restraints based on emissions intensity.

Standards, and credible systems to verify their implementation (i.e. certification), play an important role in achieving sustainability outcomes. Standards establish market trust, mitigating greenwashing, and providing a reliable marketable instrument through which finances can be drawn, for example, through green premiums and incentive schemes. Progress (or lack of progress) towards achieving near-zero emissions needs to be tracked, and the market can effectively use certified product labels to differentiate products. Standards play an important role in decarbonisation by facilitating both the supply-push and demand-pull.

The ResponsibleSteel International Production Standard, described by the IEA in its report to the G7\textsuperscript{12} as “at the forefront...with respect to fitness for purpose for a net zero steel sector.” provides an inclusive, global, transparent multi-stakeholder membership, standards and certification scheme. It is therefore well-positioned to support the net-zero transition for the steel industry. ResponsibleSteel’s labels to demarcate Certified Steel products are powerful tools for policymakers, financial institutions and downstream markets to measure progress across the industry, channel ambition, and accelerate industrial decarbonisation.

**Box 1: The Steel Standards Principles**, launched with ResponsibleSteel’s support at COP28, is the current multilateral initiative under which organisations are convening to harmonise and/or ensure interoperability between emissions accounting methodologies and standards, as well as a common definition for ‘near-zero emissions’ steel production. The aim is to reduce fragmentation and incompatibility of standards and methodologies, and thereby easy trade frictions, administrative burdens, and market uncertainty. Ultimately, this will support effective, efficient decision making across the steel value chain, and accelerate global decarbonisation efforts.

**The ResponsibleSteel International Production Standard, Principle 10**

Within the Production Standard, 13 Principles for sustainable steel production are established, covering governance, environmental, and social aspects. The requirements of ResponsibleSteel’s Principle 10 (GHG Emissions and Climate Change) support the Paris Agreement. There are different levels of maturity in ResponsibleSteel Certification: (i) **Core Site Certification**, where steelmakers must comply with all Core requirements, and (ii) **Steel Certification**, where steelmakers must comply with all Progress and Core requirements. The Core Site Certification ensures comprehensive management of ESG (environment, social and governance) sustainability risks. Yet, only under the more comprehensive Steel Certification can steelmakers market or label their products as ResponsibleSteel Certified Steel as they have demonstrated progress in

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achieving Responsible Sourcing (Principle 3) and Decarbonisation (Principle 10).

Within Principle 10 there are seven criteria, of which two are exclusively Progress. The Core criteria mandate that: (10.1) the corporate owner has published a science-based target\(^{13}\) to reduce the company’s GHG emissions in line with the achievement of the goals of the Paris Agreement, (10.2) the corporate owner is implementing the recommendation of the Taskforce on Climate-Related Financial Disclosures, (10.3) GHG emissions are measured at site-level using a recognised international or regional standard, and (10.5) GHG emission reduction targets are in place and being implemented at the site. The Progress criteria require that: (10.4) GHG emissions are measured at the site level from ‘cradle-to-crude’ following internationally consistent scope boundaries and GHG accounting rules, as set out by ResponsibleSteel, and (10.6) the site has achieved at least Progress Level 1, is tracking towards near-zero emissions and the Product Carbon Footprint (PCF) or Global Warming Potential value within the Environmental Production Declaration (EPD) is disclosed in line with a recognised international or regional standard. Reporting requirements (10.7) are relevant for both Core and Progress criteria.

The Decarbonisation Progress Levels measure the impact of interventions to reduce site-level emissions (shown in Figure 1). The Progress Levels are a set of four emissions intensity thresholds (with unit of tonnes CO\(_2\)e/tonne crude steel), which range from the basic threshold (PL1) to near-zero emissions (PL4). Comparison against the thresholds is appropriate for any carbon steel product (<8% alloy content) in the global market, agnostic to technology and region. PL4 aligns with the IEA’s near-zero emissions threshold\(^{14}\), PL1 reflects the current industry average\(^{15}\), and PL2 and PL3 are step-changes. A slightly shallower gradient towards the high-scrap end of the scrap-variable scale has been adopted to encourage increased recycling rates within the bounds of end-of-life (EOL) steel availability. At the low-scrap end of the scrap-variable scale approximately 50% of sites meet the PL1 threshold, whilst at the high-scrap end 62% of sites meet the PL1 threshold. A consistent emissions accounting methodology has been developed (under criterion 10.4) which is used for site-level emissions accounting, covering direct emissions, indirect energy-related emissions, and indirect upstream material and fuel-related emissions (refer to Figure A.1). This approach provides comparability across all sites within the global steel sector on a like-for-like basis, regardless of

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\(^{13}\) A science-based target (SBT) validated by the SBTi (Science Based Targets initiative) would be sufficient to meet the medium-term requirements of 10.1.2. Other quantitative, scientifically justified targets (or sets of targets, for example for separate processes) may also be recognised, as long as the ambition, quality and coverage of the target is comparable.


\(^{15}\) Using data from CRU’s *Steel Cost Model* related to the year 2021, which was strengthened and verified using primary industry data.
the final steel product or production process. By design, the Progress Levels are a universal tool to benchmark steel plant decarbonisation progress to near zero.

**Box 3: Scrap-variable thresholds underpin an equitable decarbonisation framework.**
Scrap availability is a function of historical steel consumption and in–use steel stock lifetimes\(^\text{16}\). Consequently, scrap resources are constrained globally, and regionally unequal; developed regions have higher scrap availability due to the previous decades of development\(^\text{17}\). Insufficient scrap means decarbonising ironmaking is critical to achieving the Paris Agreement, which is both economically and technically more challenging. Globally, scrap–based EAF production is currently 70% less emissions-intensive than iron–ore based BF–BOF production\(^\text{18}\). The lower the scrap inputs, the greater the gap between present–day operations and near–zero emissions. ResponsibleSteel’s Progress Levels are designed using a scrap–variable approach to reward emissions reductions across all production routes. There is a slight favouring towards the high–scrap end to simultaneously incentivise improvements in recycling efficiencies, especially for end–of–life scrap (currently approximately 15% of global end–of–life steel resources are not being recycled\(^\text{19}\)). Concerningly, without scrap–variable thresholds, increased use of scrap would be the primary incentive and these scarce secondary resources would be displaced to where customers are willing to pay a green premium. This would cause carbon leakage, leaving unregulated markets to produce higher emissions steel made with iron ore.

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16 The average lifetime of in–use steel stock varies based on the end–use sector: transportation (~20 years), machinery (~30 years), construction (~75 years) and products (~15 years). This is referenced from: Pauliuk, S., Milford, R., Müller, D., & Allwood, J. (2013). The Steel Scrap Age. https://pubs.acs.org/doi/10.1021/es303149z
Methodology Overview
Description of the base scenarios

The IEA's NZE scenario and MPP's CC scenario were selected for their common alignment with 1.5°C, yet distinct assumptions regarding steel demand, scrap consumption, and technology diffusion. This allowed exploration of a variety of Paris–compatible pathways. As shown in Figure 2, IEA's NZE scenario projects 2.0 billion tonnes of steel production in 2050, a minor 4% increase from today’s levels. Steel demand is assumed to stagnate under the application of material efficiency measures such as building lifetime extensions and optimising manufacturing yields. IEA also presents the stated policies scenario (STEPS) as a baseline (not modelled here due to lack of 1.5°C alignment) which forecasts 2.6 billion tonnes of steel demand in 2050. This steel demand trajectory is not dissimilar from MPP's CC scenario which utilises the business–as–usual (BAU) demand projections where steel consumption patterns and product life cycles stay relatively consistent. MPP foresee demand reaching 2.5 billion tonnes in 2050, 35% greater than today's output, which is mostly driven by growth in low–income and emerging economies. Simultaneously with increased steel demand, more end–of–life steel becomes available which is dependent on historical steel consumption and the lifetime of in–use steel stocks. MPP also model a high circularity scenario (not modelled here) which analyses to what extent demand could be reduced by optimising circular economy principles. The high circularity scenario forecasts 1.5 billion tonnes of steel demand in 2050, far lower than BAU, and it is not utilised in any MPP scenario due to its perceived unlikelihood of eventuating.

