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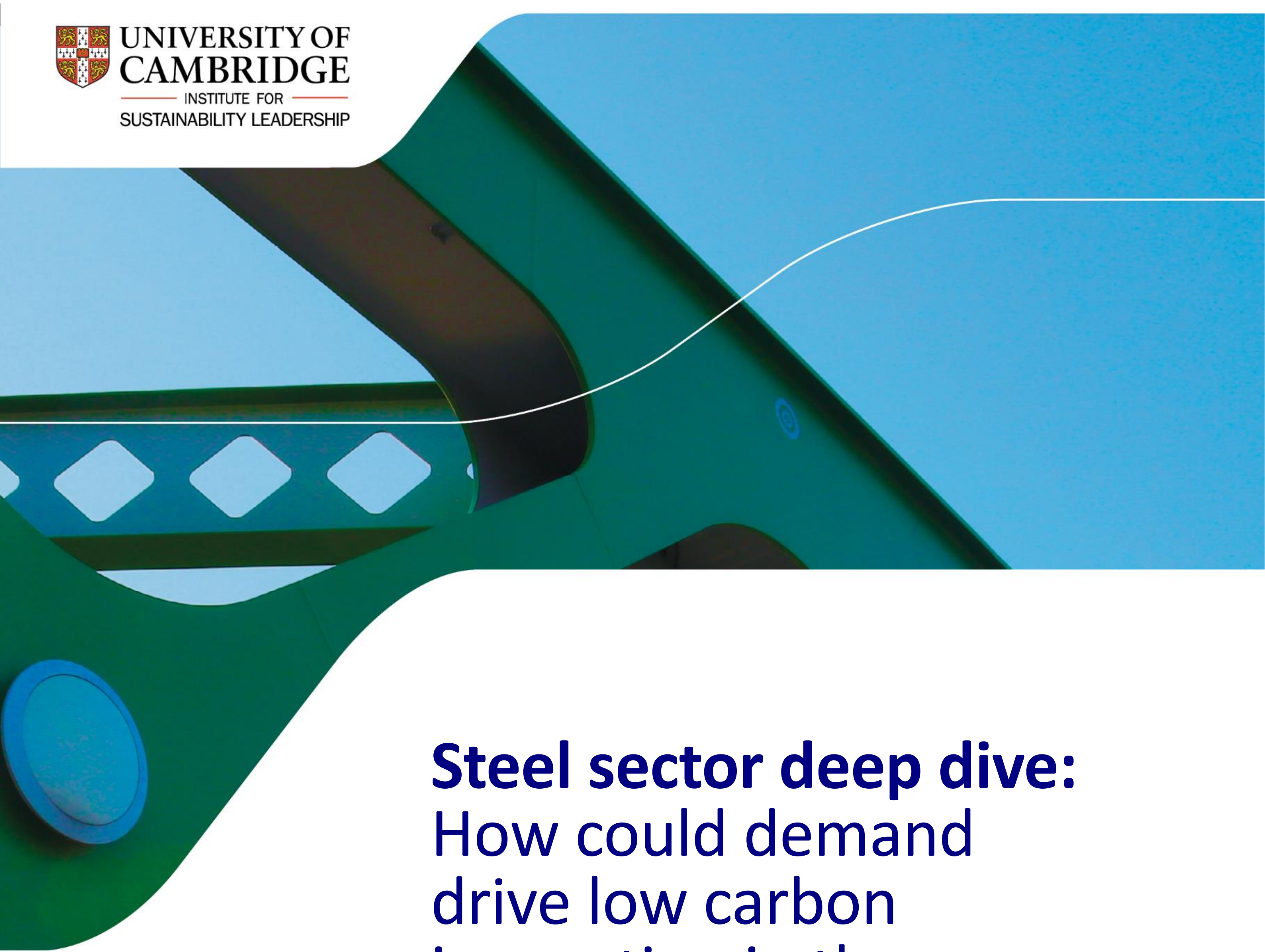

Steel sector deep dive: How could demand drive low carbon innovation in the steel industry

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1. Introduction

In this sectoral deep dive, we contextualise the industrial decarbonisation challenge by providing an overview of the UK steel industry, current steel production processes and value chains. Then, we detail the decarbonisation pathway options and present a viable strategy for the UK to achieve net zero 2050 climate commitments driven by demand-led innovation and policy.

