Building the future: a faster route to clean steel

July 2022

Methodology

This independent analysis, conducted by Green Alliance, builds on existing data and analysis available in academic and policy literature. We also consulted a number of steel industry experts.

This methodology is organised chronologically based on the illustrations and tables in the report.

Note that the key input data used for the modelling and calculations are presented in tables 1-3 in the annex at the end of this methodology. Additionally, note that all conversions from EUR to GBP are done based on an exchange rate of 1 EUR=0.8517 GBP, which corresponds to the average for the financial year 2021-22, as reported by HM Revenue and Customs.[1]

The UK steel market in 2030, if all sectors demand clean steel only (page 9)

The plotted numbers are derived directly from figure 2 of the Department for Business, Energy and Industrial Strategy's (BEIS's) 2017 report *Future capacities and capabilities of the UK steel industry*, using the values in the '2030 future opportunity' column.[2]

Direct emissions from UK steel industry in 2018 (page 10)

Figures are taken from the open access Ember steel database spreadsheet 'UK steel production dataset 2020', based on EU ETS data for the year 2018.[3] They only include the direct emissions from each site and thus do not include emissions from electricity generation or upstream or downstream in the value chain.

Total emissions of blast furnace steelmaking (BF-BOF) and electrified steelmaking using scrap (Scrap-EAF) (page 11)

The upstream emissions for BF-BOF are calculated based on average emissions associated with the mining of iron ore[4], coaland limestone, as well as the emissions associated with the smelting of ferroalloys and the transport of raw materials, taken from a McKinsey presentation on *Competitiveness and challenges in the steel industry*.[5,6,7] For Scrap-EAF, the average mining, ferroalloy smelting and transport emissions are all obtained from McKinsey.[8]

Direct BF-BOF emissions are calculated based on the actual emissions of UK BF-BOF plants in 2018 relative to their total capacity, based on the Ember database (see above).[9] The direct EAF emission are based on Vogl (2018).[10]

Electricity emissions are calculated based on the average grid emissions intensity in the UK for 2018 (0.215 tCO_2e/MWh, based on National Grid), and the electricity consumption outlined in table 1 below (see annex).[11] Values from 2018 are used for electricity to be consistent with the Ember data for direct emissions.

Processing emissions are calculated based on the average emissions of steel processing facilities in the UK, relative to their total capacity, based on Ember's spreadsheet.[12] The same processing is assumed for both BF-BOF and EAF produced steel.

Downstream emissions related to the transport and distribution of steel products are based on McKinsey data for both processes.[13]

Processes used to make steel (page 12)

Reported values for the percentage of UK production for each process are taken from World Steel data for the year 2019.[14]

Steelmaking technologies compared (page 13)

Direct emissions are obtained from the sources detailed in the annex for table 1 below (see annex). The total capital costs are based on table 2 and the annual production costs are taken from table 3 in the annex, corresponding to first green power pool (GPP) scenario in the illustration on page 28. Maximum scrap steel use is determined for the different processes from Hall (2021) and Vogl (2018).[15,16] Coal use is based on sources outlined for table 1 (see annex). The steel product range limitations on Scrap-EAF are determined from discussions with industry representatives.

UK steel sector decarbonisation to 2050 (page 16)

The share of production between different steel technologies in our proposed pathway for decarbonising the UK steel industry is based on the following assumptions:

- Blast furnace steelmaking will be fully phased out by 2035, with the remaining four blast furnaces predicted to be due for relining at the following dates: 2025 (one relining), 2030 (one relining) and 2035 (two relinings).
- At these relining dates, blast furnaces are primarily replaced by EAF steelmaking facilities of equivalent capacity, with scrap steel replacing iron ore as the dominant input.
- By 2030, hydrogen steelmaking is commercially available and is rapidly scaled up between 2030 and 2035 to maintain some level of primary steelmaking after the phase out of the blast furnaces.
- By 2035, improvements in scrap steel sorting and EAF steelmaking align with global best practices meaning that a vast majority of steel products can be in the UK via Scrap-EAF alone, with only limited capacity for primary steelmaking required for very particular product classes.
- Carbon capture and storage is predicted to be less financially attractive to steelmakers without ongoing subsidy for operational costs and because of the need to recommit to already ageing plant. It is also higher carbon on a lifecycle basis. Hydrogen costs are expected to fall over the longer term.
- Gas-DRI does not feature as an interim step towards hydrogen steelmaking because the invasion of Ukraine has brought up the price of gas to record levels and it is unlikely to return to affordable levels, meaning it is unlikely to be financially

attractive. Thus, the more likely scenario is expansion of Scrap-EAF that then transitions directly to some Hydrogen-DRI, with investment into DRI facilities.