Figure 2: Steel demand and scrap consumption trajectories under the IEA NZE and MPP CC scenarios.

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The differences in technology diffusion factors assumed by IEA NZE and MPP CC scenarios in the near and long-term are highlighted in Table 1. In the near-term, MPP foresee a far larger uptake of CCUS-equipped and H₂-based processes whilst in the long-term, the IEA foresee a slightly stronger shift away from BAU, including uptake of iron or electrolysis technology. Regarding scrap-based production (i.e. the scrap-based EAF route), similar projections are seen in both 2030 and 2050. Note that scrap-based production is distinct to overall scrap inputs to steelmaking (as shown on the secondary vertical axis of Figure 4) as the latter considers the minor portions of scrap used in ore-based steelmaking (ranging from 5–26% depending on the technology archetype).

<table>
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<tr>
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<th>IEA NZE (2023)</th>
<th>MPP CC (2022)</th>
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<tbody>
<tr>
<td></td>
<td>2030</td>
<td>2050</td>
</tr>
<tr>
<td><strong>Scrap-based production</strong></td>
<td>31%</td>
<td>45%</td>
</tr>
<tr>
<td><strong>Ore-based production</strong></td>
<td>69%</td>
<td>55%</td>
</tr>
<tr>
<td><strong>BAU</strong></td>
<td>92%</td>
<td>4%</td>
</tr>
<tr>
<td><strong>CCUS-equipped</strong></td>
<td>3%</td>
<td>37%</td>
</tr>
<tr>
<td><strong>H₂-based processes</strong></td>
<td>5%</td>
<td>44%</td>
</tr>
<tr>
<td><strong>Iron ore electrolysis</strong></td>
<td>0%</td>
<td>15%</td>
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**Connecting technology archetypes to Progress Levels**

Whilst technology diffusion factors describe the uptake of broad technology groups, technology archetypes refer to the specific production processes. ResponsibleSteel's Decarbonisation Progress Levels were determined for each technology archetype for each year, from 2020 to 2050. Utilising the MPP ST–STSM model's input data, 20 steelmaking technology archetypes were assessed, both current and emerging, of which 11 could achieve near-zero emissions based on zero-emissions electricity, zero-emissions hydrogen, or carbon capture (reducing scope 1 and 2 emissions) and decarbonised material and fuel inputs (reducing upstream scope 3). Due to the closed access nature of IEA's model, the broad technology diffusion factors for iron ore-based production (covering CCUS-equipped processes, electrolytic H₂-based, and iron ore electrolysis) were allocated to MPP technology archetypes.

The technology archetypes with near-zero emissions compatibility were the scrap based electric arc furnace (EAF), best-available-technology (BAT) blast furnace (BF)–basic oxygen furnace (BOF) with carbon capture and storage (CCS), BAT BF–BOF with carbon capture and utilisation (CCU), BAT BF–BOF with bio-energy and carbon capture utilisation and storage (BECCUS), direct reduction of iron (DRI)–EAF with natural gas feed and CCUS, DRI–EAF with H₂ feed gas (H₂–DRI–EAF), DRI–melt–BOF with CCUS, DRI–melt–BOF with H₂ feed gas, smelting reduction–EAF with CCUS, electrowinning–EAF and molten oxide electrolysis (MOE)–EAF.

Each technology archetype is characterised by unique energy and mass consumption rates, scrap portions, and emissions intensities. As illustrated in Figure 3 for a selection of technology...
archetypes, the emissions intensity of steel production is temporally variable. Temporal variability recognises the reduction in supply chain–related emissions from electricity, material, and fuel inputs which enables emissions reductions with the same furnace set-up. For example, looking at DRI with H₂ feed gas (H₂–DRI), the production of H₂ is assumed to be via electrolysis using grid power, which makes the fuel a major upstream emissions source. Consequently, the emissions intensity of the H₂–DRI–EAF route is much higher in 2030 (PL1, with corresponding H₂ emissions factor of 9 tonnes CO₂e/tonne H₂) than in 2050 (PL4, with corresponding H₂ emissions factor of zero). If the H₂–DRI–EAF plant had its own dedicated renewable energy plant, PL3 could be achievable without any other substantial supply chain decarbonisation measures. DRI–EAF plants using natural gas could reach PL2 in the near-term (not illustrated in Figure 3). The average BF–BOF route (also not illustrated in Figure 3) with just 5% scrap inputs can achieve PL1 but there are little opportunities for further emissions reductions beyond H₂ or bio–coal injection (which may enable PL2 achievement). For the BAT BF–BOF route, energy efficiency and yield improvements have already been maximised, so CO₂ capture is required to achieve Progress Levels beyond the basic threshold (PL1). For BAT BF–BOF + CCS to reach near–zero emissions (PL4), efficiency of CO₂ capture must be maximised (>90%) and upstream methane emissions from coking coal mining be dramatically reduced.

For any route relying on the EAF (including DRI–EAF, scrap–based EAF, and electrolysis–EAF), decarbonisation of the power and heat sources are necessities. However, for more ambitious Progress Levels, bio–carbon substitutions for traditionally fossil fuel–based carburising agents may be required, and lime fluxes minimised through process optimisation.

![Graph showing decarbonisation progress levels with technology archetypes and milestones.]

*Figure 3: ResponsibleSteel Decarbonisation Progress Levels with nine reference plants depicting four technology archetypes (H₂–DRI–EAF, BAT BF–BOF, BAT BF–BOF + CCS, and scrap–based EAF) at three milestones (2030, 2040, 2050).*
To connect time-variable technology archetypes to the Progress Levels, firstly the scrap percentage was determined per technology archetype as the portion of secondary metallics input to steelmaking, inclusive of home, manufacturing, and EOL scrap (refer to ResponsibleSteel criterion 10.6 in the Production Standard). Then the ‘cradle-to-crude’ GHG emissions intensity for each archetype over each year was estimated inclusive of scope 1, scope 2 and upstream scope 3, and a corresponding Progress Level assigned. Adjustments were made to ensure the site-level emissions boundary matched that of ResponsibleSteel (as illustrated in Figure A.1 for a typical integrated iron and steelmaking site) up to the point of crude steel. If the crude steel emissions intensity was less than or equal to the Progress Level 4 threshold, it was awarded PL4, if less than or equal to the Progress Level 3 threshold it was awarded PL3, and so on for PL2 and PL1. If greater than Progress Level 1 for the given scrap %, the steel was deemed ‘above PL1’ and therefore not certifiable. This process was repeated for the distinct production timelines and emissions intensities across IEA and MPP models. Whilst the emission intensities of technology archetypes change over time, the Progress Levels are static. The intention is to remove the basic threshold (an achievable entry level set at the current global average) when PL1 becomes redundant, meaning that PL2 will then represent a more appropriate entry level based on the industry's anticipated progress.