1.1 Overview of the UK steel industry

In global terms, the UK's steel industry is insignificant: the 7.2 Mtpa of crude steel produced annually in the UK serves just 0.4 per cent of the global market (WSA, 2022). Over the past 50 years, the UK steel industry has shrunk to a quarter of its size in 1970 (Rhodes, 2017). Nevertheless, it remains emissions-intensive; in 2020, the steel sector contributed to 14 per cent of the UK's manufacturing GHG emissions (ONS, 2022) and around 2.8 per cent of the UK's total energy-related CO_2 emissions (compared to 7 per cent of energy-related CO_2 emissions globally), (International Energy Agency, 2020) making decarbonisation of the steel industry crucial for the UK's ability to achieve the 2050 net zero target.

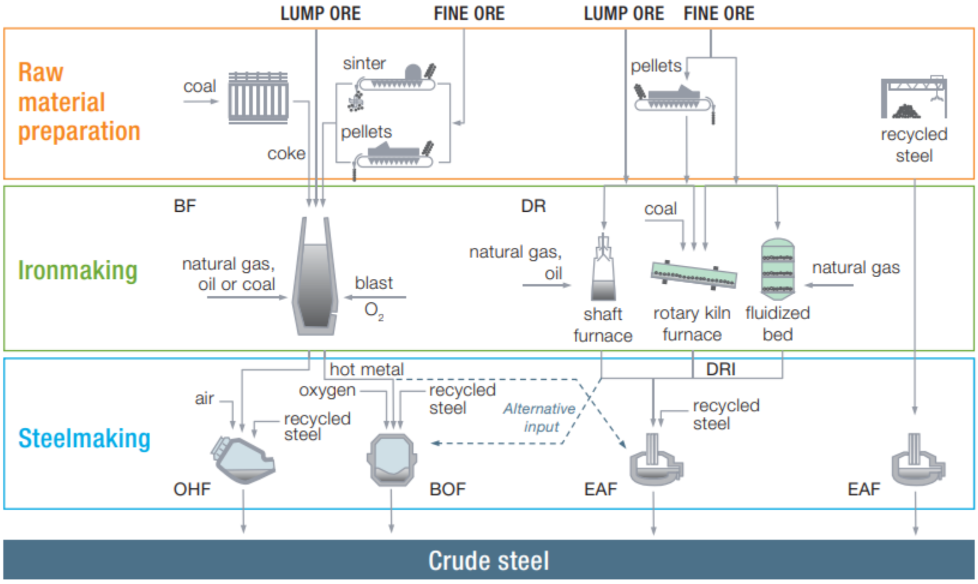
Despite the decline of domestic steel production in the UK, the government considers the sector of 'vital' national importance (UK Parliament, 2021). Steel plants are considered strategic national assets: a domestic steel industry ensures critical material supply to the national construction, aviation, and defence industries. Moreover, the industry provides stable employment for 34,500 people directly plus 43,000 throughout the supply chains at relatively high salaries (median steel sector salary being £37,629 – 45 per cent higher than the UK national median) and contributes £2.4 billion to UK GDP and supports a further £3.1 billion in supply chains (Make UK, 2022). Steel demand is forecasted to increase substantially towards 2050 with a rising population and continued economic development (Serrenho et al., 2016; Pauliuk et al., 2013). The infrastructure to deliver the clean energy transition will also require steel for wind turbines, electric vehicles, and zero-emission buildings.

2. Overview of current steel production processes

There are three distinct steps required for steel manufacturing using virgin materials: (i) raw material preparation, (ii) ironmaking, where iron ore (Fe_2O_3, Fe_3O_4) is reduced to metallic iron (Fe) and (iii) steelmaking, which combines metallic iron with scrap, alloys, fluxes (and often oxygen and carbon). Crude steel can then be cast, rolled, and/or refined in various finishing processes, depending on the steel product.

Global manufacturing processes can be classified into three main technology routes: blast furnace-basic oxygen furnace (BF-BOF), scrap-charged electric arc furnace (EAF) and direct reduction iron-electric arc furnace (DRI-EAF), as illustrated in Figure 1. Globally, the BF-BOF route produces 71 per cent of steel (1385 Mt), with 23 per cent via the scrap-EAF route (447 Mt) and 6 per cent via the DRI-EAF route (119 Mt) (WSA, 2022; MIDREX, 2022). In the UK, 82 per cent of steel is produced through the BF-BOF route, with the remaining 18 per cent made via the electric arc furnace (EAF) route.