Total emissions are calculated based on the sum of direct and indirect emissions associated with steel production, along with a contribution from steel processing (0.09tCO_2/t steel), which was calculated from the Ember spreadsheet for UK steel production.[17] The analysis assumes UK steel production stays constant between 2020 and 2050 at 2019 levels (7.2Mt), based on World Steel figures.[18] Direct emissions are calculated based on the emissions intensities of each process, as shown in table 1 (see annex). Indirect emissions from electricity use are determined from the electricity use shown in table 1, along with a projection of the UK grid emissions intensity from 2020 to 2050, based on the Climate Change Committee's (CCC's) balanced pathway in its sixth carbon budget.[19]

Residual emissions from the EAF steelmaking process (page 18)

Direct emissions for EAF are mostly obtained from Echterhof (2021), in particular the values for carbon electrode (0.007 tCO2/steel), coal (0.043 tCO2/steel) and gas (0.01 tCO2/steel).[20] Direct emissions from lime are determined based on its use per tonne of steel in an EAF (50 kg/t steel), and the chemical equation associated with the calcination of limestone into lime and carbon dioxide.[21,22] Direct emissions for steel processing are calculated as above in 'Total emissions of blast furnace steelmaking (BF-BOF) and electrified steelmaking using scrap (Scrap-EAF)'.

Use and quality of UK scrap steel (page 20)

Scrap steel figures are obtained from Hall (2021).[23] Scrap quality figures are based on table 2 in Spooner (2021), with the reported scrap identifiers used to categorise them as low ('high residual') and high ('low residual') quality scrap based on UK specifications for scrap steel.[24,25] The absolute numbers were determined based on the total amount of scrap arising from Hall (2021).[26]

Potential to increase UK self sufficiency in steel supply chains by 2035 (page 21)

The amount of scrap steel consumed and exported in 2019 is based on data from Hall (2021).[27] The UK steel production value is based on 2019 data from UK Steel.[28] The amount of iron ore imported into the UK is obtained from Statista, assuming that imports in 2019 are similar to those in 2018.[29]

Steel production in 2035 is assumed constant at 2019 levels, as explained in our sector decarbonisation analysis mentioned above. The total amount of scrap generated in 2035 is assumed constant at 2019 levels, although it is feasible that it could even be higher because of more legacy steel becoming available. The amount of iron ore imported and the amount of scrap steel recycled domestically in 2035 are calculated on the iron ore and scrap steel requirements of each steelmaking technology, shown in table 1 (annex), and their assumed share of production in our modelling (see the 'UK steel sector decarbonisation to 2050' illustration on page 16).

The economic benefits of steel sector decarbonisation by 2035 (page 22)

- **Private capital investment**

Private capital investment is calculated based on the capital investment required to achieve the clean steel production capacity modelled in 2035-50. The total capital cost of each type of plant (electric arc furnace (EAF), direct reduction (DR) shaft and electrolyser) is the capital cost per tonne of steel capacity multiplied by the estimated additional production capacity required from each plant type, as per the modelling in 'UK steel sector decarbonisation to 2050' illustration in page 16. Scrap-EAF requires only an EAF plant whereas hydrogen steelmaking requires an electrolyser, a DR shaft and an EAF. The additional EAF capacity required considers the current EAF capacity in the UK, based on the Ember spreadsheet.[30] The total capital costs for each type of plant per tonne of steel capacity are obtained from Vogl (2019) and detailed in table 2 (see annex), after conversion into GBP.[31]

- **Sector productivity**

Sector productivity is calculated based on the total market value of steel produced in UK divided by the number of labour hours required to produce that steel, based on the assumed technology mix in 2019 and 2035. The market value is assumed to be that of hot rolled coil, for which we take a value of £766/t steel, based on 2022 'Ex-Works EU' data.[32] The labour hours required to produce steel via the BF-BOF and EAF routes respectively are obtained from Steelonthenet.[33, 34] It is assumed that the productivity of the smaller proportion of hydrogen steelmaking is similar to that of Scrap-EAF.

How a green power pool would work (page 27)

The share of UK electricity supply from gas and renewables is obtained from UK government (DUKES 5.6) data for 2020.[35] The cost of renewables generation is assumed to be £50/MWh based on last contracts for difference (CfD) strike price for offshore wind of around £40/MWh and an additional £10/MWh for back up in periods of low wind. This is only an estimate of what a green power pool could offer and does not take into account any additional charges that might be imposed. The wholesale price of electricity (price to user) for grid electricity is based on April 2022 data and rounded to the nearest £5.[36] The cost of gas generation is assumed to be equivalent to the wholesale price of electricity, as based on the marginal pricing model where the maximum production cost sets the production cost.

Effect of a green power pool on different technologies, relative to blast furnace relining (page 28)

The annual production cost of different steel technologies is calculated based on an approach outlined in Vogl (2018) and subsequently applied in Pimm (2021) to the UK energy system.[37,38] This approach consists of calculating the equivalent annual cost for the capital costs based on the assumed lifetime of each investment (20 years for all except the electrolyser which is ten years) and interest rate (five per cent). The annual production cost per tonne of steel is then the sum of the operational costs per tonne of steel plus the equivalent annual cost (EAC) of the capital costs per tonne of steel capacity. The annual cost of blast furnace relining is subtracted from each of these to obtain the relative cost of production.