**Assumptions and caveats**

Firstly, neither the base models nor the consequent analysis are predictors of what will happen in the future. Simply, the data-centric approach allows scenario-analysis to be conducted based on a series of assumptions. We use the model outputs to inform best-practice. Secondly, the modelling is based on averages for each technology archetype, although in practice site-level emissions would be distributed above/below this value. Given the uncertainty of ranges around the average, associated distribution has not been modelled. Best efforts were made to ensure a rigorous methodology was followed and the results peer reviewed, yet, like any modelling exercise, a level of uncertainty remains.

For further details on the methodology including emissions accounting, refer to Appendix A. The findings and their implications are discussed in the following sections.
Finding 1: The entire industry needs to shift but radical change at scale takes time

In assessing the time-bound ResponsibleSteel Certification ambition to align with a 1.5°C compatible Pathway, we found that the entire industry needs to shift in the next 6 years. Under both the analyses of IEA and MPP models, for the steel industry to achieve its Paris Agreement obligations, every steel plant in the world needs to reach at least the basic threshold (PL1) by 2030. This means global steel production must collectively be better than today’s average. Compared to 2020, in 2030 an additional 500–800 Mt of PL1 ResponsibleSteel Certified Steel would be required (~30% of total production in 2030), alongside 100–150 Mt of PL2 (~6% of total production in 2030), and 100–500 Mt of PL3 (~15% of total production in 2030). The range in certification quantities reflects the variance in IEA and MPP models (refer to Figure 4). The basic threshold (PL1) is readily accessible to all steelmakers given improvements in energy efficiency, yield improvements, raw material quality, and/or process reliability, among other non–capital–intensive measures21. Until decarbonised steelmaking technology and the supply chains that support them mature, the sector will mostly be relying on smaller emission reductions across a large pool of steel production to deliver cumulative impact. Investment timing will be critical to minimise the risk of stranded assets, considering long asset lifetimes and project mobilisation timelines (from final investment decision to operation). As coal–based steelmaking capacity reaches the end of its technical operating life, this is an opportunity for furnace retirement and consequent investment in near–zero emissions steel projects.

Reaching lower and near-zero emissions requires steelmakers to move beyond simple process improvements. Some basic technology archetypes are already appropriate for lower emissions (PL2) steel production, for example the DRI–EAF route with natural gas feed. On the other hand, some production routes require substantive changes to move beyond the basic threshold, for example the BF–BOF route with partial substitution of coke using H₂ or bio-coal, and/or CCUS.

To reach near-zero emissions, plants require: substitution of fossil fuels using non–carbon alternatives, electrification using 100% renewable power, and/or very high efficiency CO₂ capture (>90%). In addition, the decarbonisation of energy and material inputs is required, including H₂ using electrolysis with zero emissions electricity (termed green H₂ when renewable sources are used).

Whilst the IEA foresees 8% of near-zero emissions iron production in 2030, this does not translate to 8% near-zero emissions steel production (PL4). This is due to residual direct emissions from steelmaking (namely from lime fluxes, carburising agents, and graphite electrodes) and upstream indirect emissions (from iron ore mining, H₂ production using electrolysis with grid power, and ferroalloys, among others).

For the energy-intensive ironmaking process, decoupling from fossil fuels is possible using zero emissions electricity sources. Green electrons can power the: (i) production of green H₂ for direct reduction of iron ore, (ii) direct electrolysis of iron ore at very high-temperatures (molten oxide electrolysis), or (iii) direct electrolysis of iron ore at low-temperatures (electrowinning).

Innovation and technology development are opening the possibilities for industrial change.

**Globally, all additional installed capacity will need to be near-zero emissions compatible.** Compatibility refers to projects that have the required infrastructure to achieve near-zero emissions. Although they don’t immediately achieve near zero, the project is underpinned by demonstrable plans to reduce emissions through operational changes. Following, lower emissions (PL2) and much lower emissions (PL3) steel production represent positive steps towards achieving sectorial decarbonisation so long as the invested assets have the capacity to achieve near-zero emissions (PL4). For example, a DRI–EAF plant that initially utilises natural gas and grid power, with plans to switch to blends of natural gas and H₂ in the near-term, and 100% H₂ shortly thereafter, paired with renewable power. Investing in future-proofed assets is key to avoiding stranded assets.

Despite the fact that less than 1 Mt of near-zero emissions steel is currently being produced, it must dominate in 2050 to align with the Paris Agreement. Emission reduction requirements intensify over time; from 2040, all new capacity will have to be operating at much lower emissions (PL3) or near-zero emissions (PL4).

Significantly, in the decade from 2040 to 2050, an additional 1350–1600 Mt of PL4 ResponsibleSteel Certified Steel (or equivalent) would be required. In the final years pre–2050, a dash for near-zero emissions steel is observed industry wide (see Figure 5). This does not represent a sudden influx of new plants, but rather existing capacity achieving deep emissions reductions through procurement of near zero–emissions energy and materials.

**We need to strike the balance between commissioning new near-zero emissions capacity and retiring existing emissions-intensive capacity.** Some excess capacity is a normal component of efficient operations (the optimal plant utilisation factor sits around 85–95%). Yet, in 2023, the global steel capacity–production gap widened to 610 Mt (equal to 32% excess capacity). OECD analysis shows that achieving a reasonable one-third reduction in excess global capacity would lead to 2–14% of sectoral emission reductions, and a more efficient market. Any new capacity should add to the lowest emissions capacity, in tandem with plans to transition away from the higher emitting capacity. Capacity replacement will not be necessary for all sites as some existing facilities will play a role in near-zero emissions operations, including EAFs (with scrap and/or DRI inputs), and BOFs (with molten iron inputs, i.e. the DRI–melter–BOF route).

There are several compounding issues contributing to excess steelmaking capacity, including fluctuating global steel demand, steelmaking companies constantly seeking growth, and new steelmakers entering an already crowded market. Whilst there are many risks associated with full or partial shutdown of operations, Principle 4 of the Production Standard, ‘Decommissioning and Closure’, supports steelmakers to minimise the associated adverse social, economic, and environmental impacts. Integrated industrial policies should simultaneously support industrial (de)growth and decarbonisation strategies.

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**Decarbonisation will not be a linear process.** Industry-wide, we can expect a slower pace of change from now to 2030, and accelerated rates towards 2040 and 2050. However, with the right policies and finance mechanisms in place, the near-term trajectory could be altered – instead of 0–1% of near-zero emissions (PL4) steel in 2030, 5–10% of global steel production could reach this ambition. Emerging technology must first reach the milestones of pilot plant (lab scale), demonstration plant (~0.1 Mtpa), then commercial plant (>1 Mtpa), to prove operational viability before expanding across companies and regions.

Change will not be linear. Technology maturity and diffusion can be illustrated through a sigmoidal (S)–curve where a period of exponential growth is observed before slowing down when market share is achieved and competition from other technologies stabilises growth rates. Step–changes in emissions intensity reduction will occur as the financial and policy conditions become more favourable, demand signals intensify, technology matures, and the supply chains that support them become more robust. Many challenges could affect the speed and nature of decarbonisation. Reaching near-zero emissions relies on an integrated and comprehensive decarbonisation strategy.