Figure 1: Current steel production routes



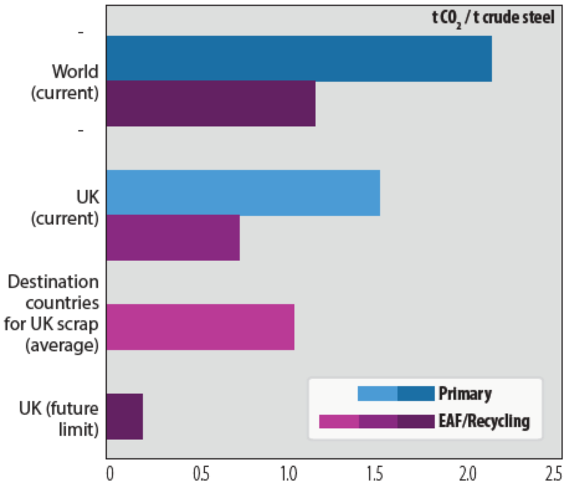
Source: WSA, 2023

The integrated BF-BOF route combines raw material processing, ironmaking, and steelmaking in the same facility. The route uses coal and iron ore as the raw material inputs, which are processed into coke and sinter. Coke combustion is also the primary energy source for the BF-BOF route. The average global emissions for the BF-BOF steelmaking route are 2.15 t CO_2/t steel. In the UK, the emissions from this approach are nearly 30 per cent lower (1.55 t CO_2/t steel) due to the use of more efficient technology (Allwood et al., 2019).

The EAF route can be charged with 100 per cent scrap steel, bypassing the need for carbon-intensive ironmaking. However, the EAF route is an electricity-intensive process that requires large quantities of recycled steel. Because there is no need for the ironmaking process, global average emissions from the EAF route are much lower than the BF-BOF, around 1.15 t CO_2/t steel, considering scope 1 and scope 2 emissions (and given global average electricity intensity of 574 CO_2/kWh). In the UK, more energy-efficient processes and larger shares of renewable energy have reduced average EAF emissions to 0.75 t CO_2/t steel (given a UK electricity intensity of 365 g CO_2/kWh) (Allwood et al., 2019). With a 100 per cent renewable energy source, this route could reach near-zero emission intensity. The difference between the CO_2 emissions of the BF-BOF and the EAF routes, globally and in the UK, are shown in Figure 2.

The DRI-EAF route, although not operational in the UK, has been expanding globally with a capacity growth rate of 11 per cent p.a. over the past five years (MIDREX, 2022). Instead of reducing iron ore in a molten bath (as in the BF), direct reduction removes oxygen from iron ore (a compound of iron and oxygen) in the solid state below the melting point of iron (1535°C) to produce sponge iron (Barrington, 2018). A gaseous mixture of hydrogen and carbon monoxide is used as the reductant, derived most commonly from natural gas, with an average emission intensity of 1.2 t CO_2/t steel (Mission Possible Partnership, 2022). The iron product can be fed directly into an EAF or transported as hot briquetted iron (HBI) (unlike the hot metal produced in the blast furnace, which must be directly fed into the BOF). By replacing natural gas entirely with hydrogen, this route could be used to produce very low-CO_2 steel.

Figure 2: CO_2 emissions of steel production



Source: Allwood et al., 2019

3. Overview of the steel industry value chain

International trade is essential to iron and steel supply chains due to global raw material availability, product diversity and producer specialisation.

The UK is a net importer of steel: in 2021, 10.8 Mt of crude steel was consumed to develop steel-containing products for the construction, automotive, and machinery industries, among others. In the same year, the UK produced 7.2 Mt of crude steel in 2021, of which 3.5 Mt (just under 50 per cent) was exported. Another 6.5 Mt of steel was imported (WSA, 2023a) into the UK, mainly from Germany, Belgium and Spain (International Trade Administration, 2017). The UK is the world's third largest net importer of indirect steel (ie products containing large quantities of steel) behind only the US and Russia. In 2021, it imported 12 Mtpa and exported 6 Mtpa of steel-containing products (WSA, 2022). The UK's combined direct and indirect steel consumption was 16.8 Mt in 2021, or 250 kg per capita.

The UK has six steel manufacturing companies (Make UK, 2023) operating across six sites: Tata Steel (4.9 Mtpa capacity BF-BOF in Port Talbot), British Steel (3.2 Mtpa capacity BF-BOF in Scunthorpe), Liberty Steel (1.2 Mtpa capacity EAF in Rotherham, 1.1 Mtpa capacity EAF in Newport), Celsa (1.2 Mtpa capacity EAF in Cardiff), Marcegaglia (0.5 Mtpa capacity EAF in Sheffield) and Sheffield Forgemasters (40 ktpa capacity EAF in Sheffield).

