Carbon Performance Assessment of Steelmakers Discussion Paper

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Transition Pathway Initiative

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EXECUTIVE SUMMARY

The Transition Pathway Initiative (TPI) is a global initiative led by asset owners and supported by asset managers. Aimed at investors and free to use, it assesses companies' progress on the transition to a low-carbon economy, supporting efforts to address climate change.

TPI assesses companies' progress in two ways: (1) Management Quality and (2) Carbon Performance. Management Quality is a measure of the quality of companies' governance/management of greenhouse gas emissions and climate-related risks. Carbon Performance is a quantitative comparison of companies' current and targeted carbon emissions against international climate goals.

In March 2022, we published our current Carbon Performance methodology for the steel sector. The methodology assesses all steel companies, regardless of their production-specific characteristics, against the same combined emissions intensity benchmarks that treat primary and secondary steel production together. However, there is a systematic difference between primary and secondary steelmaking, which investors may wish to take into account when evaluating steelmakers' approaches to the low-carbon transition. Primary steel is significantly more emissions-intensive than secondary steelmaking and also more challenging to decarbonise. Therefore, this discussion paper proposes updates to TPI's steel methodology, principally the creation of separate emissions intensity benchmarks for primary and secondary steelmaking (Figure ES1).

In order to derive the benchmarks, detailed data on emissions and production by different technology types are needed. As these are not available from our current data source, the International Energy Agency (IEA), we use the Mission Possible Partnership's (MPP) Steel Sector Transition Strategy Model (ST-STSM) as our new source of steel emissions and production data.

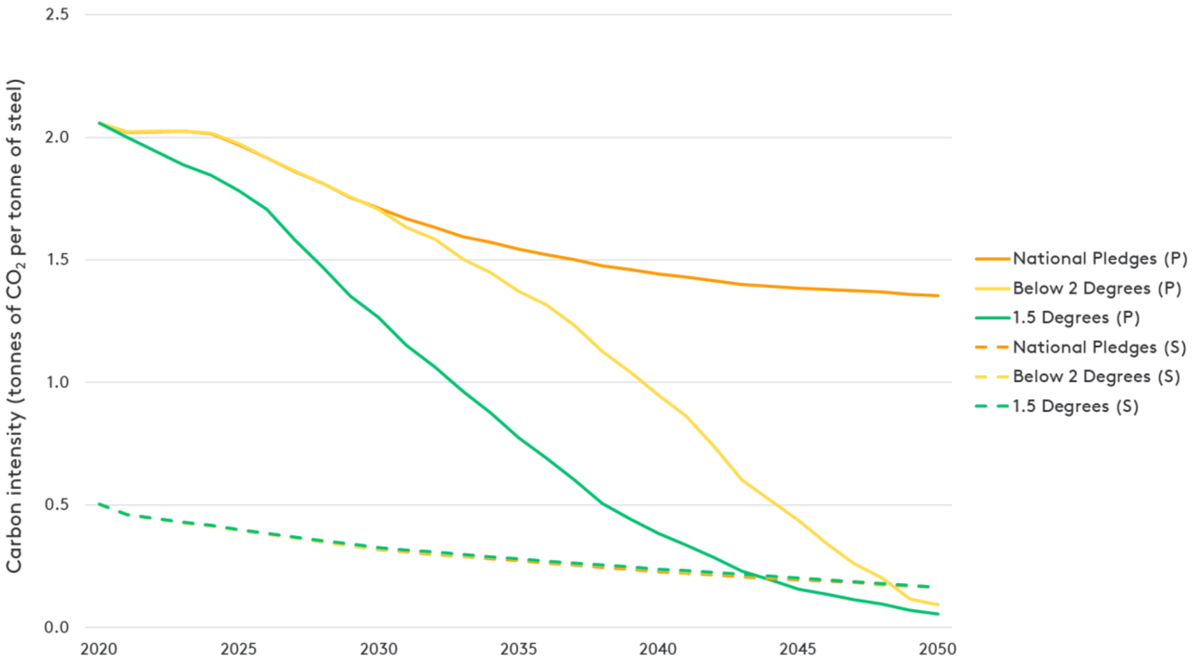
In addition to laying out the methodology, as a proof of concept, this report presents assessment results for hypothetical companies evaluated against separate primary and secondary benchmarks, demonstrating the additional insights that can be gained into different types of steelmakers.

While split pathways provide additional insights, the principal Carbon Performance alignment scores of steelmakers published on the TPI online tool will still be based on combined primary/secondary benchmarks, consistent with our approach to other sectors (Figure ES2). We take this approach because at present most steelmakers cannot be practically assessed against split benchmarks based on the sector's level of disclosure. Specifically, the split benchmarks require steelmakers producing both primary and secondary steel to disclose separate emissions and production data, as well as set emissions reduction targets for each type of production. Very few steel companies we have analysed disclose this information yet. As a result, they would receive Carbon Performance alignment scores of "No or unsuitable disclosure". For those companies with sufficiently detailed disclosure, complementary alignment scores against the split benchmarks will also be available to view on the TPI tool, similar to the approach taken for electricity utilities, which are assessed against both global and region-specific benchmarks.

We are seeking feedback from industry experts, companies, researchers, investors, and other stakeholders on the following topics:

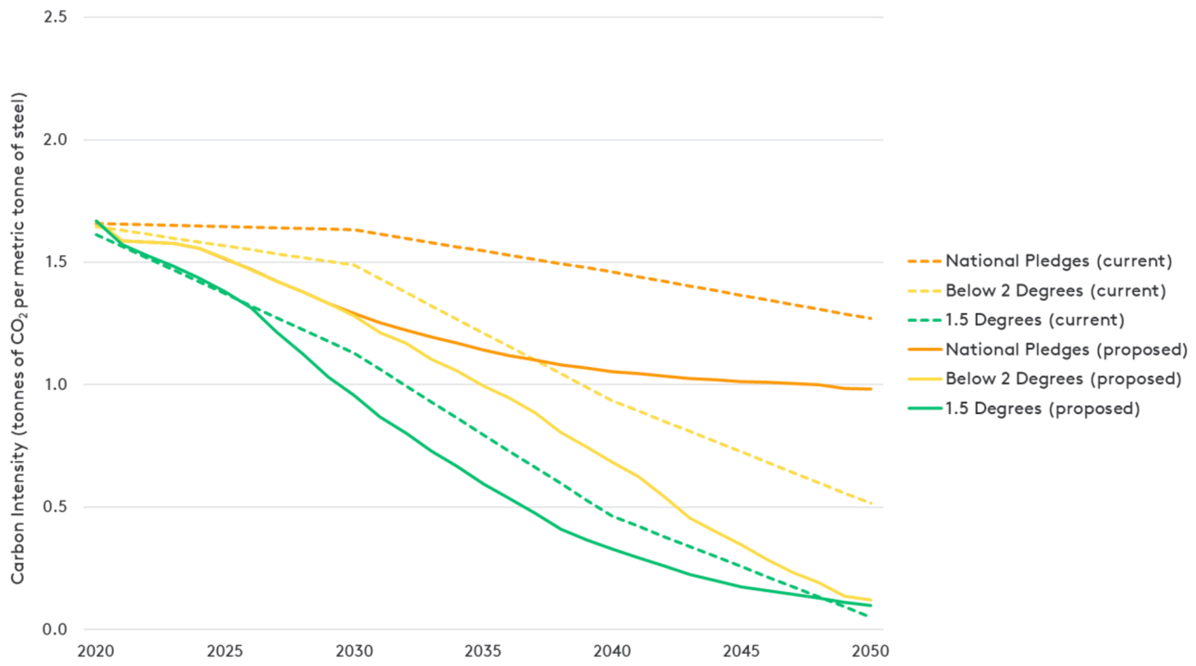
1. Primary and secondary emissions intensity benchmarks:
    a. The proposed shift towards using MPP's ST-STSM model, which is a bottom-up sectoral model, as opposed to IEA's economy-wide model (see Section 3.3.1);
    b. ST-STSM model assumptions that underpin Scope 1 and 2 emissions, steel production, and the share of secondary steel under each benchmark scenario (see Section 3.3.1);
    c. Categorisation of technologies as either primary or secondary, along with the corresponding production in each benchmark scenario (see Section 3.3.2);
    d. Our proposal to continue using the combined emissions intensity benchmark for determining Carbon Performance alignment scores for steel companies, while providing separate scores using primary and secondary emissions intensity benchmarks, and corresponding company pathways, as a *complementary* insight on our online tool.
2. Off-gases:
    a. Approach to account for emissions from steel off-gases within MPP's ST-STSM model. Specifically, we propose to include off-gases that are combusted in flare stacks or for electricity generation. We welcome comments and further information on other significant off-gas emissions sources outside these end-of-life categories, which may need further consideration (see Section 3.3.3).

Figure ES1: Emissions intensity benchmarks split by primary (P) and secondary (S) steelmaking.



Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data.

Figure ES2: Comparison between current (dashed) and proposed (solid) combined emissions intensity benchmarks.



Note:

1. Please see Section 3.3.1 for details on the key underlying assumptions and the reason for deviation between current (IEA-based) and proposed (MPP-based) emission intensity benchmarks.

Source: Transition Pathway Initiative (TPI) analysis of IEA and Mission Possible Partnership (MPP) data.

1. INTRODUCTION

1.1 The Transition Pathway Initiative

The Transition Pathway Initiative (TPI) is a global initiative led by asset owners and supported by asset managers. Established in January 2017, TPI investors now collectively represent over US$50 trillion of assets under management and advice.