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**Figure 4:** Global ResponsibleSteel certification requirements at key milestones according to the 1.5°C–aligned pathway, based on the (a) IEA NZE scenario, and (b) MPP CC scenario. Whilst the left–hand vertical axis shows the crude steel production at different Progress Levels, the right–hand vertical axis indicates the scrap inputs to steelmaking (measured as a portion of total metallics). Note that the historical milestone of 2020 represents actual industry production, in terms of total output and site–level emissions intensities. Source: ResponsibleSteel analysis based on IEA NZE and MPP CC scenarios.
Figure 5: Global 1.5°C-aligned ResponsibleSteel certification pathways from 2020 to 2050, based on the (a) IEA NZE scenario and (b) MPP CC scenario. The historical years from 2020–2023 have been modified to more accurately represent observed industry production, in terms of output and site-level emissions intensities. Also note that the sharp edges are an artefact of the analysis; transitions would be smoother, but they illustrate trends. Source: ResponsibleSteel analysis based on IEA NZE and MPP CC scenarios.
Finding 2: Global objectives require regionally nuanced approaches

Regional differences were analysed in terms of Progress Level achievement using MPP's disaggregated results (not available from IEA), to investigate the spatial and temporal diversity of transition pathways. The global results were split into 11 regions, from which we selected six major regions for assessment – mainland China, India, East Asia (exc. mainland China), Southeast Asia, Europe, and North America. These regions represent 85% of projected steel production in 2030 (41% outside mainland China), and 80% in 2050 (46% outside mainland China).

The dominance of Chinese steel production is forecast to be enduring; despite the projected decrease in output, mainland China is set to remain the leading producing region by a large margin in 2050.

Overall global production is increasing over time to meet increased demand from emerging and developing economies. Of note, MPP expects India's demand to reach 445 Mt by 2050 from 120 Mt today which more than offsets declining demand in China, Europe, Japan, and the Republic of Korea.

Although not considered in this analysis, variance in national net-zero targets exists for China and India who have committed to achieve net-zero economies by 2060 and 2070, respectively. Despite this, many steelmakers have adopted earlier decarbonisation targets; for example, the Chinese state-owned iron and steel company Baowu (the world's largest steel producer) has committed to carbon neutrality by 205025.

Regions are affected by unique risks and opportunities associated with industrial decarbonisation. As illustrated in Figure 6, whilst some regions benefit from high scrap availability which enables high scrap inputs into steelmaking (around 60–70% in North America, Europe, and East Asia (exc. mainland China)), other regions have very low scrap availability and corresponding scrap inputs (about 15% in India). Notably, scrap inputs are expected to increase significantly in mainland China, from about 30% in 2030 to 50% in 2050, which reflects the increase in end-of-life steel availability following a large period of steel consumption in construction over the last 40 years.

Regarding iron ore, as the largest iron ore producers in the world with high renewable energy potential, Australia and Brazil, are well–positioned to expand green iron production26. Other opportunities to invest in lower/near-zero emissions production lie within the funds made available through strategic climate policies such as the European Union's Emissions Trading Scheme (ETS) and Carbon Border Adjustment Mechanism (CBAM) as well as the United States’ Inflation Reduction Act (IRA). Carbon prices and/or emissions reduction incentive schemes will play strong roles in shifting the market.

These regional nuances in policies and carbon prices are not wholly captured by the MPP CC scenario, where a global price on carbon is set at $0/tonne CO₂ in 2023, rising linearly to $200/tonne CO₂ in 2050. Here, the regionally disaggregated results are shown to illustrate pathway variability, not to imply the pathway a region should or will take.

**Under the common global goal of achieving the commitments of the Paris Agreement, regions will forge unique pathways to net zero 2050.** The decarbonisation trajectories of India and Germany, for example, will likely be completely disparate because of their distinct existing assets, policy landscape, available finance mechanisms, power grid emissions factors, scrap availability, and energy and material endowments.

The optimal decarbonisation pathway for each steelmaker will be unique, as they weigh up the prospects of capital-intensive investments, transitional improvements, and closures. The heterogeneity of steel decarbonisation pathways across regions and companies is not only reflected in the differences in the transition speed, but differences in technology uptake, barriers encountered, and the policies needed to address these.

Amongst this disparity, global coordination is required to: (i) ensure a level playing field, (ii) ease trade frictions, (iii) foster inter-regional support and knowledge sharing, and (iv) ensure the cumulative global steel sector budget is not exceeded. As an internationally consistent standard, ResponsibleSteel can provide the global framework for sectoral decarbonisation whilst supporting heterogenous pathways to net zero 2050.

ResponsibleSteel (under criterion 10.1) allows variability in determination of the Paris-aligned corporate pathway in acknowledgement of the diverse conditions of individual steelmakers.

**In general, developed economies can move faster than emerging economies.** The greatest regional differences in steel certification are observed in 2030 and 2040, with synchronisation by 2050 as near-zero emissions must be achieved industry wide to align with the Paris Agreement (refer to Figure 6). North America and Europe could lead decarbonisation efforts; the analysis foresees that all steel produced in these developed regions will be at least much lower emissions (PL3) by 2040, and 98% near-zero emissions (PL4) by 2050. Japan and the Republic of Korea (which comprise most of East Asian production) are developed nations that could also join this accelerated pace with the right policies, although their current policy landscape is not as supportive of lower/near-zero emissions steel investments and consequently a lagging presence of PL1 and PL2 steel is seen in 2040.

In contrast, developing Southeast Asia may observe just a slither of PL4 steel production in 2040. Interestingly, India is the only region in which uncertifiable steel persists into 2030, i.e. sits above the basic threshold (PL1). This reflects the high ongoing fossil fuel dependence for power production, which is relied on by scrap-based EAF producers. Extra efforts to decarbonise the power sector in India are needed for the steel sector to achieve at least PL1 by 2030, which will be supported by the Indian Government's ambition to reach 250 GW renewables capacity by 2027 (double the capacity in 2022).²⁸

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However, in terms of relative portions of near-zero emissions achievement, India could be the region with the largest market share of PL4 in 2040, underpinned by a new growth market and step-change in technology dependence (e.g. direct reduction furnaces replacing blast furnaces) and energy inputs (e.g. green H₂ substituting natural gas and gasified coal as the DRI feed gas). China is outgrowing its 'developing' classification and has the potential to lead steel decarbonisation efforts under a favourable climate policy landscape.

In absolute terms, the greatest amount of near-zero emissions (PL4) steel would be produced in China in 2040. Ambitious regional policies are needed to push the BAU trajectory, whilst considering local resource constraints and international obligations.

Despite the variability and uncertainty in each region’s 1.5°C-aligned trajectory, the global long-term objective of near-zero emissions (PL4) holds true. As an example of this uncertainty, MPP’s demand forecast for India is conservative – 220 Mtpa in 2030, up to 340 Mtpa in 2050 – compared to the Indian government’s expansion targets – 300 Mtpa by 2030 and 500 Mtpa by 2047. According to MPP’s forecasts, India’s steel production will increase from 6% of global output in 2023 to 13% by 2050, whilst IEA forecast up to 20% by 2050.

This larger production profile would most likely mean a larger portion of PL2 and PL3 steel observed in 2030 and 2040, and maintenance of PL4 predominance in 2050. Regardless, the globally common objective of near-zero emissions (PL4) by 2050 provides a united long-term ambition for industrial decarbonisation.