The industry is import-dependent for primary steelmaking due to the lack of domestic iron ore and coking coal supply, raw materials used intensely for BF-BOF operations. Iron ore is mainly imported from Canada, Sweden, Brazil and South Africa (OEC, 2023), and coking coal is principally imported from the US (65 per cent), Australia (19 per cent) and EU (11 per cent) (Department for Energy Security & Net Zero, 2023). In contrast, the UK has excess scrap; the majority (approximately 80 per cent) of the 11.3 Mt of scrap steel produced annually (Hall et al., 2021) is exported to destinations including Turkey and India, whilst the remainder is used in domestic secondary steelmaking.

The global steel market is dominated by China, which produces over 50 per cent of the worldwide output. The oversupply of steel in the global market during the past decade has pushed down market prices and diminished profit margins in the UK, where relative labour and energy costs are much higher than in China. Protectionist policies to prevent cheap imports from gaining domestic market advantage have included anti-dumping measures (applied to certain steel imports to the UK) and steel safeguards (eg, additional tariffs applied above the import quota from certain regions) (Hutton & Rhodes, 2021). The UK Government also compensates energy-intensive industries, such as the steel industry, where at least 20 per cent of gross value added (UK Department for Business and Trade, 2023) is attributed to electricity. This compensation is intended for procuring renewable or lower-carbon electricity at a price premium. However, the current level of support is not sufficient to counter the impact of high electricity prices, especially for companies that operate EAF furnaces. Thus the industry remains uncompetitive: Liberty Steel's primary financial backer Greensill Capital filed for insolvency in 2021 (UK House of Commons: BEIS Committee, 2021). This was followed by a recent announcement stating that the company would undergo a restructuring process, to ensure a sustainable future for the LSUK businesses and their workforce. This places 440 jobs at risk (BBC, 2023) as three facilities will be idled, and the production at the Rotherham facility will be scaled back. Liberty Steel will focus on high-value alloy steel production at Speciality Steel UK (SSUK) sites in Rotherham, Stocksbridge and Brinsworth, serving strategic aerospace, energy and engineering supply chains. SSUK will ramp up high-value production at specialist plants through 2023 (Liberty Steel, 2023).

In 2022, the Cumbria coal mine development was approved (the first in 30 years) to produce coking coal for blast furnaces (BBC, 2022). The implications of this decision are concerning. Firstly, of the circa 2.8 million tonnes of coal to be produced annually, 85 per cent is expected to be exported mainly to Europe (The Engineer, 2023). Hence, fossil fuels will be exported to other countries to produce emissions-intensive steel (UK Climate Change Committee, 2021), locking-in fossil-based asset use and presenting opportunities for carbon leakage. Secondly, a portion of the coking coal is still expected to be used in domestic primary steelmaking using the conventional BF-BOF route. This limits the feasible roadmap to net zero steelmaking; fossil fuel-dependent manufacturing can only be decarbonised through CCS technology, which has not yet been trialled at a demonstration or commercial level. As a geopolitical concern, the UK's 'leadership' on climate action has been undermined by the approval of this fossil fuel mining asset.

4. Current industry decarbonisation strategies and progress

The UK steel sector is calling for a clear national Net-Zero Steel Strategy, research funding, and financial support mechanisms to ensure domestic steelmaking survives the coming decades. Pragmatic efforts in the iron and steel sector to pilot near-zero emission technologies are mainly absent, alongside a specific policy framework with explicit technology-led roadmaps (UK Parliament, 2022). The economics of investment in decarbonised steelmaking pilot projects are unfavourable, and without government support, businesses are struggling to turn promising solutions into pragmatic emission reductions. Decarbonising the steel sector in line with climate policy is inevitable (the only other option being deindustrialisation). Still, if the UK remains stagnant regarding serious public and private investment, the opportunity to secure first-mover markets will be lost.

The UK's net zero commitments cover all territorial GHG emissions across all sectors for materials and goods produced within the UK, thus excluding extra-territorial Scope 3 emissions. However, the entire supply chain, including operations in other countries, must be considered when we measure (and plan to abate) emissions. We need to consider emissions from domestic production, the embodied carbon from imported iron and steel products, and the use of metallurgical coal in offshore steelmaking operations, often neglected as 'scope 3' emissions.