On an annual basis, TPI assesses companies' progress on the transition to a low-carbon economy in terms of their:

- Management Quality – all companies are assessed on the quality of their governance and management of greenhouse gas emissions and of risks and opportunities related to the low-carbon transition;
- Carbon Performance – in selected sectors, TPI quantitatively benchmarks companies' carbon emissions against international climate goals.

TPI publishes the results of its analysis through an open access online tool hosted by the TPI Global Climate Transition Centre at the London School of Economics (LSE): www.transitionpathwayinitiative.org

Investors are encouraged to use the data, indicators, and online tool to inform their investment research, decision making, engagement with companies, proxy voting and dialogue with fund managers and policy makers, bearing in mind the Disclaimer that can be found at the beginning of this document. Further details of how investors can use TPI assessments can be found on our website.

1.2 About this report

This discussion paper proposes an updated methodology to assess the Carbon Performance of steelmakers, with a focus on including separate assessments for primary and secondary steelmaking.

The structure of the paper is as follows:

- *Section 2* provides contextual information on how TPI performs Carbon Performance assessments across various sectors.
- *Section 3* describes the methodology for creating independent emissions intensity benchmarks for primary and secondary steelmaking.
- *Section 4* presents illustrative Carbon Performance assessment results of hypothetical companies assessed against the primary and secondary benchmarks.
- *Section 5* discusses the limitations of this methodology.

2. TPI'S CARBON PERFORMANCE ASSESSMENT

TPI's Carbon Performance assessment is based on the Sectoral Decarbonisation Approach (SDA). [1] The SDA translates greenhouse gas emissions targets made at the international level (e.g., under the Paris Agreement to the UN Framework Convention on Climate Change) into appropriate benchmarks, against which the performance of individual companies can be compared.[1]

The SDA is built on the principle of recognising that different sectors of the economy (e.g., oil and gas production, electricity generation, and automobile manufacturing) face different challenges arising from the low-carbon transition, including where emissions are concentrated in the value chain, and how costly it is to reduce emissions.

Therefore, the SDA takes a sector-by-sector approach, comparing companies within each sector against each other and against sector-specific benchmarks, which establish the performance of an average company that is aligned with international emissions targets.

Applying the SDA can be broken down into the following steps:

- A global carbon budget is established, which is consistent with international emissions targets, for example keeping global warming below 2°C. To do this rigorously, some input from a climate model is required.
- The global carbon budget is allocated across time and to different regions and industrial sectors. This typically requires an Integrated Assessment Model (IAM), and these models usually allocate emissions reductions by region and by sector according to where it is cheapest to reduce emissions and when (i.e., the allocation is cost-effective). Cost-effectiveness is, however, subject to some constraints, such as political and public preferences, and the availability of capital. This step is therefore driven primarily by economic and engineering considerations, but with some awareness of political and social factors.
- In order to compare companies of different sizes, sectoral emissions are normalised by a relevant measure of sectoral activity (e.g., physical production, economic activity). This results in a benchmark pathway for emissions intensity in each sector:

$$\text{Emissions intensity} = \frac{\text{Emissions}}{\text{Activity}}$$

- Assumptions about sectoral activity need to be consistent with the emissions modelled and therefore should be taken from the same economy-energy modelling, where possible.
- Companies' recent and current emissions intensity is calculated, and their future emissions intensity can be estimated based on emissions targets they

[1] The Sectoral Decarbonization approach (SDA) was created by CDP, WWF and WRI in 2015.

have set (i.e. this assumes companies exactly meet their targets).[2] Together these establish emissions intensity pathways for companies.

- Companies' emissions intensity pathways are compared with each other and with the relevant sectoral benchmark pathway.

TPI currently uses three sectoral benchmarks for the assessment of companies in most sectors, including steel:

1. A **1.5 Degrees** scenario, which is consistent with the overall aim of the Paris Agreement to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels". [2]
2. A **Below 2 Degrees** scenario, which is also consistent with the overall aim of the Paris Agreement to limit warming, albeit at the middle of the range of ambition. [3]
3. A **National Pledges** scenario which is insufficient to put the world on a path to limit warming to 2°C, even if it will constitute a departure from a business-as-usual trend. [3]

[2] Alternatively, future emissions intensity could be calculated based on other data provided by companies on their business strategy and capital expenditure plans.

3. PROPOSED UPDATES FOR STEEL CARBON PERFORMANCE METHODOLOGY

3.1 Current methodology and proposed updates

TPI currently assesses steel companies based on its Carbon Performance Methodology published in March 2022. [4] The methodology derives three emissions intensity benchmarks (National Pledges, Below 2 Degrees and 1.5 Degrees) using inputs from the International Energy Agency (IEA), via its biennial Energy Technology Perspectives (ETP) reports, World Energy Outlook (WEO) reports, and its Net Zero by 2050 report. [3,5-8] The benchmarks are stated in terms of Scope 1 and 2 CO_2 emissions per tonne of crude steel production, with estimated Scope 2 emissions adjusted by subtracting emissions from onsite power generation, as these are understood to be part of the steel sector's direct emissions. Hence, TPI's current methodology provides the benchmark that an *average* steel company needs to meet in order to be considered 'aligned' in the short (2025), medium (2035) and long (2050) term (i.e., its emissions intensity must be equal to or lower than the benchmark at these dates).

The above approach is informed by TPI's design principles, including providing assessments that are easy to understand and use, and pitching corporate assessments at a high level of aggregation. It has also been designed to work in a context of limited public disclosures on emissions and/or activity by companies, a problem faced in all sectors. The current methodology described above thus assesses all steel companies, regardless of their production-specific characteristics such as technology type and scrap share, against the same 'combined' emission intensity benchmarks. However, there is a systematic difference between the emissions intensity of primary and secondary steelmaking, which investors may wish to take into account when evaluating steelmakers' approaches to the low-carbon transition. Specifically, because the emissions intensity of primary steelmaking is higher than secondary steelmaking, a combined benchmark that includes all steelmaking may be excessively strict when applied to a pure primary steelmaker and excessively lenient when applied to a pure primary steelmaker. This issue remains for steelmakers that make a mix of primary and secondary steel at a proportion that differs significantly from the global average, which is represented in the combined benchmarks. This issue becomes more intuitive when comparing hypothetical steelmakers against the split benchmarks (see Section XX). Therefore, we propose to provide supplementary 'split' emissions intensity benchmarks, which separately evaluate the alignment of primary and secondary steelmaking.

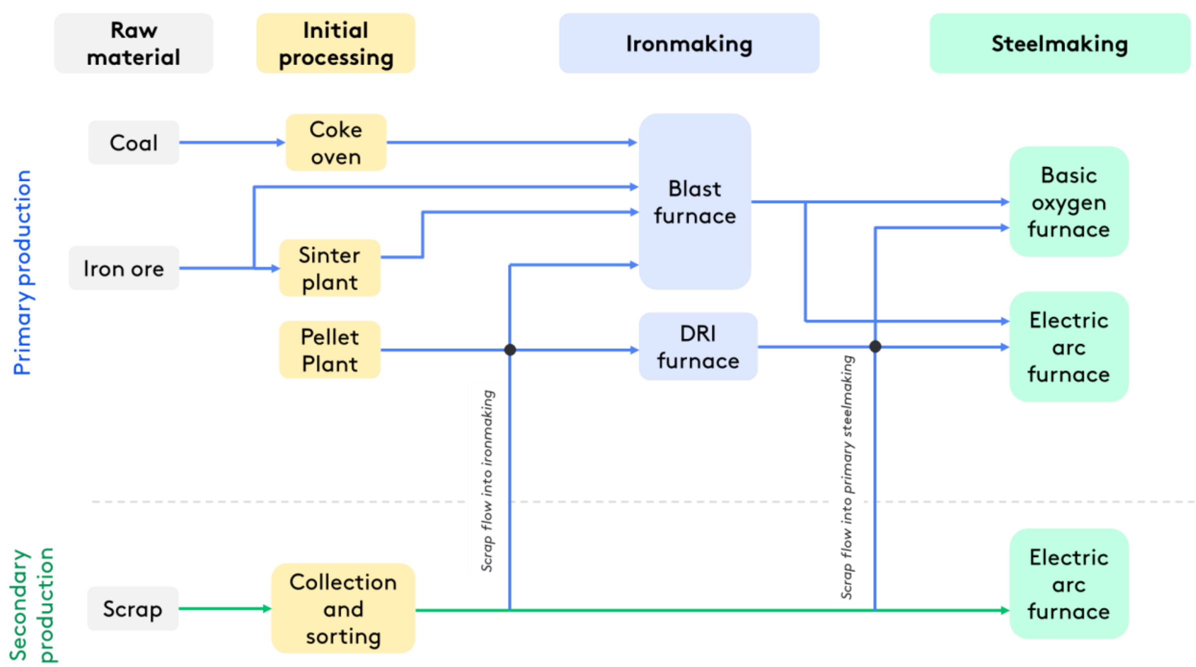
The subsequent sections elaborate on this approach.

3.2 Split emissions intensity benchmarks

Steel is primarily produced via two technologies: Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF). In 2021, crude steel production via these two routes accounted for 71% and 29% of global crude steel production, respectively. [9] Depending on the combination of technology type, processes and scrap share, steelmaking can be classified as primary or secondary (Figure 1). Primary steel production involves using iron ore as the primary input, with scrap steel typically accounting for 15-25% of the metallic input. Given the presence of scrap as an input in primary production, steelmakers can increase their scrap share (up to a certain threshold) to decrease their primary steelmaking emissions, as scrap displaces the need for virgin iron ore and metallurgical coal, thereby reducing processing and smelting emissions. The blast furnace (BF) is a crucial piece of equipment used for primary steel production, with approximately 75% of global primary steel being produced using the BF-BOF combination route. [10] In contrast, secondary steel is produced in EAFs, which use 100% scrap steel without any iron ore input. However, it should be noted that, not only can scrap be used in primary production, but iron ore can also be reduced using hydrogen and then processed in an EAF. Adopting this production route with green hydrogen is one way of decarbonising primary steel production. Thus, iron ore is not exclusively associated with blast furnaces, nor is the EAF exclusively associated with secondary production. As a result, establishing a boundary between primary and secondary steel production for split benchmarks and company assessments is challenging from both the modelling and disclosure perspectives.