29 India is the world’s largest DRI producer but the only DRI producing nation relying on coal gasification, which is referenced from: Sponge Iron Manufacturer’s Association. (2023). DRI Update. http://www.spongeironindia.com/images/publications/May-2023.pdf
Figure 6: Regional 1.5°C–aligned ResponsibleSteel certification pathways, for (a) mainland China, (b) India, (c) Southeast Asia, (d) North America, (e) Europe, and (f) East Asia (exc. mainland China), in descending order of steel production in 2050. Whilst the left-hand vertical axis shows the crude steel production at different Progress Levels, the right-hand vertical axis indicates the scrap inputs to steelmaking (measured as a portion of total metallics). Source: ResponsibleSteel analysis based on the MPP CC scenario.
Finding 3: The reduction of supply chain emissions is critical to reach near zero

As overall emissions reduce over time, the shares of different emission sources shift. Emission sources were assessed over time for each technology archetype to determine the direct and indirect contributions, revealing critical insights into what levers must be pulled and pushed to reach near zero.

ResponsibleSteel requires steelmaking sites to account for their indirect upstream emissions related to material and fuel inputs (upstream scope 3), moving beyond the current norm for emissions accounting practices which generally only include direct emissions from on-site combustion (scope 1) and indirect energy-related emissions from off-site combustion related to electricity and steam production (scope 2).

Indirect emissions can be more challenging to manage as they occur outside the physical site boundary and create intersectoral dependencies. It was found that direct emissions take up a larger fraction of emissions over time across all technology archetypes (refer to Figure 7). In addition, upstream emissions related to material and fuel inputs take up a larger fraction of emissions over time for most technology archetypes. Industry wide, the sum of upstream scope 3 emissions may increase from one-quarter in 2030 to one-third in 2050.

Tackling residual scope 1 and upstream scope 3 emissions sources will be crucial in the last stretch of the net-zero journey.

To minimise direct emissions, the industry must substitute fossil fuels for zero emissions alternatives, and/or effectively capture CO₂ emissions for permanent storage or utilisation.

To decarbonise the high-scrap production route, the EAF must be powered using zero emissions energy sources, and heat produced either via direct electrification or zero emissions fuels such as green H₂ or biomethane.

For the low-scrap production route, achieving near-zero emissions ironmaking relies on 100% green H₂-based direct reduction of iron (DRI), 100% renewables-powered direct electrolysis (at molten state, or low-temperature electrowinning), or CCUS-equipped processes. For CCUS-equipped processes to reach near-zero emissions (PL4), the capture rate must be very high (>90%), CO₂ storage/utilisation permanent, operations powered using zero emissions energy sources, and upstream methane leakage from coal mining largely eliminated. The H₂–DRI–EAF steelmaking route offers more than 95% emission reductions, provided that electrolysis for H₂ production and EAF furnaces are powered using zero emissions energy sources

There is no clear near zero emissions technology ‘winner’ at this point in time. The development of key decarbonisation technologies is being pursued by existing and emerging companies. Operational viability is being tested and commerciality is in sight. Building on knowledge from the existing natural gas-based DRI furnaces, the green H₂–based production

facilities being developed separately by SSAB\textsuperscript{36} and H\textsubscript{2} Green Steel\textsuperscript{37} in Sweden and are expected to start commercial-scale operation in 2026. Although a commercial-scale CCS-equipped steel plant exists (located in Abu Dhabi), the production route is natural gas-based DRI-EAF and it captures a limited one-quarter of its total emissions, which is used for enhanced oil recovery\textsuperscript{38}.

The major challenge for CCUS is to commercialise the retrofitting of CO\textsubscript{2} capture technology to the large fleet of existing BF-BOF plants, with multiple flue-gas stacks. As a positive step forward, partial CO\textsubscript{2} capture and utilisation to produce methanol is in operation at pilot-scale at ArcelorMittal’s BF-BOF plant in Belgium\textsuperscript{39}.

Several other technologies are in development, including electrowinning, molten oxide electrolysis, smelting reduction paired with carbon capture, and bio-carbon substitutes.

**Residual direct emissions must not be neglected on the pathway to near zero.** Once most direct emissions are mitigated by transformational technology investments, minor emissions sources will rise in importance, especially those from lime fluxes, carburising agents, and graphite electrodes which are core components in steelmaking chemistry. Additionally, expected leakage from carbon capture technology will be present.

As a result, direct emissions sources may comprise around two-thirds of the emissions intensity of steel production in 2050. Carburising agents, and graphite electrodes should be substitutable by bio-carbon, yet the application of sustainable forestry and robust accounting of emissions associated with the growth, harvesting and processing of biomaterials must be verified. Innovative materials research and technology development are necessary to ensure residual direct emissions are minimised, and near zero is achievable.

**Steelmakers are large (and increasing) consumers of electricity, so purchasing low/zero emissions electricity will have a significant impact in creating a ‘demand pull’ for clean power.** The vast majority of the steel sector’s indirect energy-related emissions are derived from electricity inputs (rather than steam, heating or cooling). This is distinct to the emissions from on-site combustion of coal, coke and natural gas which are included within direct emissions. This electricity can either be procured from the grid or self-generated. Self-generation incorporates on-site power plants which utilise process gases, and behind-the-meter power plants (e.g. a solar farm that directly feeds the steel plant). Under the decarbonisation trajectories for grid power used by the IEA NZE and MPP CC scenarios, the emissions factor for electricity reaches zero by 2044 and 2050, respectively, which effectively eliminates long-term scope 2 emissions.

Accordingly, there is a steep reduction in the emissions intensity of electricity-intensive routes

\begin{itemize}
  \item \textsuperscript{36} SSAB. (2024). The road to sustainable steel. https://www.ssab.com/en-gb/fossil-free-steel/ssab-zero/the-road-to-sustainable-steel
  \item \textsuperscript{37} H\textsubscript{2} Green Steel. (2023). H\textsubscript{2} Green Steel has entered into a long-term frame agreement with Fortum for electricity supply. https://www.h2greensteel.com/latestnews/h2-green-steel-has-entered-into-a-long-term-frame-agreement-with-fortum-for-electricity-supply-1
  \item \textsuperscript{38} IEEFA. (2021). Carbon Capture for Steel?. https://ieefa.org/resources/carbon-capture-steel
  \item \textsuperscript{39} ArcelorMittal. (2024). Trial carbon capture unit begins operating on blast furnace at ArcelorMittal Gent, Belgium. https://corporate.arcelormittal.com/media/news-articles/trial-carbon-capture-unit-begins-operating-on-blast-furnace-at-arcelormittal-gent-belgium
\end{itemize}
from 2030 to 2050 (e.g. the electrowinning-EAF route, as illustrated in Figure 7). Whilst the pathway to eliminating energy-related emissions may be clear (i.e. replace fossil fuels with renewables for power generation), acquiring the required permits, raising capital, and working within the natural resource constraints with potentially unfavourable economics is a major task. Market-based instruments can be effective means of funding renewable energy projects and reducing the emissions intensity of electricity inputs, without the need for a direct input of zero emissions electrons to the steel plant. These instruments include renewable energy certificates (RECs), power purchase agreements (PPAs), and green tariffs, which are considered under ResponsibleSteel’s emissions accounting methodology, and are ideally placed as near-term solutions for near-zero emissions electricity supply.