To decrease sectorial emissions from 11.4 Mt CO_2-e per year in 2020 to zero by 2050, a gradual phase-out of carbon-intensive production processes and replacement by near-zero emission technology is required. Incremental measures, such as improved energy efficiency of fossil-fuel-consuming blast furnaces[1], will help to reduce emissions in the short-term but will be insufficient alone – a paradigm shift is required. Green hydrogen, electrification, and carbon capture and storage are the three deep decarbonisation technologies the sector will depend on, alongside incremental decarbonisation measures such as demand reduction and improved material circularity. It must be noted that A combination of these emission reduction technologies and mechanisms is likely to constitute the

[1] For the integrated BF-BOF route, minimising fossil-fuelled energy use has been a long-standing business priority for cost reduction with consequent reduction of emissions. However, the energy intensity of state-of-the-art blast furnaces, which are used in the UK, is already approaching the practical minimum (International Energy Agency, 2020) energy requirement of 18.6 GJ/t (Fruehan, et al., 2000) , making further emission abatement negligible (and potentially not worth the financial investment). These integrated facilities optimise heat retention, gas recovery, onsite power generation and slag production for furnace performance enhancement, with the aim to reduce fuel consumption and maximise secondary energy recycling. Steel scrap is commonly added to the BOF, up to 30 per cent of the charge, with roughly linear reduction in iron ore reductant requirement (Wang et al., 2009).

roadmap to net zero, and we should continue to invest in the development of all prospective low-emission technologies. These decarbonisation solutions present unique strengths and limitations, as discussed below.

4.1 Low carbon hydrogen-based production

Today's direct reduction (DR) facilities for ironmaking primarily use natural gas as feedstock. Removing this type of carbon-based iron ore reductants is critical to decarbonisation. Replacing natural gas with 100 per cent low carbon hydrogen feedstock in the DR process represents a viable near-zero emission production route of high technology readiness level, producing water vapour (H_2O) instead of CO_2 as the reduction by-product. This approach was used in a successful pilot project in August 2021 by HYBRIT (SSAB 2021), a Swedish partnership between iron ore miner LKAB, renewable energy producer Vattenfall, and steel producer SSAB. A demonstration-scale project using this approach is currently underway.

Assuming that exclusively renewable electricity is used to power the electrolysers to produce hydrogen, the EAF, and other energy-consuming processes, emissions from iron-and steelmaking could be reduced to 0.05 t CO_2/t steel (3 per cent of the UK's average BF-BOF emission intensity) (Vogl et al., 2018, p. 740). The remaining emissions arise from the partial oxidation of added carbon in the EAF (for steel alloying) and limestone (for slag forming). They can, therefore, not be eradicated through fuel-switching. The flexibility of electrolysis and EAF operations, variability of renewable energy (eg our inability to control when the sun shines or the wind blows), and ability to charge the EAF with high levels of scrap all present multiple process optimisation opportunities for the industry to reduce energy consumption and costs. Co-location of high-quality renewables and iron ore resources could substantially reduce the cost of green H2-based steel production, confronting the traditional paradigm of fossil-based steel supply chains (Devlin et al., 2023).

For supply chain decarbonisation, the H_2 used by the steel industry would need to be produced entirely using renewable or other low carbon power and transported securely to the sites where it is being consumed. The current methods of steam methane reformation (grey H_2) or coal gasification (brown H_2) would need to be combined with CCS (blue H_2) or replaced by water electrolysis (green H_2) in which renewable electricity powers an electrolyser to separate water molecules (H_2O) into hydrogen and oxygen (see summary of H2 use in the industry in the Technical report).

4.2 Complete electrification

The scrap-based electric arc furnace (EAF) route represents marked improvements in energy use, with complete elimination of raw material processing and ironmaking and a practical minimum energy requirement of 1.6 GJ/t (<10 per cent of the BF-BOF route) (Fruehan, et al., 2000). However, to minimise the emissions from EAF production route, large quantities of renewable, or other low carbon, electricity must be available to power the EAFs.

Increasing the use of scrap-based EAF production is currently constrained by scrap availability (ie the amount of steel that gets recycled) and scrap quality (ie presence of contamination sources in recycled steel). (Serrenho et al., 2016) estimate that, by 2050, 30 Mt of scrap will be available on an annual basis. This is close to the estimated total material requirement if the UK switched to EAF-based production. However, this would require a significant expansion in the UK's EAF capacity and scrap quality control, additional renewable power generation capacity, and substantial improvements to transmission and distribution infrastructure. However, around 70 per cent of the UK's in-use steel stocks are in buildings and infrastructure, therefore of higher quality. This improves the viability of upscaling the scrap-based steelmaking route using EAF technology. The following case study discusses the opportunity that scrap steel recycling presents and possible challenges that would need to be addressed to fully realise it.