Secondary steelmaking requires less energy than primary steelmaking, the latter of which requires chemical energy to reduce iron ore to metallic iron using carbon-based reducing agents such as metallurgical coal. According to the IEA, BF-BOF production uses approximately 10 times more energy per tonne of steel than EAF-scrap based production. [11] Through its higher energy needs and its current reliance on metallurgical coal for the reduction reaction and as a source of heat, primary steelmaking is significantly more emissions-intensive than secondary steelmaking.

Figure 1: Simplified steel production via primary or secondary route and flow of materials.



Notes:

1. Scrap is often used in primary production and iron ore can be reduced using hydrogen and then processed in electric arc furnaces; this means that the material inputs themselves are not exclusively associated with primary or

secondary steelmaking processes. Therefore, it is important to define the scrap share percentage alongside the steelmaking technology to determine whether steel production is primary or secondary.

2. Secondary steel is defined as steel produced in electric arc furnaces (EAF) using 100% scrap.

Using combined emissions intensity benchmarks for primary and secondary steelmaking not only has the benefit of simplicity, it also accurately signals that secondary steelmakers are less exposed to transition risk than primary steelmakers. The combined benchmark approach encourages companies to increase their scrap share in primary production, and increase their production of secondary steel in order to reduce their emissions and align with the benchmarks.

However, the potential of the steel industry as a whole to decrease its emissions and comply with absolute carbon budgets by increasing scrap usage is ultimately limited by the availability of scrap steel. Globally, it is estimated that around 85% of available steel scrap is already collected for recycling, but production from recycled steel is still much too small to meet global steel demand. [12, 13] Thus, primary steelmaking is expected to be the dominant process, at least up to 2050. Indeed, in IEA's Net Zero Emissions (NZE) scenario, secondary steel production is only expected to reach 43% of global steel supply by 2050, with the majority of steel demand still expected to be met through primary production. [14]

Decarbonisation levers other than increased scrap use are required to reduce emissions from primary steelmaking. [15,16] Given the limitations in scrap availability and the continued expected dominance of primary steel, it is important to incentivise the development of primary steelmaking processes with near-zero emissions while also promoting the use of scrap. This approach is necessary to achieve absolute GHG emissions reductions and comply with the sectoral carbon budgets represented by the emissions intensity benchmarks.

Therefore, considering the different emissions' profiles and decarbonisation challenges facing primary and secondary steel, TPI proposes to provide supplementary 'split' benchmarks to separately assess primary and secondary steelmaking. We hope the increased transparency provides investors with a more detailed and nuanced view of steel companies' progress towards a low-carbon economy.

3.3 Deriving the primary and secondary emissions intensity benchmarks

In order to derive primary and secondary emissions intensity benchmarks, we need the following key inputs:

- Emissions: a time path of carbon emissions for each production route until 2050, which is consistent with the delivery of a particular climate target (e.g., limiting global warming to 1.5°C).
- Activity: corresponding estimates of primary and secondary steel production until 2050.

A key challenge in creating separate benchmarks for primary and secondary steel production is obtaining the corresponding emissions and activity data. IEA, which is the current data source for TPI's steel methodology, does not provide separate emissions data for primary and secondary steelmaking, and only provides secondary production data for the NZE scenario.

An alternative source to IEA for steel emissions and production data is the Mission Possible Project's (MPP) Steel Sector Transition Strategy Model (ST-STSM). The ST-STSM is an agent-based simulation model, meaning that production and emissions mitigation decisions are made at the level of individual steel plants. This model evaluates the potential technological, economic, and carbon impacts associated with the transition of over 700 steel plants across 12 geopolitical regions towards net zero production. [17] The model accounts for region-specific factors, including resource availability, feedstock prices, crude steel demand, scrap availability, and steel production capacity. The MPP scenarios comparable to TPI's National Pledges, Below 2 Degrees and 1.5 Degrees benchmarks are Baseline, Tech Moratorium and Carbon Cost, respectively. The scenarios are considered to be consistent with TPI's benchmark categories because of consistency between the associated carbon budgets (see Section 3.3.1).

Overall, as our analysis below shows, the ST-STSM model roughly mirrors IEA's data on critical assumptions such as the share of secondary steel production. Meanwhile, all three MPP scenarios have the same projections for steel demand, and these are roughly consistent with the IEA's Stated Policies Scenario (STEPS). Most importantly, the cumulative carbon budgets of MPP's benchmark scenarios are approximately 11% lower than TPI's current IEA-based benchmarks, making it consistent with – indeed slightly more ambitious than – the steel carbon budget in the IEA's economy-wide model.

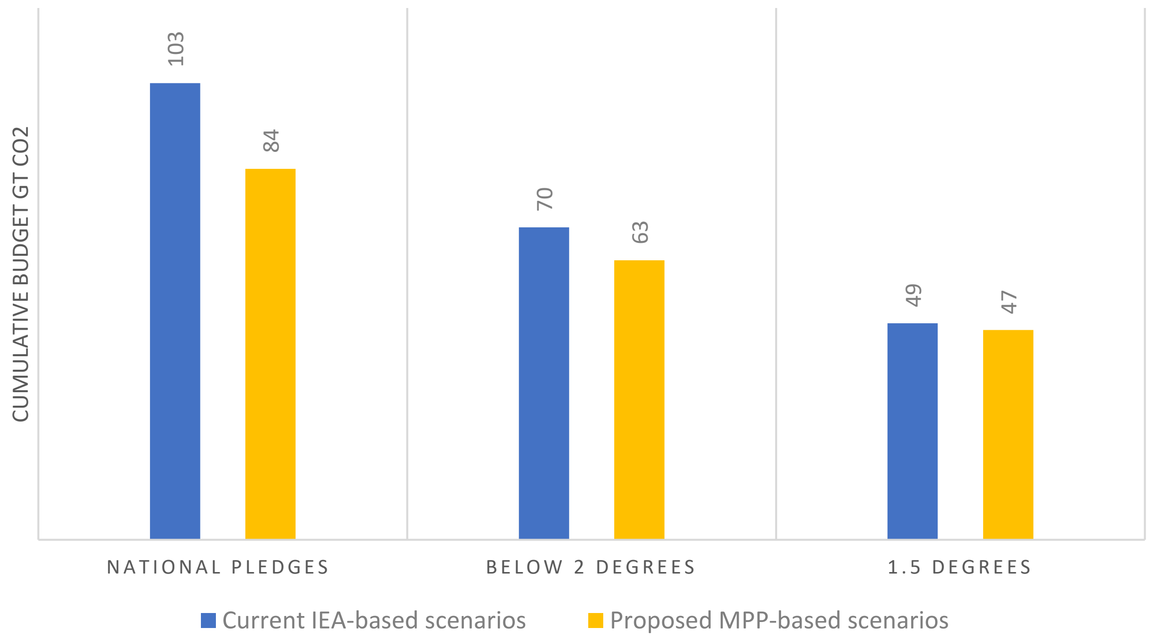
3.3.1 Comparison of key assumptions between IEA and MPP's ST-STSM

When incorporating emissions and activity projections from a model, it is important to understand and assess its key underlying assumptions. To this end, Figures 2-4 provide a comparison of the MPP and IEA scenarios on key dimensions, including the cumulative carbon budget, steel demand, and the share of secondary steel production. This comparison allows us to assess the suitability of MPP-based scenarios for TPI's Carbon Performance benchmarks.

Assumption 1: Cumulative carbon budget

To ensure the environmental integrity of the TPI benchmarks, the cumulative carbon emissions projected by a model should be at least as low as the corresponding sectoral carbon budget required to deliver a particular climate target (Section 2). As illustrated in Figure 2, the proposed MPP-based benchmark scenarios have *lower* cumulative carbon emissions than the current IEA-based benchmarks used by TPI (11% lower on average). It should be noted that the difference is minimal in the 1.5 Degrees benchmark scenario (2 Gt or 3%).

Figure 2: Comparison of cumulative carbon emissions in the IEA and MPP scenarios.