**Elimination of upstream emissions caused by the extraction and preparation of materials and fuels requires concerted intersectoral collaboration.** Upstream inputs are material contributors to the emissions intensity of steelmaking, including iron ore, coal, natural gas, hydrogen, ferroalloys, non-ferrous metals, quicklime, limestone, dolomite and oxygen (and pig iron/DRI/hot briquetted iron if the steelmaking site imports iron).

The emissions intensity of electrolytically produced hydrogen is contingent on the emissions factor of the input electricity, which in this analysis is the grid power. For H₂-based steelmaking routes, the procurement/production of H₂ using zero emissions electricity inputs is priority.

The methane emissions from coking coal mining, and natural gas extraction and processing, present potentially large contributors to the sector’s indirect emissions. In 2021, an estimated 12 Mt of methane was released from coking coal mining⁴⁰, equivalent to 335 Mt CO₂e (using a 100-year GWP factor of 27.9) or 9% of the sector’s scope 1 and scope 2 emissions. More work is required to increase the data accuracy of these methane emissions from mines.

To achieve near-zero emissions steelmaking, wide-scale energy systems change is required; for example, all mining equipment should be operating on biofuels, hydrogen, or electrified and powered using renewables. In this analysis, a material and fuel emissions factor reduction rate of 3.5% p.a. was assumed for most inputs, apart from ferroalloys, quicklime, and graphite electrodes where 7% p.a. reduction was assumed.

This ambition is achievable; 7% p.a. reduction is observed in the IEA NZE scenario for cement, which involves quicklime (CaO) production from calcium carbonate (CaCO₃) and is roughly the same speed as steel decarbonisation.

The achievement of near-zero emissions requires steelmakers to not only know their upstream supply chain, but to work alongside them to decarbonise operations.

Figure 7: Emissions distribution for five technology archetypes with near-zero emissions compatibility, in (i) 2030 and (ii) 2050. All units are in tonnes CO₂e/tonne crude steel. All electricity is assumed to be sourced from the grid (causing indirect energy-related emissions in 2030), including to produce electrolytic hydrogen (causing high indirect fuel-related emissions for the H₂-DRI-EAF route in 2030). Source: ResponsibleSteel analysis based on the MPP CC scenario.
**Finding 4: The decarbonisation challenge is heightened under higher steel demand trajectories**

There are two ways to get to net zero across the steel sector: reduce the emissions intensity of steel production, and/or reduce overall steel consumption. Progress Levels measure the former, but the value of reducing the overall amount of steel required in the economy should also be rewarded.

Steel consumption can be reduced by increasing the durability and utilised lifetimes of steel-containing products and infrastructure, reducing steel demand by doing more with less (i.e. lightweighting vehicles, and designing buildings to minimise material consumption), and increasing the amount of re-used steel.

Standards targeted at downstream steel users are best placed to reward the reduced consumption of steel for the same functional unit. For example, the World Green Building Council rewards efficient resource utilisation through a lifecycle assessment of the building. Two distinct demand projections are assessed here: IEA NZE projects 2.0 Gtpa steel demand in 2050, whilst MPP BAU projects 2.5 Gtpa. The key differences relate to the near-term achievement of near-zero emissions (PL4), and timing of the phase out of the basic threshold (PL1). In the MPP model, 7% PL4 is achieved in 2035 and all PL1 certification is eliminated by 2040, whereas in the IEA model just 1% PL4 is achieved by 2035 and PL1 is more gradually phased out over an additional decade to 2050.

It should also be noted that MPP's CC scenario falls 15% below the estimated sectoral carbon budget, which would be a contributing reason for the increased certification requirements under the MPP model.

Despite differences in steel demand, the certification pathways are not disparate due to the common goals of near-zero emissions in 2050 and substantial near-term emission reductions. 1.5°C-aligned pathways will always be challenging given the high level of ambition. In relative terms (as shown in Figure 8), both IEA and MPP certification results are comparable and greater alignment manifests towards 2050. Importantly, there is agreement in the scrap portion of inputs to steelmaking. The scrap share increases from about 35% today, to 48% under IEA projections and 45% under MPP projections by 2050 (see Figure 4).

This represents a comparable decadal increase of 5% for IEA and 4% for MPP. This means that about 50% of steel production in 2050 will be reliant on iron ore inputs, whilst the other half will utilise available scrap resources. This allows the industry to plan for the decarbonisation of ironmaking simultaneously with enhanced circular economy practices to maximise value retention in secondary material flows.

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The Progress Levels provide a stable benchmarking system against a backdrop of variable steel demand projections. The uncertain dynamics of steel demand and potential fluctuations of site-level outputs mean that decarbonisation progress should be tracked in emissions intensity units, with subsequent declaration of overall steel production and site-level emissions. This assures transparency and the ability to assess the true impact of investments in decarbonisation measures. Analysis of financial reports from steel companies has shown that in the near term, the market is expected to grow faster than the decarbonisation pathways have anticipated. If this growth mentality causes a company to produce more steel in the roadmap to 2050 than it originally plans to, the Paris-aligned pathway would need to be resubmitted to ResponsibleSteel (and the same applies to SBTi pathways). Nevertheless, if a company’s steel output varies over time, the Progress Levels remain an objective measure of decarbonisation.

Figure 8: Global 1.5°C-aligned ResponsibleSteel certification requirements in (a) 2035 and (b) 2045, with direct comparison across the IEA NZE and MPP CC scenarios. Source: ResponsibleSteel analysis based on IEA NZE and MPP CC scenarios.

Calls to Action
ResponsibleSteel Certification provides a clear tool for the steel value chain to drive the changes required to achieve the goals of the Paris Agreement.

The 1.5°C–aligned pathway to 2050 is ambitious, requiring an industry-wide shift towards near-zero emissions steel. The steel sector’s industrial decarbonisation challenge needs international and transparent certification to compare global steelmaking sites on a like-for-like basis, create equitable guardrails for sustainable change, and incentivise decarbonisation progress.

In May 2024, almost 7% of global production was already covered by ResponsibleSteel’s Core Site Certification⁴⁵, representing the start of the journey to chart the industry’s journey towards net zero. Today, ResponsibleSteel's goal is to propagate the utility of Certified Steel on the market and thereby commence driving sector-wide decarbonisation. By 2050, the goal is to support a competitive market dominated by Certified Steel to near-zero emissions (PL4). The required systems-level change depends on value chain cooperation and collaboration. Value chain members in the ecosystem of industrial change hold unique responsibilities:

**Steelmakers**

- Work towards achieving and labelling ResponsibleSteel Certified Steel to demonstrate site-level decarbonisation progress from the basic threshold (PL1) to lower emissions (PL2), much lower emissions (PL3), and near-zero emissions (PL4) steel production.
- Get certified now – more than half of steel production is already certifiable to (at least) PL1. Achieving certification at the entry level is an essential component of creating productive market signals and supporting stakeholder calls for consistent and comparable data for benchmarking steel plants globally.
- By mapping the company’s Paris-aligned pathway (under criterion 10.1) using ResponsibleSteel's Decarbonisation Progress Levels (under criterion 10.6), you can understand the company’s time-variable certification pathway. This is a powerful communication tool to stimulate market demand and capital investments.
- Demonstrate how Progress Levels can be used as a common global language to compare site-level decarbonisation efforts.
- Use ResponsibleSteel Progress Levels as a mapping tool in your scenario analysis, alongside other Core Site Certification criteria, to align with the requirements of the Climate related Disclosure Standard S2 of the International Sustainability Standards Board (ISSB) and similar requirements under other reporting regulations.