Case study 1: Liberty Steel and High Value Manufacturing Catapult – The UK's scrap steel opportunity

The use of scrap steel to make new steel is good for the climate and the environment. However, the viability of this depends on the availability of competitively priced renewable electricity and high-quality steel scrap.

Abating emissions from domestic steel production is imperative to the UK's climate commitments: the sector is responsible for 14 per cent of the country's manufacturing GHG emissions (ONS, 2022). Two steelmaking routes exist: the blast furnace-basic oxygen furnace (BF-BOF) route, which mainly relies on coke and iron ore, and the electric arc furnace (EAF) route, which primarily relies on electricity and scrap steel. The scrap-based EAF steelmaking route can reduce emissions by 90 per cent if powered exclusively be renewable energy, emitting 0.16 t CO_2/t crude steel, compared with 1.79 t CO_2/t crude steel emitted by the conventional BF-BOF route (using the best available technology) (Mission Possible Partnership, 2022). Currently, emission-intensive BF-BOF production dominates the UK steel industry, with 82 per cent of the ~7.2 Mt of annual steel production using this technology (UK Parliament, 2022a).

Although the steel produced in the UK has a lower average carbon intensity (of 1.58 t CO_2/t steel compared with the global average of 1.89 t CO_2/t steel) (World Steel Association, 2022b), this 'relatively cleaner' production is an underwhelming improvement over the past few decades, suggesting that the emission reduction potential in the UK steel industry has hardly been realised.

Optimising local scrap resources will be advantageous for UK steel sector decarbonisation. Eighty per cent of scrap steel is exported, whereas iron ore is imported (from Canada, Brazil and South Africa, in addition to Sweden) (OEC, 2023). Currently, 2.6 Mtpa of scrap is used in domestic production but this could increase to 6.1 Mtpa just by full utilisation of existing facilities (Hall et al., 2021). Underutilised production capacity is common; Tata Steel is producing ~3 Mt of steel annually but has capacity to produce 5 Mt. While the BOF is often charged with a portion of scrap (typically 17 per cent of the charge), the EAF can be charged with 100 per cent scrap. With the installation of new EAF facilities, conversion of all 11.3 Mtpa of available domestic scrap could serve almost the entirety of the UK's steel demand (Hall et al., 2021).

One of the biggest barriers for industrial change is cost: it is capital intensive to invest in new EAF facilities and retire existing BF-BOF facilities. This shift to EAF-based production in the UK is advantageous, considering potential production-based emission reductions and resource availability. However, it requires significant capital investment in new facilities and integrated supply chain management to assure high-quality and consistent scrap flows within the UK.

The clean energy transition in the UK is made more complex by the current unfavourable economics of steelmaking in the UK compared with a competitive international market. Liberty Steel's EAF in Rotherham has been producing only one-off orders for aerospace and defence customers for the past 18 months, primarily because of the soaring prices of electricity. China produces over 50 per cent of the 2 billion tonnes of crude steel produced globally (World Steel Association, 2022a) and accounts for 14 per cent of global exports, advantaged by cheap coal and labour, plus large economies of scale. The true profitability of the state-owned Chinese steel sector is, however, contested, with definitive anti-dumping regulations imposed by the EU and UK (Global Trade Alert, 2016; UK Trade Remedies Authority, 2022).

However, the steel sector is an essential supplier to the construction, automotive, aviation and defence industries, which are critical to the UK's economy and national security. Considering the downstream supply chain and employment that rely on UK steel, the argument for making the industry more sustainable becomes increasingly compelling. Moreover, the UK steel industry has the ability to produce high-quality diversified steel products and lead the world in clean steel production if the right support and demand signals are made. Investing in and promoting the growth of EAF production is crucial to establishing a sustainable steel industry in the UK, but two key conditions must be met to make it financially feasible. These are:

1. Cheap, reliable and abundant renewable electricity supply

The EAF route requires just 8 per cent of the thermal energy requirement of the BF route, but five times more electrical energy (0.703 vs 0.128 MWh/t) (Lopez et al., 2022). A stable renewable power supply is therefore needed to support electrification and decarbonisation of steel manufacturing. To achieve this, the national electricity grid capacity needs to increase, and energy sources switched to renewables, and/or captive, islanded renewable energy systems developed specifically for high-demand uses, such as the steel industry. As the EAF works in a flexible batch mode, it can be integrated with variable renewable energy to optimise available resources as a demand–response management technique to balance the power grid.