Notes:

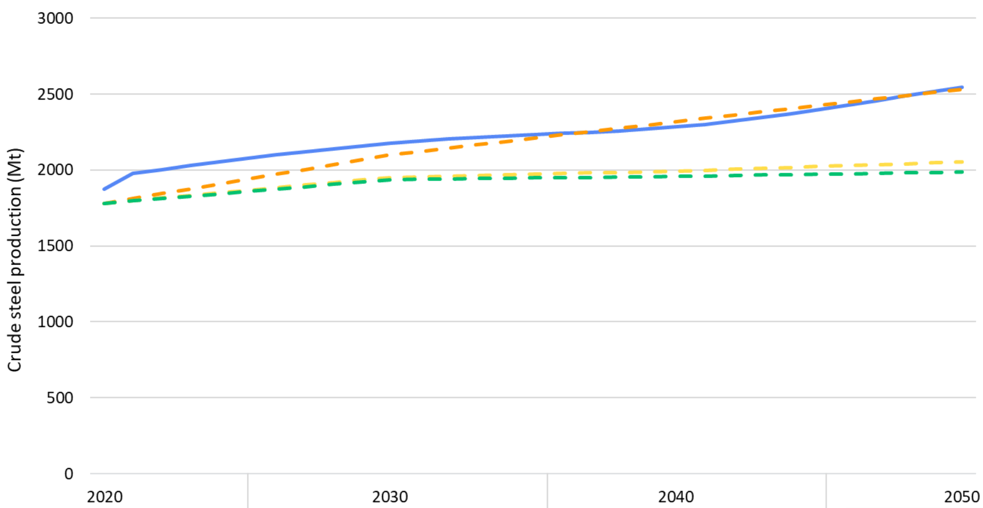
1. The cumulative emissions represent Scope 1 and 2 emissions summed for each year from 2020 to 2050.
2. The MPP scenarios comparable to TPI's National Pledges, Below 2 Degrees and 1.5 Degrees benchmarks are Baseline, Tech Moratorium and Carbon Cost, respectively.
3. The IEA's scenarios comparable to TPI's National Pledges, Below 2 Degrees and 1.5 Degrees benchmarks are Stated Policies Scenario (STEPS), Sustainable Development Scenario (SDS) and Net Zero Emissions by 2050 Scenario (NZE), respectively.
4. The MPP scenarios' cumulative carbon emissions are on average 11% lower than those of the corresponding IEA-based scenarios. Specifically, the National Pledges scenario is 19% lower, Below 2 Degrees scenario 10% lower and 1.5 Degrees scenario 3% lower.

Source: Transition Pathway Initiative (TPI) analysis of International Energy Agency (IEA) and Mission Possible Partnership (MPP) data.

Assumption 2: Global steel demand

As previously mentioned, one important model assumption to consider is total global steel demand until 2050. As shown in Figure 3, all of the MPP-based scenarios assume the same level of steel demand in each year. According to MPP, the demand was modelled to maximally align with other prominent business-as-usual trajectories for steel demand, including the IEA STEPS scenario, MPP's "The Circular Economy" baseline projection, and the ArcelorMittal Climate Action Report modelling (2019). [17] MPP's steel demand projection is roughly consistent with the IEA's STEPS projection but is higher than its SDS or NZE scenarios, as seen in Figure 3. Effectively, this means that the MPP scenarios do not consider steel demand management, for example through substitution with alternative low-carbon construction materials, as part of the sector's decarbonisation. The implications of the projected steel demand for the resulting benchmarks are discussed in the next section.

Figure 3: Comparison of crude steel production (2020 to 2050) between IEA and MPP.



	2020	2030	2040	2050
All scenarios (MPP-based)	1,876	2,175	2,285	2,547
National Pledges (IEA-based)	1,781	2,099	2,319	2,533
Below 2 Degress (IEA-based)	1,781	1,952	1,993	2,054
1.5 Degrees (IEA-based)	1,781	1,937	1,958	1,987

Note:

1. The dashed lines represent data taken from IEA publications. Energy Technology Perspectives (ETP) 2020 [6] was used for National pledges and Below 2 Degrees, and Net Zero by 2050, 2021 [8] for the 1.5 Degrees scenario.

Source: Transition Pathway Initiative (TPI) analysis of International Energy Agency (IEA) and Mission Possible Partnership (MPP) data.

Assumption 3: Share of secondary steel

Lastly, a critical model assumption to consider when selecting a model for TPI's supplementary primary and secondary steel benchmarks is the proportion of global steel demand expected to be met through secondary steel production. As demonstrated in Figure 4, IEA's NZE scenario, which is the only scenario for which the IEA provides secondary production data, is similar to the most ambitious MPP scenario, with an average difference of three percentage points across all years. Given the lack of IEA data on any other scenario, we could only conduct a comparison between the IEA and MPP assumptions for the most ambitious scenarios (i.e., those used for TPI's 1.5 Degrees benchmark).

An important difference to note is that the share of secondary steel tends to increase only slowly until 2030 in the MPP scenarios, while the IEA predicts faster growth in secondary steel production before 2030. This adoption lag may be explained by the ability of the ST-STSM model to better capture constraints faced by current steel plants in switching to a new technology archetype (BF-BOF to EAF). [17] Infrastructure lock-in of current steel plant assets can negatively impact the business case for EAF adoption prior to 2030. Nevertheless, for the most ambitious scenario, both models predict an increase in the share of secondary steel in global supply from current levels of approximately 28-31% to 40-43% in 2050.

Figure 4: Comparison of share of secondary steel production (2021 to 2050) in the global supply between IEA and MPP.

	2021	2030	2040	2050
1.5 Degrees (IEA-based)	31%	39%	40%	43%
1.5 Degrees (MPP-based)	28%	33%	39%	40%
Below 2 Degrees (MPP-based)	28%	31%	37%	38%
National Pledges (MPP-based)	28%	30%	32%	31%

Note:

1. It was not possible to create IEA-based Below 2 Degrees and National Pledges benchmark scenarios as relevant data was not disclosed by IEA.

Source: Transition Pathway Initiative (TPI) analysis of IEA's Energy Technology Perspective (ETP) 2023 and Mission Possible Partnership (MPP) data.

Overall, when comparing the MPP and IEA scenarios across the variables discussed above, a relatively consistent image of the steel sector's expected decarbonisation trajectory emerges. Both models indicate that although secondary steel is expected to play a crucial role in global steel supply, the majority of supply is anticipated to originate from primary steel production. The overall consistency between these assumptions provides a high level of confidence in the adoption of MPP-based scenarios for TPI's split (primary and secondary) emissions intensity benchmarks.

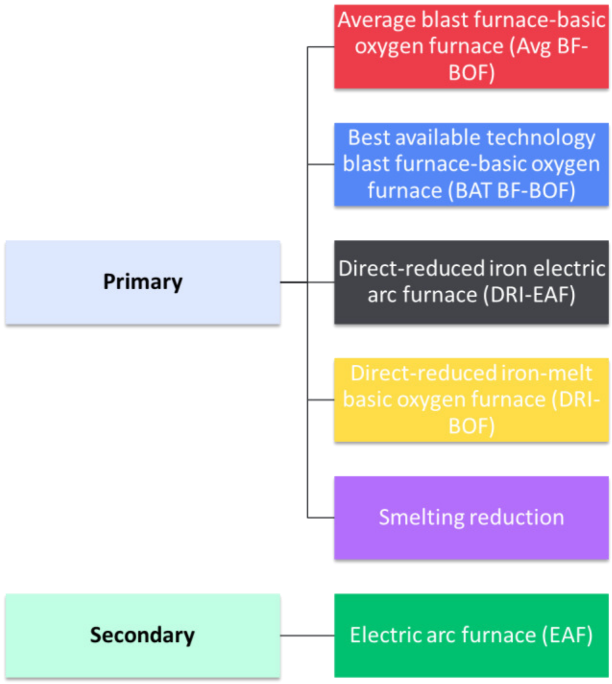
3.3.2 Data aggregation by technology archetype

To develop primary and secondary emissions intensity benchmarks, granular production and emissions data sorted into primary and secondary steelmaking categories are required. MPP's ST-STSM model evaluates 20 steelmaking technology archetypes, including those currently used or expected to become available for commercial deployment by 2050.[3] We categorise technology and corresponding emissions and production data as primary or secondary steelmaking based on the definition provided in Section 3.2 (Figure 1). Only EAF utilising 100% scrap input is classified as secondary production and all other technologies are classified as primary production (Figure 5). Figures 6 & 7 present the technology-specific data on production and emissions that are used to construct the primary and secondary

[3] See Appendix I for the detailed definition of each steelmaking technology considered by MPP.

emissions intensity benchmarks (Figure ES1), illustrating the evolution of steelmaking technologies across different scenarios. Each scenario outlines which steel production technologies and processes are utilised in a given year to meet steel demand until 2050.

Figure 5: Categorisation of steelmaking technologies as primary or secondary.

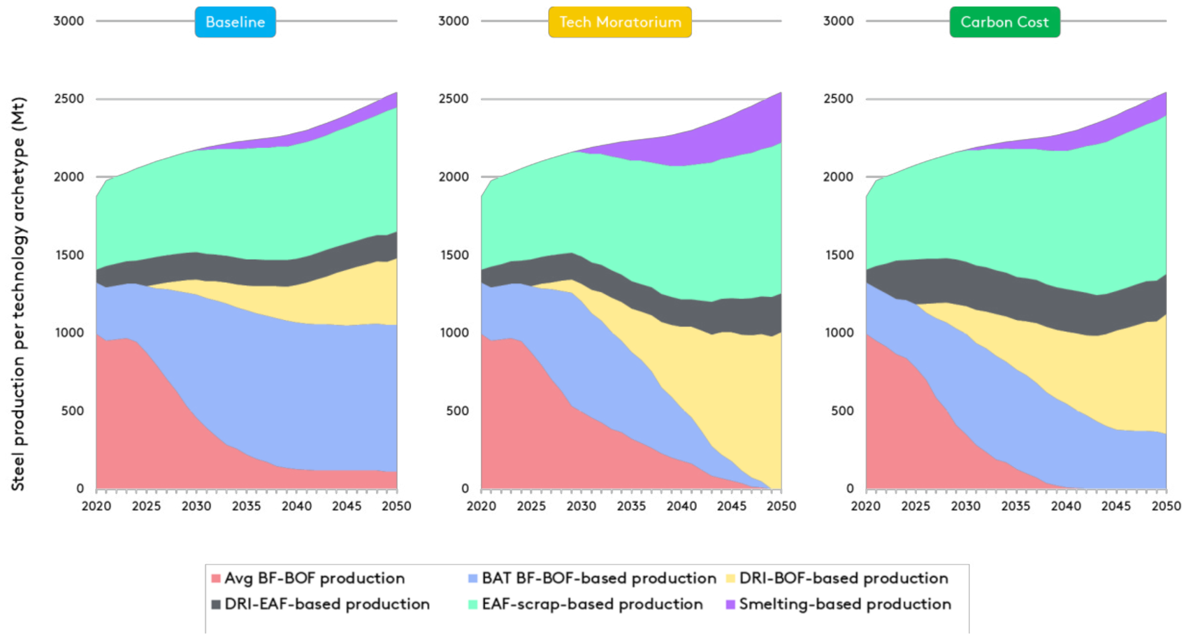


Notes:

1. Secondary steel is defined as steel produced in Electric Arc Furnace (EAF) using 100% scrap.
2. BAT (best available technology) BF-BOF represents upgraded BF-BOF with improvements to its operations, including an increased PCI ratio of 270 kg/t HM from 196 kg /t HM (Pulverized Coal Injected per tonne of hot metal as coke replacement), scrap ratio (25%), and general heating efficiency gain (10%).
3. DRI-EAF steelmaking replaces coal with natural gas as the carbon source in a shaft furnace rather than a blast furnace.
4. DRI-Melt-BOF combines DRI shaft furnace with Basic Oxygen Furnace.
5. Smelting reduction involves producing liquid hot metal from iron ore without coke.
6. Please see Appendix I for detailed technology definitions.

Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data.

Figure 6: Projected steel production (2020 to 2050) by production route and MPP benchmark scenario.

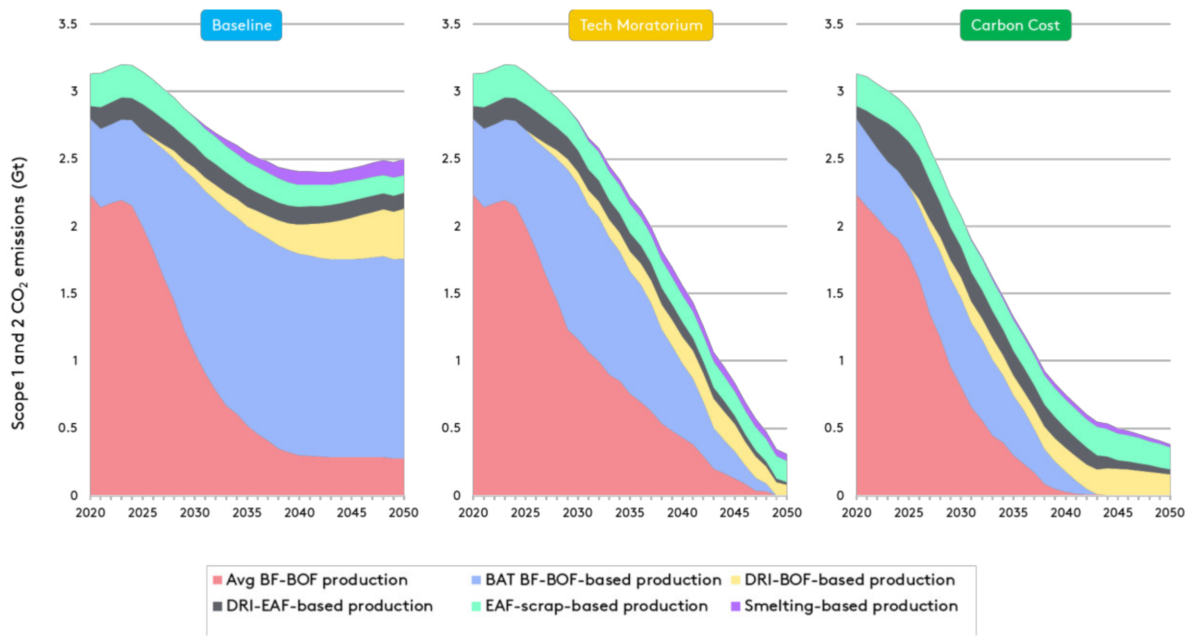


Notes:

1. MPP's Baseline, Tech Moratorium and Carbon Cost scenarios are consistent with and adopted for TPI's National Pledges, Below 2 Degrees and 1.5 Degrees, respectively.
2. The magnitude of each wedge is indicative of the production volume attributed to the corresponding production/technology route.
3. Please see Appendix II for the underlying production figures categorised as primary and secondary using Figure 5.

Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data.

Figure 7: Projected steel Scope 1 and 2 emissions (2020 to 2050) by production route and MPP benchmark scenario.



Notes:

1. MPP's Baseline, Tech Moratorium and Carbon Cost scenarios are consistent with and adopted for TPI's National Pledges, Below 2 Degrees and 1.5 Degrees, respectively.
2. The magnitude of each wedge is indicative of the Scope 1 and 2 CO_2 emissions attributed to the corresponding production/technology route.
3. Net negative emissions resulting from BAT BF-BOF-based production are not shown here. However, when this route is combined with bioenergy with carbon capture and utilisation or storage (BECCUS) or carbon capture, utilisation, and storage (CCUS), the resulting net negative emissions amount to -0.02 Gt of CO_2 in 2043 and gradually increase to -0.13 Gt of CO_2 in 2050.
4. Please see Appendix II for the underlying production figures categorised as primary and secondary using Figure 5.

Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data.

Based on Figure 6, secondary steel production using EAF-scrap-based production is expected to play a key role in all scenarios, but the dominant technologies for primary steelmaking vary amongst the scenarios. For instance, in MPP's Baseline scenario, the best available technology blast furnace-basic oxygen furnace (BAT BF-BOF) is expected to be the main method of steel production, whereas in Tech Moratorium and Carbon Cost, this changes to direct-reduced iron-melt basic oxygen furnace (DRI-BOF). This difference is reflected in the corresponding emissions profiles of the scenarios in Figure 7. Using the categorisation of the technology archetypes as primary or secondary (Figure 5), the corresponding emissions and production data were used to construct the final split emissions intensity benchmarks (Section 3.3.4).

3.3.3 Emissions from flaring and utilisation of off-gases

In steel production, off-gases are generated at various stages of steelmaking using blast furnace technology. Three main off-gases are generated: [18]

1. Coke Oven Gas (COG) produced in the production of coke from metallurgical coal in coke ovens;
2. Blast Furnace Gas (BFG) produced in the blast furnace where coke is heated with iron at high temperatures;
3. Basic Oxygen Furnace Gas (BOFG) produced in the oxygen furnace where molten iron is introduced from the blast furnace.

Table 1 shows the typical composition of these off-gases, which contain combustible gases like methane (only present in COG) and carbon monoxide. Off-gases from steelmaking include other gases, such as hydrogen, which do not have a significant climate impact and therefore can be ignored for the purposes of assessing Carbon Performance. During steelmaking, COG and BFG are produced continuously, whereas BOFG is produced intermittently. COG exhibits a relatively higher heating value in comparison to BFG and BOFG, while BFG is generated in the greatest quantities.[4] Typically, the life cycle of these off-gases in the steelmaking process is comprised of three end-of-life fates: [19]

[4] Higher heating value represents the maximum amount of heat that can be obtained from a substance through combustion.

1. Consumption: used in various milling processes such as coking, sintering and blast furnace processing primarily for heat production.
2. Electricity generation: if the quality of surplus gas is sufficient, it is combusted to produce electricity.
3. Combustion: off-gases which aren't consumed or used for electricity generation are burned (flared) with resulting emissions.

Table 1: Typical off-gas composition in steelmaking. [20-21]

	Unit	Coke oven gas (COG)	Blast furnace gas (BFG)	Basic oxygen furnace gas (BOFG)
Carbon Dioxide – CO_2	% vol	1.2	21.6	20.0
Methane – CH_4	% vol	22.0	0.0	0.0
Hydrogen – H_2	% vol	60.7	3.7	3.2
Nitrogen – N_2	% vol	5.8	46.6	18.1
Carbon Monoxide - CO	% vol	4.1	23.5	54.0
Water vapour – H_2O	% vol	4.0	4.0	4.0
Hydrocarbon - C_xH_y	% vol	2.0	0.0	0.0
Argon/oxygen – Ar + O_2	% vol	0.2	0.6	0.7

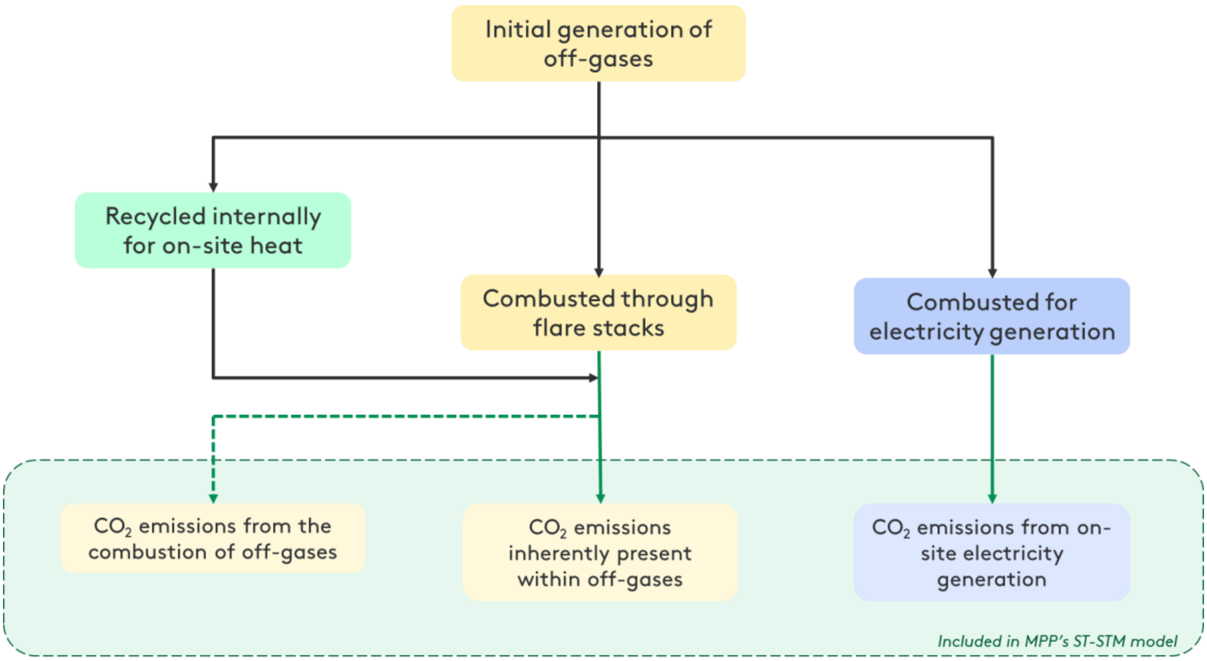
Notes:

1. The values represent the volumetric percentage represented of a specific gas within the corresponding off-gas type. Please note the corresponding weight percentage for each gas will differ due to their differing molecular masses.