**Steel buyers**

- Use the procurement power of Progress Levels by setting supply-related milestones. For example, all products must be at least PL1 by 2025, and at

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least PL2 by 2035. With ResponsibleSteel Steel Certification comes a suite of emissions-related metrics, including a company-level Paris-aligned target, the site-based Progress Levels, and a product-based PCF/EPD. An integrated procurement strategy that uses multiple metrics as performance indices will ensure climate-related risk management.

- Think about what Progress Levels you should be specifying over time, based on industry capacity and alignment with your own scope 3 targets. Look for progress, acknowledging that change takes time, and willingness to pay for a green premium will accelerate the process. In certification terms, this may mean procuring PL1/PL2 steel in the near-term, whilst anticipating greater supply of PL3/PL4 thereafter.
- Support initiatives to amplify demand-pull signals such as SteelZero and First Movers Coalition (FMC). SteelZero’s updated commitment framework calls for steel buyers to utilise at least 50% of lower emission (PL2) steel by 2030, a near-term milestone where 300–800 Mt of Certified Steel to PL2 (or equivalent) would be available if the industry follows the 1.5°C–aligned trajectory.
- Develop and implement an integrated procurement strategy where both site-level decarbonisation ratings (using Progress Levels) and product-level absolute emissions (using PCFs/EPDs) are valorised.

**Suppliers to steelmakers**

- Certify the lifecycle emissions of the supplied material and/or fuel, and demonstrate its contribution to the steelmaker’s Progress Level compared to the ResponsibleSteel default embodied GHG value [Annex 5 of the Production Standard].
- Demonstrate your contribution to the decarbonisation of the steel supply chain by establishing your own Paris-aligned pathway to near zero 2050 and providing your customers with primary data. As upstream emissions are expected to contribute a greater percentage of site-level emissions over time, it will become an increasingly important component of the sector’s decarbonisation strategy to engage with suppliers who can provide primary emissions data, are actively decarbonising their operations and can anticipate further GHG reductions.

**Investors and financial institutions**

- Regard ResponsibleSteel Certification as a framework of common indicators for sustainability performance and disclosure across steel companies in your portfolio on climate and ESG.
- Ask for Core Site Certification as a demonstration that companies are managing ESG risks well, and preparing to align with the ISSB’s Sustainability and Climate disclosure standards
- Ask for Certified Steel Progress Levels to enable you to compare the progress of different stocks towards near zero on a like–for–like basis, regardless of technology used or products generated.

• In the near-term, channel transition finance to sites engaging in radical systems change to achieve near-zero emissions, as well as sites undergoing significant transitional improvements, using Certified Steel Progress Levels as a consistent indicator of transition.

• Note the large degree of alignment between ResponsibleSteel Decarbonisation Progress Levels and a number of other initiatives. For example, the Sustainable STEEL Principles, published by the Rocky Mountain Institute (RMI), provide guidance for banks measuring and disclosing the status steel-lending portfolios in relation to 1.5°C climate targets. Efforts between RMI and ResponsibleSteel to further align are being pursued in keeping with the Steel Standards Principles.

**Policymakers**

• Cross-disciplinary policy collaboration – climate, industry, procurement, innovation, trade – will support effective implementation.

• Use ResponsibleSteel GHG measurement requirements as a common language to compare the embodied emissions of steel equitably and globally.

• Effective policy must focus on both incentivising transitional improvements for high-emitting conventional plants in the near term and shifts to near zero emission production technology in the medium term. Heterogenous regional decarbonisation pathways call for heterogenous policy measures.

• Take advantage of Progress Levels as common language in trade policies to ease trade frictions and minimise carbon leakage.

• Use Progress Levels as yardsticks in national scenario analysis to compare your local industry’s roadmap against the global average, and that of trading partners.

**Industry representatives**

• Encourage ResponsibleSteel Certified Steel among your members and map the collective pathway for combined membership through the lens of the Progress Levels.

• Cultivate collaboration to ensure technology is diffused across companies and geographies, especially from developed to developing regions (technology assistance). Certification is focused on the individual company and site (or portfolio of sites), however, the challenge is common and requires platforms where knowledge-sharing across regions and companies is coordinated.

**Civil society organisations**

• Use ResponsibleSteel’s universally consistent benchmarking system to push various value chain levers.

• Hold steelmakers accountable to transparent emissions accounting and mandate change using the language of the ResponsibleSteel Progress Levels.

• Encourage investors to value ResponsibleSteel Certification as good practice across their steel portfolio. In addition, influence steel consumers to procure

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ResponsibleSteel Certified Steel at more ambitious Progress Levels over time, in line with the analysis in this report.

- In addition, influence steel consumers to procure ResponsibleSteel Certified Steel at more ambitious Progress Levels over time, in line with the analysis in this report.

### Endorsers of the Steel Standards Principles

- As a first step towards achieving harmonisation, enable all steel to be assessed for its embodied emissions from cradle-to-crude. Crude steel is the single point in the production line where all steel products align on a comparable basis. This requires all measurement standards (both product and site-based) to enable data collection with a disaggregated crude steel cut-off.
- Aligned emissions factors and the upstream boundary are also key to harmonisation. Standardised emissions accounting methodologies need to extend to how input material embodied GHG values are calculated, which is especially important for coal, natural gas, biomaterials, and hydrogen.
- Standardising bodies should avoid duplication of, or overlap with, existing standards such as ResponsibleSteel's where they are regarded as fit for purpose to support 1.5°C-aligned pathways, as outlined under the World Trade Organisation's Principle of Coherence48.
- For aspects that prove impossible to align, work towards interoperability and possibly mutual recognition.

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[https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm](https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm)
Appendix A: Methodology Details

The foundations of this analysis were two existing 1.5°C compatible pathways to net zero 2050 – that of the MPP (CC scenario) and IEA (NZE scenario). To develop these pathways, both organisations developed detailed bottom-up techno-economic energy system models. Whilst the IEA integrate the entire global energy system within their GEC model, MPP isolated the steel sector and pre-allocated a carbon budget. The models were executed under optimisation frameworks to minimise costs whilst satisfying carbon budget and resource constraints, as well as other real-world considerations (e.g. policy, existing asset lifetimes, technology maturity, and preferences towards technology paths). By nature of forecasting, both models carry significant uncertainty in terms of assumptions about steel demand, scrap availability, emerging technology viability, natural resource availability, and finance accessibility.

In MPP's 2022 report "Making Net-Zero Steel Possible", results from the ST-STSM model and three scenarios were presented – Baseline, Carbon Cost (CC), and Technology Moratorium (TM) – with only CC meeting the 1.5°C carbon budget requirements (47 Gt CO₂ for direct and energy-related indirect emissions; 15% below the allocated budget). MPP pre-allocated emissions to the steel sector based on equitable sectoral division across key energy sectors, equal to 56 Gt CO₂ for direct and energy-related indirect emissions (11.2% of the total global carbon budget). For the CC scenario, the carbon price applied started at $0/t CO₂ in 2023, rising linearly to $200/t CO₂ in 2050 (globally constant; an improvement on the modelling would be to have regionally differentiated carbon prices that better reflect the specific policy and economic landscapes). Even though the TM scenario limited technology uptake to only near-zero emissions technologies from 2030 onward, the budget was exceeded by 12.5%, totalling 63 Gt CO₂ for direct and energy-related indirect emissions over the 30-year period. A detailed breakdown of the MPP results is publicly available, and the model is open access inclusive of the input data.