The capital costs for each of the clean steel technologies are outlined in table 2 (annex) and the operational costs are outlined in table 3 (annex), with these broken into the contributing elements. Note that these indicative costs have been obtained from the academic literature, based on a variety of sources but are not necessarily fully representative of the true costs faced by steel companies in the UK as costs can vary dramatically depending on global commodity prices, plant location and various policy instruments affecting the cost faced by producers.

The April 2022 scenario is based on steelmakers paying a price of electricity equivalent to the wholesale price in April 2022 (£175/MWh, as outlined above) and gas price (only applicable to Gas-DR-EAR production) of £19.3/GJ, based on Ember reported data for January 2022.[39] Due to the invasion of Ukraine, it is assumed that the gas price will continue to be high in the future and, thus, the gas price is kept constant for the other two scenarios. This scenario also assumes steelmakers are paying a limited carbon price of £6.6 t/CO_2 on the direct steelmaking emissions of each technology (table 1 of the annex). This limited carbon price accounts for the free allocations that blast furnace steelmakers receive relative to a full carbon price of £70 t/CO_2. The carbon price value is obtained based on the average EU emissions trading scheme (ETS) price between Jan 2022 and April 2022.

The first GPP scenario assumes the same conditions as the April 2022 scenario except that now the electricity cost to steelmakers is reduced to £50/MWh, the estimated price offered to steel producers under a GPP as discussed above.

The second GPP scenario assumes the same as the first GPP scenario except that, in addition, steelmakers now pay the full carbon price of £70 t/CO_2.

Annex

Table 1: Resource use for different steelmaking processes

The electricity use values are obtained from Steelonthenet and Vogl (2018).[40,41] The direct emissions values are obtained from the Ember spreadsheet and Vogl (2019).[42,43] The gas use for Gas-DR-EAF is obtained from IIPI.[44] Other resource values are obtained from either Fischedick (2014) or Vogl (2018).[45,46]

Process	Electricity (MWh/t steel)	Direct emissions (tCO2/t steel)	t coal/t steel	t lime/t steel	t scrap steel/t steel	t iron ore/t steel	Gas: GJ/t steel
BF-BOF	0.1	1.9	0.7	0.3	0.2	1.8	0.0
Scrap-EAF	0.7	0.1	0.0	0.1	1.1	0.0	0.0
Gas-DR-EAF	0.8	1.0	0.0	0.1	0.3	1.5	10.4
BF-BOF-CCS	0.1	0.7	0.6	0.3	0.2	1.8	0.0
Hydrogen-DR-EAF	3.5	0.1	0.0	0.1	0.3	1.5	0.0
Hydrogen-DR-Scrap-EAF (50:50)	2.1	0.1	0.0	0.1	0.6	0.8	0.0

Table 2: Capital costs of steelmaking

The capital cost values are largely obtained from Vogl (2018), except for the capital cost of CCS which is determined from West (2020).[47,48]

£ per tonne of steel capacity	BF-BOF	Scrap-EAF	Gas-DR-EAF	BF-BOF-CCS	Hydrogen-DR-EAF	Hydrogen-DR-Scrap-EAF (50:50)
Relining	41	0	0	41	0	0
Carbon capture and storage	0	0	0	198	0	0
EAF	0	157	157	0	157	157
Direct reduction shaft	0	0	196	0	196	196
Electrolyser	0	0	0	0	136	136
Total capital costs	41	157	353	239	489	489

Table 3: Operational and annual production costs of steelmaking, considering electricity cost of £50/MWh and limited carbon pricing at £70/tCO2

Operational costs are obtained based on the resource use in table 1 and the cost of each resource, as obtained from either Fischedick (2014) or Vogl (2018). [49,50] The additional operational cost of CCS is obtained from West (2020) (operational and variable costs) and Element Energy data for CCS transport storage costs. [51,52] The carbon and electricity costs shown in the table correspond to the first GPP scenario of the illustration 'Effect of a green power pool on different technologies, relative to blast furnace relining' on page 28 of the report.

£ per tonne of steel	BF-BOF	Scrap-EAF	Gas-DR-EAF	BF-BOF-CCS	Hydrogen-DR-EAF	Hydrogen-DR-Scrap-EAF (50:50)
Iron Ore	153	0	128	153	128	64
Scrap	0	169	0	0	0	84
Coal	119	0	0	102	0	0
Gas	0	0	188	0	0	0
Alloy	17	17	17	17	17	17
Lime	23	4	4	23	4	4
Labour	32	45	45	32	45	45
Electrode	0	7	7	0	7	7
Oxygen	0	0	0	0	-13	-13
BF Slag	-14	0	0	-14	0	0
O&M	11	5	11	17	15	15
CCS cost	0	0	0	42	0	0
Electricity	7	33	38	7	174	103
Carbon cost	13	1	7	4	1	1
Total OpEx	362	280	444	384	377	326
CapEx EAC	3	13	28	19	46	46
Annual production cost	365	292	472	404	423	372

Endnotes

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