Source: Transition Pathway Initiative (TPI) analysis of research literature.

Based on our analysis of steel company disclosures, many steel companies utilise steel off-gases for electricity generation. According to the IEA, around 60% of off-gases are used to fulfil on-site heat requirements, the emissions from which fall under companies' Scope 1 emissions disclosure and are included in the IEA and MPP emissions benchmarks. The remaining portion (40%) is used to produce power for the steel sector. [11] According to MPP, the ST-STSM model includes CO_2 emissions from on-site electricity generation as part of the projected Scope 1 steel sector emissions. [17] However, as mentioned above some off-gases are burned directly without being consumed internally or used for electricity generation – this is not captured by the aforementioned IEA figures. TPI assumes the CO_2 emissions resulting from the combustion of off-gases in flare stacks are included as part of the ST-STSM model's Scope 1 direct process emissions – please see Figure 8 for an illustration on the type of CO_2 emissions accounted for in the model. TPI makes this assumption due to MPP's steel system boundaries for emissions coinciding with the World Steel Association approach, which includes estimates of the emissions from flared off-gases [22].

Figure 8: Accounting for GHG emissions from off-gases in MPP's ST-STSM.



Notes:

1. From the literature, the above scenarios represent the typical end-of-life fate of off-gases. [18] Other potential scenarios are assumed to be negligible.

Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data.

3.3.4 Primary and secondary emissions intensity benchmarks

Using the results from Sections 3.3.2 & 3.3.3, TPI has developed new combined and split primary and secondary emissions intensity benchmarks, presented in Figures ES2 & ES1, respectively, and Table 2. As shown in Figure ES2, the proposed benchmarks based on the MPP ST-STSM model are lower than the current IEA-based benchmarks, due to the lower cumulative carbon budgets and the higher activity denominator for Below 2 Degrees and 1.5 Degrees.

One important feature of the split benchmarks is that the secondary steel benchmarks are the same in each of the three scenarios (see Figure ES1). It should be noted that the underlying emissions and production data are different. This is due to slightly different levels of secondary steel production as a share of total steel production between the three scenarios (as illustrated in Figure 4). However, dividing the emissions and production data to calculate emissions intensities cancels out these differences such that all three scenarios have nearly identical secondary steel benchmarks. In practical terms, this means alignment against the secondary steel benchmark would only be measured against the 1.5 Degrees benchmark.

Another striking aspect of the split benchmarks is that the Below 2 Degrees and 1.5 Degrees primary benchmarks eventually become lower than the secondary benchmarks. As seen in Figure 6, primary steel produced through BF-BOF is expected to decrease drastically by 2050. In the Below 2 Degrees scenario, production from BF-BOF is expected to reach zero, with the majority of primary steel expected to be produced through DRI-BOF. The same is true for 1.5 Degrees, but there is a more sustained reliance on BF-BOF alongside DRI-BOF. Despite the relatively greater reliance on BF-BOF and DRI-BOF in the 1.5 Degrees scenario, it still has a lower overall carbon budget (Figure 7), as these technologies are expected to be combined with various carbon capture, biomass, and hydrogen technology solutions to reduce the net emissions from production (please see Appendix I for further details of technology combinations considered within the ST-STSM). On the other hand, both scenarios exhibit significant reliance on secondary steel production using EAF (38-40%). In MPP's modelling of secondary steel production, the decarbonisation of direct emissions from the EAF process, which involves the use of natural gas to melt scrap steel, was not modelled, while indirect (Scope 2) emissions from power grid decarbonisation were considered. Due to the combination of primary production technologies with low-carbon solutions like carbon capture and the lack of EAF process decarbonisation in secondary steel production, the primary Below 2 Degrees and 1.5 Degrees scenarios eventually become slightly lower than the secondary benchmarks.

Table 2: Proposed combined, primary, and secondary emissions intensity benchmarks.

Carbon intensity (tCO_2 / t steel)	2020	2030	2040	2050
	Combined			
National Pledges	1.67	1.29	1.05	0.98
Below 2 Degrees	1.67	1.28	0.68	0.12
1.5 Degrees	1.67	0.96	0.33	0.10
	Primary			
National Pledges	2.06	1.71	1.44	1.35
Below 2 Degrees	2.06	1.71	0.95	0.09
1.5 Degrees	2.06	1.27	0.39	0.06
	Secondary			
National Pledges	0.50	0.32	0.23	0.16
Below 2 Degrees	0.50	0.32	0.23	0.16
1.5 Degrees	0.50	0.32	0.23	0.16

Notes:

1. Please see Figure 5 for the classification of furnace technologies as primary or secondary.
2. The data in the table provides a summary of emissions data presented in Figure ES2 (combined production) & ES1 (split primary and secondary).

Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data

4. EXAMPLE COMPANY CARBON PERFORMANCE ASSESSMENTS

To illustrate the additional insights provided by the primary and secondary benchmarks, we have created three hypothetical example company emissions intensity pathways. The example companies represent the three main types of steelmaker: a company producing primary steel only (Company A), a company producing secondary steel only (Company B), and a company producing both primary and secondary steel (Company C). Table 3 provides a summary of these companies' alignment scores in 2025, 2035 and 2050 against the combined (Figure 9), primary, and secondary (Figure 10) benchmarks. The principal Carbon Performance alignment scores for steelmakers will continue to be based on combined emissions intensity benchmarks, consistent with TPI's current approach of assessing companies at the entity level across all sectors. The assessment against primary and secondary benchmarks is proposed as a complementary analysis to deepen investors' understanding of company strategy. This approach enables several key insights:

- Additional insight is provided into the decarbonisation expectations on a primary steel producer. Relative to the combined benchmark, the primary benchmark gives primary steelmakers a higher threshold for alignment in the short (2025) and medium (2035) term. For example, Company A, a primary steelmaker, is *Not aligned* in 2035 when assessed against the combined benchmark but is aligned with the primary steel benchmark for *Below 2 Degrees* in 2035.
- Additional insight is provided into the decarbonisation expectations on a secondary steel producer. For example, Company B, a secondary steelmaker, is 1.5 Degrees aligned in the short, medium, and long term when assessed against the combined benchmarks, but it is not aligned with any secondary steel benchmark.
- Additional insight is provided into the decarbonisation expectations on the primary and secondary steel business segments of the same company. For example, Company C's alignment scores are the same when assessed against the combined and primary benchmarks. However, secondary production is only 1.5 Degrees-aligned in the long term (2050) and *Not aligned* in the short (2025) and medium (2035) terms.

Table 3: Company selection for preliminary Carbon Performance assessments

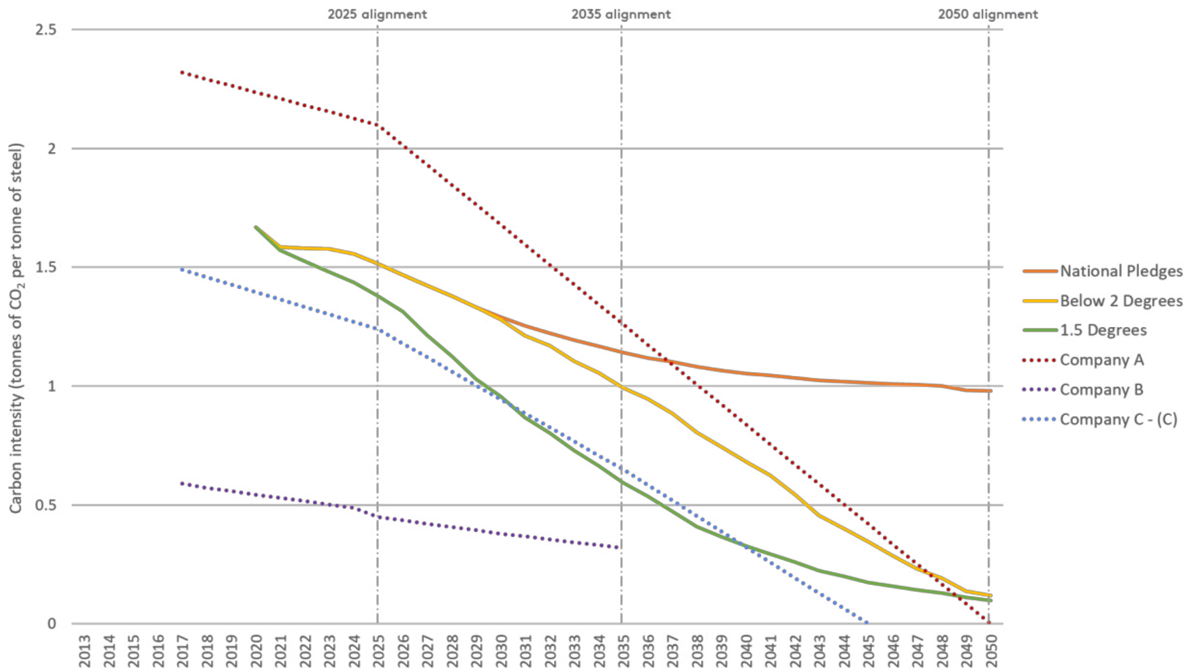
Company	Benchmark type	Alignment in 2025	Alignment in 2035	Alignment in 2050
Company A	**Combined**	**Not aligned**	**Not aligned**	**1.5 Degrees**
Company A	*Primary only*	*Not aligned*	*Below 2 Degrees*	*1.5 Degrees*
Company A	*Secondary only*	*-------------------- Not assessed--------------------*		
Company B	**Combined**	**1.5 Degrees**	**1.5 Degrees**	**Not Aligned**
Company B	*Primary only*	*-------------------- Not assessed--------------------*		