However, current industrial electricity tariffs in the UK (£137/MWh, including taxes) are 40 per cent higher than the EU median and 120 per cent above US prices (DESNZ, 2022). Globally, electricity accounts for ~12 per cent of EAF steel costs (Steel On The Net, 2020), but this percentage would be much larger in the UK. Electricity market reform will be required to appropriately reflect the growing share of cheap renewables: electricity auctions for UK offshore wind are reaching £48/MWh (in today's money) (Carbon Brief, 2022) for production in 2026–27, which is more than 60 per cent below the current industrial electricity tariffs. Nearly half of the UK's delivered power in 2020 was zero carbon, with renewables accounting for 43 per cent and nuclear for 16 per cent (National Grid, 2023a), and the UK government has committed to complete decarbonisation of the power grid by 2035. Novel renewable electricity contracts such as long-term power purchase agreements (already in place) and green power pools (recently proposed) (Grubb et al., 2022) may be successful in supporting low carbon electricity generation and consumption, and maintaining efficient supply–demand market dynamics.

2. High-quality scrap recycling

To improve the retention and use of scrap steel in the UK, circular practices must be improved across the supply chain and a strong domestic demand market created. Improving the quality of secondary material flows will be critical; scrap steel is 100 per cent recyclable, but inherent material losses (1 tonne of scrap steel yields about 0.91 tonnes of new crude steel) and inadequate recycling practices reduce the actual recycled rate of end-of-life (EOL) scrap to ~85 per cent (Tata Steel, 2023). Scrap is produced at various points throughout the supply chain, and is classified into three categories: home scrap, produced within the steel mill; prompt scrap, generated by industrial customers (eg the automotive and construction sectors) within manufacturing / construction processes; and end-of-life or post-consumer scrap (Bataille et al., 2021). Home and prompt scrap are pre-consumer and generally of very high quality as the steel has not been contaminated by other elements, unlike post-consumer scrap, which is commonly affected by residual elements such as copper, nickel, chromium and tin. (Dworak et al., 2022) Scrap pre-treatment technology would help to reduce impurities, alongside comprehensive recycling standards and regulation. Impurities may also be diluted by charging a portion of metallic iron directly into the EAF.

Reducing the influence of residual elements is important to preserve scrap quality, and hence downstream product potential. A common misconception exists that recycled BF-BOF steel is good quality, whereas EAF steel is poor quality and therefore suitable only for certain applications such as reinforcement steel in construction and packaging. However, if high-quality, low-impurity scrap is fed into the EAF (which does come at a price premium), the crude steel produced will consequently be of similar quality, especially as some impurities can be removed via EAF slag (but this does come with added costs in electricity demand and slag formers, eg limestone). As a testimony to this, Liberty's EAF facility in Rotherham is a specialist manufacturer of high-end alloys and stainless steels, serving the aerospace and defence sectors and specialist engineering applications (Liberty Steel, 2017). Admittedly, some elements cannot be removed in the EAF slag (termed 'tramp elements'), including tungsten, molybdenum, cobalt, nickel, tin and copper – of these, tin and copper are the most concerning because they are not alloying elements (Nakajima et al., 2011). Contaminant control in scrap recycling is essential to expand typical EAF product lines.

Another deep decarbonisation technology prospect is the direct electrolysis of iron ore in a molten metal state, to produce liquid metallic iron through the sole application of electrical energy. However, this approach has yet to be validated outside the laboratory. A key technical challenge is developing molten electrolyte cells that can withstand temperatures over 1538°C and uses affordable and readily available materials. Given continued R&D investments at the global level, a pilot-scale project is foreseeable by 2030 (Bailera, et al. 2021).