The key data utilised from MPP for the certification pathway analysis were: (i) mass and energy consumption of technology archetypes, and (ii) breakdown of production output and emissions by year and technology archetypes. The production output and emissions were available at both global and regional levels (grouped into 11 regions), permitting analysis at a refined spatial scale. The emissions boundary covered direct and energy-related indirect (scope 1 and 2) emissions, up to the point of hot rolled steel. Adjustments were made to align the emissions boundary to that of ResponsibleSteel (see Figure A.1), requiring removal of hot rolling emissions and addition of upstream indirect emissions related to material and fuel inputs (see Table A.1).

The IEA presented the steel sector’s roadmap within the global Net Zero Scenario (NZeS) in the 2021 report “Net Zero by 2050: A Roadmap for the Global Energy Sector”. This was updated in 2023 with a new release “Net Zero Roadmap: A Global Pathway to Keep the 1.5°C Goal in Reach.” The IEA globally aggregated 1.5°C-aligned pathways across all energy-consuming sectors, such that cumulative emissions did not exceed the 500 Gt CO₂, and net zero was achieved by 2050. An alternative Sustainable Development Scenario, more closely aligned to a 2°C pathway, was presented in the 2020 report “Iron and Steel Technology Roadmap”. Due to data confidentiality agreements with IEA’s member countries, neither the model, input data nor detailed results breakdown are publicly available.
The key data utilised from IEA for the certification pathway analysis, all at global level, were: (i) technology diffusion factors, (ii) steel demand forecasts, (iii) scrap availability forecasts, and (iv) grid emissions factors. IEA’s general technology diffusion factors for iron ore–based production were given for the following broad categories: CCUS–equipped processes, electrolytic hydrogen–based production, and iron ore electrolysis. The production quantities under these categories were distributed over MPP’s technology archetypes to determine the breakdown in production output over time on a more granular level. To then determine emissions factors for technology archetypes over time, MPP’s combined direct and energy–related indirect (scope 1 and 2) emissions were split up by subtraction of the estimated energy–related indirect (scope 2) emissions using MPP’s global grid emissions factor forecasts and electricity consumption factors for each technology archetype. IEA’s energy–related indirect (scope 2) emissions were then adjusted using the IEA global grid emissions factor forecasts. Adjustments were again made to align the emissions boundary to that of ResponsibleSteel.

For both the IEA and MPP models, upstream indirect (scope 3) emissions related to material and fuel inputs were added. The emissions factor for each input was based on the ‘cradle–to–gate’ GHG emissions. Inputs with a non–zero emissions factor included iron ore, coal, coke, natural gas, hydrogen, limestone, burnt lime, ferroalloys, non–ferrous metals, and graphite electrodes. Scrap and biomaterials were assumed to have zero associated emissions. The emissions factor for iron ore and coal including the methane emissions caused during mining, released from the geological formations. Hydrogen production was assumed to be electrolysytically produced using grid power, so was a function of the grid emissions factor (decreasing over time) and low–temperature electrolysis efficiency (increasing over time from 64% in 2020 to 74% of the lower heating value by 2050). Emission factors for each input correlated to the base value of the ResponsibleSteel default embodied GHG values, i.e. without the conservative factors applied (x1.2 for all materials excluding iron ore and coal which are x1.6 due to enhanced uncertainty of methane emissions). The emissions factor for ferroalloys and non–ferrous metals was given the default value equivalent to cold iron, as specified within the ResponsibleSteel default embodied GHG values. This approach has been taken to adequately compare steels with less than 8% alloy content, each with variable alloy inputs and associated distinct emissions factors. The emissions factors were reduced over time to reflect intersectoral decarbonisation, at a rate of 3.5% per annum for most inputs excluding ferroalloys, burnt lime, and graphite electrodes which took on a more aggressive rate of 7% per annum (required to reach near zero by 2050). The indirect material/fuel–related upstream emissions factor for each technology archetype in each year was the sum product of the consumption rate and emissions factor for every input. Emissions associated with transportation of material to site were not included, which is a deviation from the ResponsibleSteel emissions boundary, due to lack of data on the average distances from suppliers to sites across the global steel sector.
ResponsibleSteel’s Emissions Boundary (under criterion 10.4) for Representative Iron and Steelmaking Sites

For illustrative purposes only - not all processes are shown.

1. For the full list of scope 3 requirements, refer to Annex 10 of the standard. For any non-listed items (e.g., graphite electrodes and refractories), if they are likely to contribute more than 5% of the scope 3 emissions they must also be included. The emissions boundary for each input is determined by materiality in accordance with recognised international standards. Refer to Criterion 10.4.5 for further details.

2. Upstream embodied GHG emissions for scrap metal are counted as zero, but emissions for transportation are included.

3. CO₂ sequestration associated with production of biomass-based products can be claimed when this is independently verified using a recognised standard. In the absence of independently verified primary data the emissions associated with the growth, harvesting and processing of biological materials are assigned a default net upstream GHG emissions factor of zero.

4. Oxygen plant is often located onsite for a BF-BOF plant.

5. Material processing can also be carried out offsite, with imports of iron ore sinter, iron ore pellets, coke and/or lime.

6. Credit given if re-used processes gases/generated electricity is greater than consumed gases/electricity upstream of crude steel.

For further information, please refer to the ResponsibleSteel Standard and its accompanying Annex 10.
Table A.1: Emissions boundary comparison between ResponsibleSteel, MPP, IEA and SBTi.

<table>
<thead>
<tr>
<th>Purpose</th>
<th>ResponsibleSteel (2022)</th>
<th>IEA (2020), Iron and Steel Technology Roadmap</th>
<th>IEA (2022), Achieving Net Zero Heavy Industry Sectors in G7 Members</th>
<th>IEA (2023), Net Zero Roadmap: A Global Pathway to Keep the 1.5°C Goal in Reach</th>
<th>SBTi (2023), Steel Sector Guidance</th>
<th>MPP (2022), Steel Sector Transition Strategy</th>
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<tr>
<td>Scope inclusions</td>
<td>Scope 1, scope 2, and upstream scope 3</td>
<td>Scope 1 (including lime kilns, ore sintering and pelletising, coking) and Scope 2. Builds on the accounting methodology of IEA World Energy Balances, where electricity related emissions are attributed to the power sector</td>
<td>Scope 1 (including lime kilns, ore sintering and pelletising, coking), scope 2 and some upstream scope 3 (iron ore, limestone, fossil fuels). Excludes scope 3 emissions associated with electrodes, alloys, and refractories.</td>
<td>Scope 1 (including lime kilns, ore sintering and pelletising, coking).</td>
<td>Scope 1 and scope 2. Based on IEA NZE scenario (2021 version).</td>
<td>Scope 1 and scope 2 (some scope 3 emissions factors provided)</td>
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<td>Crude steel</td>
<td>Finished steel product</td>
<td>Hot rolled steel</td>
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<td>t CO₂/t crude steel</td>
<td>t CO₂/t crude steel</td>
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