Company B	*Secondary only*	*Not aligned*	*Not aligned*	*Not aligned*
Company C	Combined	1.5 Degrees	Below 2 Degrees	1.5 Degrees
Company C	*Primary only*	*1.5 Degrees*	*Below 2 Degrees*	*1.5 Degrees*
Company C	*Secondary only*	*Not aligned*	*Not aligned*	*1.5 Degrees*

Notes:

1. There is no alignment score for Company A against the secondary benchmarks as it is only a primary steel producer.
2. There is no alignment score for Company B against the primary benchmarks as it is only a secondary steel producer.

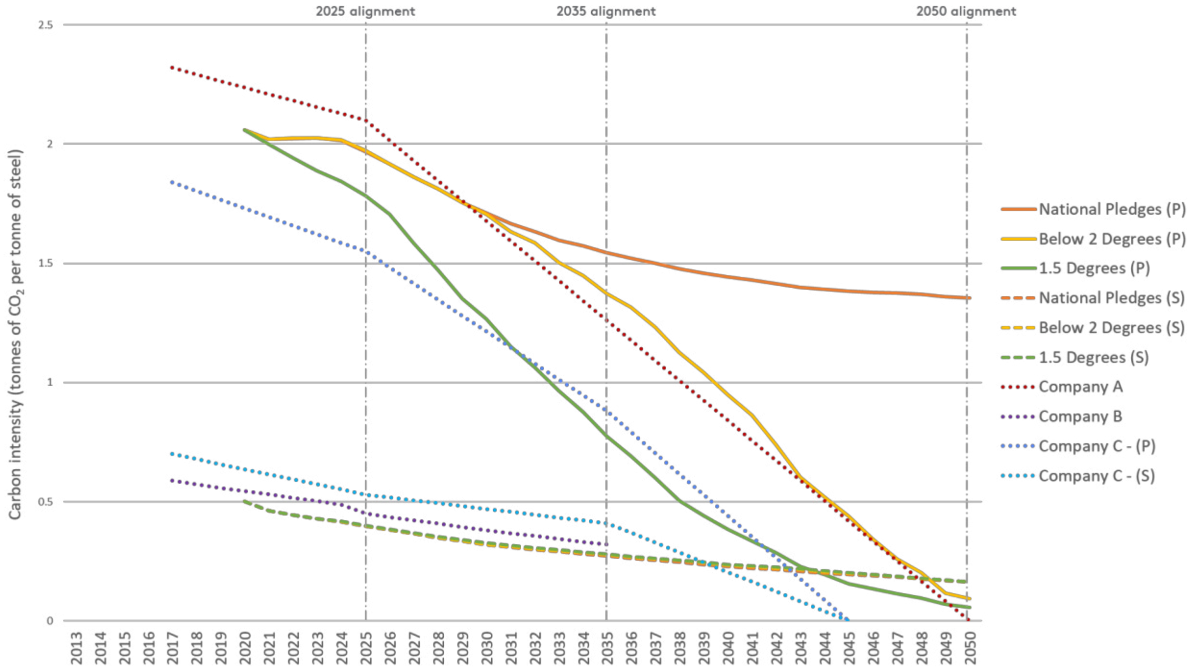
Figure 9: Carbon Performance assessments of hypothetical steel companies against the combined MPP-based benchmarks.



Notes:

1. The (C) in the legend denotes the combined emissions intensity pathway of Company C representing Scope 1 & 2 emissions and production from primary and secondary steelmaking.

Figure 10: Carbon Performance assessment of hypothetical steel companies against the primary and secondary MPP-based benchmarks.



Notes:

1. The (P) in the legend denotes the primary steel emissions intensity pathways. For Company C this represents Scope 1 & 2 emissions and production from primary steelmaking only.
2. The (S) in the legend denotes the secondary steel emissions intensity pathways. For Company C this represents Scope 1 & 2 emissions and production from secondary steelmaking only.

5. DISCUSSION

This discussion paper has described a methodology that could be used to separately assess steel companies on primary and secondary emissions intensity benchmarks. TPI proposes to continue assessing steel companies on a combined emissions intensity benchmark when providing Carbon Performance alignment scores. However, *where company disclosure allows*, TPI will provide supplementary insights on the alignment of steel companies using separate primary and secondary emissions intensity benchmarks. This will enable investors and other stakeholders to better understand the different decarbonisation challenges facing each production route. As discussed in Section 4, the additional insights are particularly valuable when assessing steelmakers that exclusively produce either primary or secondary steel. The split benchmarks provide primary steelmakers with a higher threshold for alignment compared to the combined benchmarks, due to the removal of secondary steel emissions and production. Conversely, the split benchmarks enable a stricter assessment of secondary steelmakers who have a much lower emissions intensity starting point.

5.1 Limitations of this methodology

The development of emissions intensity benchmarks for primary and secondary steelmaking acknowledges their distinct decarbonisation challenges. While increasing the share of scrap steel can lower carbon emissions, scrap steel alone cannot plausibly meet global steel demand. In addition to the approach proposed in this report, company-specific benchmarks could be designed based on a steelmaker's individual scrap share. This approach would offer a single alignment outcome, as opposed to the three alignment outcomes proposed in this discussion paper. However, the use of company-specific benchmarks would require companies to disclose estimates of future scrap share, which may be considered commercially sensitive. Additionally, sector-wide benchmarks provide straightforward comparability across companies, mitigating against any spurious claims for special treatment and reducing potential confusion among investors.

A challenge that this new methodology raises is its reliance on additional disclosure from steelmakers that produce both primary and secondary steel. Specifically, for steelmakers to be assessed against the split primary and secondary benchmarks, they will need to disclose separate emissions and production data, as well as set emissions reduction targets that address primary and secondary production (the exception to this is that companies that exclusively produce either primary or secondary steel need not establish separate emissions data or production-based targets). The current landscape of steel company disclosures is limited and therefore constrains our deployment of the split benchmarks approach.

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APPENDIX I – TECHNOLOGY DEFINITIONS

Table 4: Characteristics of technologies considered in MPP's ST-STSM model. [17]

Technology	Technology overview
Average blast furnace-basic oxygen furnace (Avg BF-BOF)	Classical vertically integrated steel production, from coke ovens till hot rolling of steel. Feed consisting of iron ore and coke (made on-site) is prepared via pelletising and sintering and then fed into a blast furnace, where it undergoes a set of reactions ending in stripping iron ore of oxygen, thus producing molten iron with relatively large carbon content, called Hot Metal. Energy-rich off-gases generated in the plant (Coke Oven Gas, Blast Furnace gas, and Basic Oxygen Furnace gas) are mixed together to form "Factory gas" which is then used to provide heat required for internal processes with surplus sent to integrated Combined Heat and Power plant to generate steam and electricity. Electricity is routed back to steel plant to supply the internal demand, surplus is sold to the grid, resulting in small revenue stream and carbon credit. Hot metal (HM) is refined in a basic oxygen furnace (BOF) using pure oxygen, which reacts with carbon and ore impurities, generating heat. Scrap steel is used as a coolant in the process and could also improve the economics of the process, depending on the market circumstances. Business case assumes a ~5.0% scrap ratio and 195 kg PCI/t HM (Pulverized Coal Injected per t of Hot Metal as coke replacement).
Best available technology blast furnace-basic oxygen furnace (BAT BF-BOF)	Business case represents modernized BF-BOF route with several improvements to its operations, including increased PCI ratio (270 kg/t HM), scrap ratio (25%), and general heating efficiency gain (10%).
Best available technology blast furnace-basic oxygen furnace (BAT BF-BOF) with CCU	BAT BF-BOF route in which PCI injection is fully replaced with high-carbon biomass source (i.e., wood charcoal) and surplus off-gases are used to generate methanol to be used in chemicals industry rather than being burned in CHP plant. Carbon credit from use of biomass is given based on mass of biocarbon injected according to the formula: bio-PCI mass/t of steel * % biocarbon content * 44/12 (CO2/C conversion factor). Emissions throughout the facility are calculated similar to BAT BF-BOF. Biomass is assumed to come from sustainable source (i.e. it is sustainably sourced wood, forest residue, or bio-organic fraction of municipal solid waste). One could argue that capturing, i.e., waste streams should come with additional carbon credit, hence we make assumption that credits and emissions from the biomass mix used in the facility cancel each other out and the upstream biomass emissions are net-zero. Surplus off-gases and CO2 resulting from burning off-gases for internal heat supply are routed to methanol synthesis. Supply of hydrogen coming from Coke Oven Gas and Blast Furnace gas is grossly inadequate to process all carbon-bearing molecules (mainly CO and CO2), therefore large amount of green hydrogen (~175 kgH2/t casted steel) has to be supplied in order to trap all carbon atoms in methanol. Biomass credit is assumed to be allocated in full to steel industry,

	implying that methanol is later used to create products allowing for long-term storage of carbon, i.e., plastics. It is important to note that - as of now - there is no bio-based replacement for coke in Blast Furnace. Apart from providing reductants for reaction with iron ore, coke provides mechanical support which bio-based solutions like wood charcoal can't and thus would require significant changes to the furnace (esp. decrease in size) to replace both coke and PCI
Best available technology blast furnace-basic oxygen furnace (BAT BF-BOF) with CCUS	BAT BF-BOF route in which CO_2 emissions from all major parts of the process are captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO_2) required for regeneration of sorbent is assumed to be supplied with electricity. Internal consumption of power is high enough to warrant significant purchase of power from the grid (auto-generation is insufficient to cover the needs). Capture efficiency is assumed to be 90%, constant across analysed period In addition to CCS, business case assumes implementation of Top Gas Recycling, in which reductant-rich off-gas from Blast Furnace is recycled back to the furnace to utilize its leftover potential to reduce iron ore. We assume that recycling of 25% of the BF gas would allow 16% reduction in solid reductant input (both coke and PCI)
Best available technology blast furnace-basic oxygen with part of carbon input replaced with biomass and with CCUS applied	BAT BF-BOF route in which PCI injection is fully replaced with high-carbon biomass source (i.e., wood charcoal). Top Gas Recycling is implemented and recycles 25% of BF gas, resulting in 16% reduction in required solid reductant input (spread equally across coke and PCI). Carbon credit from use of biomass is given based on mass of biocarbon injected according to the formula: bio-PCI mass/t of steel * % biocarbon content * 44/12 (CO_2/C conversion factor). Emissions throughout the facility are calculated similar to BAT BF-BOF. Biomass is assumed to come from sustainable source (i.e. it is sustainably sourced wood, forest residue, or bio-organic fraction of municipal solid waste). One could argue that capturing, i.e., waste streams should come with additional carbon credit, hence we make assumption that credits and emissions from the biomass mix used in the facility cancel each other out and the upstream biomass emissions are net-zero. CO_2 emissions from all major parts of the process are captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO_2) required for regeneration of sorbent is assumed to be supplied with electricity. Internal consumption of power is high enough to warrant significant purchase of power from the grid (auto-generation is insufficient to cover the needs). Capture efficiency is assumed to be 90%, constant across analysed period It is important to note that - as of now - there is no bio-based replacement for coke in Blast Furnace. Apart from providing reductants for reaction with iron ore, coke provides mechanical support which bio-based solutions like wood charcoal can't and thus would require significant changes to the furnace (esp. decrease in size) to replace both coke and PCI
Best available technology blast furnace-basic oxygen furnace (BAT	BAT BF-BOF route in which pre-treated biomass replaces PCI (Pulverized Coal Injection) in the blast furnace. Wood charcoal assumed as reference. Carbon credit from use of biomass is given based on mass of biocarbon injected according to the formula: bio-PCI mass/t of steel * % carbon content * 44/12 (CO_2/C conversion factor). It is important to note that - as of now - there is no bio-based replacement for coke in the

BF-BOF) with biomass PCI	Blast Furnace. Apart from providing reductants for reaction with iron ore, coke provides mechanical support which bio-based solutions like wood charcoal can't and thus require significant changes to the furnace (esp. decrease in size) to replace both coke and PCI
Best available technology blast furnace-basic oxygen furnace (BAT BF-BOF) with H2 injection	BAT BF-BOF route in which part of injected coal is replaced with green hydrogen. It is assumed that hydrogen can replace only up to 120 kg coal/t HM (out of total 270 kg coal/t HM) due to endothermic nature of iron reduction with hydrogen, which may disturb the blast furnace temperature profile and render it inoperable.
Electric arc furnace (EAF)	Dominant steel recycling technology in which scrap steel is melted in an arc furnace using electric current with natural gas used to meet all other heat requirements (especially at hot rolling stage). Power consumption in EAF is assumed to be ~1.9 GJ electricity/t liquid steel with 100% scrap feed. EAF process decarbonisation was not modelled as part of this effort (aside from scope 2 emissions decrease due to power grid decarbonisation).
DRI-EAF	Steelmaking process replacing coal as carbon source with natural gas in shaft furnace rather than blast furnace. Modelling based on MIDREX® technology in which natural gas is first converted via Steam Methane Reforming process to mixture of carbon monoxide and hydrogen which is then fed into the shaft furnace as reductant. Assumed ~10 GJ/t DRI (shaft furnace consumption).
DRI-EAF with CCUS	CO2 resulting from all main processes is captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO2) required for regeneration of sorbent is assumed to be supplied with electricity.
DRI-EAF with 100% green H2	DRI-EAF route in which natural gas is replaced with green hydrogen as reductant. Since the reaction of hydrogen with iron ore is endothermic, additional heating of the shaft furnace is required, along with preheating of hydrogen feed. All additional heating requirements are assumed to be met with electric heating. Hydrogen consumption is assumed to be 63 kg/t iron, which is ~17% higher than theoretical requirement for reduction of hematite (54 kgH2/tFe) due to presence of impurities in ore, i.e., silica.
DRI-EAF with 50% green H2	DRI-EAF route in which 50% of shaft furnace natural gas feed is replaced with green hydrogen. Since the reaction of hydrogen with iron ore is endothermic, additional heating of the shaft furnace is required, along with preheating of hydrogen feed. All additional heating requirements are assumed to be met with natural gas. Hydrogen is mixed only with shaft furnace feed, remaining processes (i.e., hot rolling) uses 100% natural gas for heating.
DRI-EAF with 50% biomethane	DRI-EAF route in which natural gas used across the plant is blended in equal proportions with biomethane.
DRI-Melt-BOF	Combination of DRI shaft furnace with Basic Oxygen Furnace. DRI is made using natural gas, similar to the DRI-EAF route, but then solid (still hot) sponge iron is fed into the melter where it is melted using natural

	gas as source of heat. Liquid sponge iron is fed into BOF where it undergoes oxygen treatment similar to BF-BOF route.
DRI-Melt-BOF with 100% green H2	DRI-BOF route in which natural gas in shaft furnace is replaced with hydrogen. Since the reaction of hydrogen with iron ore is endothermic, additional heating of the shaft furnace is required, along with preheating of hydrogen feed. All additional heating requirements are assumed to be met with electric heating. Hydrogen consumption is assumed to be 63 kg/t iron, which is ~17% higher than theoretical requirement for reduction of hematite (54 kgH2/tFe) due to presence of impurities in ore, i.e., silica. Since there is no carbon in the sponge iron coming from Hydrogen DRI process, there is less heat generated during oxygen treatment in BOF. In addition, heating in melter is assumed to be provided with electricity to avoid natural gas- related emissions.
DRI-Melt-BOF with CCUS	CO2 resulting from all main processes is captured using post-combustion amine-based CCS solution. Heating (3.6 GJ/tCO2) required for regeneration of sorbent is assumed to be supplied with electricity.
Smelting reduction	Type of process in which liquid hot metal is produced from iron ore without coke. Business case is based on HIsarna, a type of smelting reduction in which iron ore fines are injected at the top of Cyclone Converter Furnace along with pure oxygen, while coal powder is supplied at the bottom. The process reduces iron ore into liquid pig iron without coke production and iron ore agglomeration steps. Pig iron is fed into BOF where it undergoes oxygen treatment similar to BF-BOF route. Coal consumption is assumed to be 12.7 GJ/t pig iron, scrap ratio is assumed to be similar to BAT BF-BOF (25%). BOF gases are assumed to be utilised on-site for heat generation.
Smelting reduction with CCUS	Given high concentration of CO2 in off-gases coming from CCF (>85%), CO2 is assumed to be captured using cryogenic distillation using ~2.2 GJ electricity/tCO2 with 90% capture efficiency.

Source: Mission Possible Partnership (MPP) model specification

APPENDIX II – SUMMARY OF PRODUCTION AND EMISSIONS DATA

Table 5: Summary of production data by primary and secondary production (Mt of crude steel).

	2020	2030	2040	2050
	Primary			
Baseline	1,406	1,521	1,552	1,749
Tech Moratorium	1,406	1,507	1,430	1,579
Carbon Cost	1,406	1,461	1,397	1,527
	Secondary			
Baseline	470	654	733	798
Tech Moratorium	470	668	855	968
Carbon Cost	470	714	887	1,020

Notes:

1. Please see Figure 5 for the classification of furnace technologies as primary or secondary.
2. The data in the table provides a summary of production data presented in Figure 6.

Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data.

Table 6: Summary of Scope 1 and 2 emissions data by primary and secondary production (Gt of CO_2).

	2020	2030	2040	2050
	Primary			
Baseline	2.90	2.60	2.24	2.37
Tech Moratorium	2.90	2.57	1.36	0.15
Carbon Cost	2.90	1.85	0.54	0.09
	Secondary			
Baseline	0.24	0.21	0.17	0.13
Tech Moratorium	0.24	0.21	0.20	0.16
Carbon Cost	0.24	0.23	0.21	0.17

Notes:

1. Please see Figure 5 for the classification of furnace technologies as primary or secondary.
2. The data in the table provides a summary of emissions data presented in Figure 7.

Source: Transition Pathway Initiative (TPI) analysis of Mission Possible Partnership (MPP) data.