4.3 Carbon capture and storage (CCS)

According to the UK's Industrial Decarbonisation Strategy (2021), Carbon Capture, Usage and Storage (CCUS) is expected to play a key role (UK Department for Business, Energy and Industrial Strategy 2021) in supporting industrial decarbonisation in the UK by mitigating 8 Mt of CO_2 emissions by per year by 2050. Carbon capture and storage (CCS) in the steel industry could reduce CO_2 emissions from fossil-based steel production (BF-BOF route) by 50-80 per cent. However, the efficiency of CCUS in steel industry decarbonisation is subject to several challenges and constraints, including the following:

- Effective deployment of CCS is difficult in the integrated BF-BOF plant due to large number of emission points: significant CO_2 emissions exit the stacks of the power plant, hot stoves, coke ovens, sinter plant, and lime kiln. The upper threshold of potential emission reductions, 80 per cent, can only be achieved if this technology is installed to collect the high CO_2 concentration flue gases at all these points (assuming a 90 per cent CO_2 capture efficiency). The estimated cost would be approximately £30-80 per tonne of captured CO_2 (International Energy Agency, 2019), plus £19 per tonne of CO_2 for transport and storage (Richardson-Barlow, et al., 2022) – potentially well above the UK ETS value of £53/t CO_2 at the start of 2022 (Gov.UK, 2022). However, the cost of CCS could be reduced if the steam produced from excess heat was used to drive the capture process (Biermann, et al., 2019), or in combination with a top gas recycling BF (Fischedick, et al., 2014). Biomass substitution and CCS could also be used simultaneously, costing a UK BF-BOF steel plant 97 EUR/t CO_2 avoided (Mandova, et al., 2019).
- CCS consumes energy in the process, and the captured CO_2 must be transported and stored (forever) in a geological reservoir at depths of more than 1 km, such as depleted gas fields or saline aquifers (the UK has an estimated storage capacity of 78 billion tonnes, primarily within saline aquifers (Bentham, et al., 2014). Alternatively, the captured CO_2 could be re-used within steel production (CCU), closing resource loops (Ras, et al., 2019).
- CCUS for the steel industry remains untested at the commercial scale. No demonstration or commercial-scale projects yet exist for BF-BOF + CCS (Fan & Friedmann, 2021). However, CCS can also be retrofitted to DRI-EAF facilities, as has been done for the operational plant in the Al Reyadah Project, Abu Dhabi. Since 2016, 0.8 Mt CO_2 per year has been captured from the 3.2Mtpa steel plant using post-combustion amine scrubbing capture technology installed above the syngas-fed DR shaft furnace, then transported 43km to be stored in depleted oilfields (University of Edinburgh, 2023). However, this is believed to currently capture only around 20 per cent of total plant emissions.

One innovative approach for CCS in the steel industry is the combined use with smelting reduction technology (HIsarna technology), where coal is still used as the ore reductant. Tata Steel's plans to build a commercial-scale HIsarna + CCS plant in Ijmuiden, Netherlands, following a successful pilot plant, was overturned following a decision to switch to DRI technology (S&P Global, 2021).

The UK should not rely on the BF-BOF + CCS route due to its significant technical and economic uncertainty and the large scale of residual emissions (Fan & Friedmann, 2021). Relining blast furnaces should also be avoided. This capital-intensive process occurs approximately every 20 years and locks in fossil-fuel asset use for the next investment period.

4.4 Demand reduction and improved circularity

Emissions from UK the steel industry could also be cut through demand reduction, circular economy interventions and offshoring of the ironmaking process. **Material efficiency** improvements could reduce the steel required to perform the same function. Steel waste is especially abundant in the automotive industry: on average, just 55 per cent of the steel purchased by car manufacturers ends up in the vehicle (Allwood, et al., 2019).

Material substitution could see steel being replaced with other materials. Timber, for example, can be processed into manufactured wood products (eg glue-laminated (glulam) or cross-laminated) to replace steel and concrete in buildings, with the current tallest timber building in the world standing 25-stories high (USDA 2022). However, the fact that steel is used widely for its high-strength properties makes material substitution challenging, especially in the automotive and construction sectors.

Circular economy interventions could drive steel demand reduction by increasing the lifetime of steel products, increasing the re-use of materials (indirect material recirculation) and increasing the availability and use of steel scrap in new steel production (closed-loop recycling) through the EAF route. The combined global impact of an effective circular economy – together with improved material efficiency and substitution – have been estimated to drive a 40 per cent reduction in total steel demand in 2050. However, the effectiveness and impact of circular approaches depend on the cost, consumer and producer behaviours, technology development, and availability of sustainable low carbon material substitutes (Mission Possible Partnership 2022, 34) (see Exhibit 1.4). The following case study discusses a possible circular economy solution.

Case study 2: Rolls-Royce / Schaeffler – Refurbishment and recycling of steel components in the aerospace industry

Schaeffler is committed to climate neutral production by 2030, and a climate neutral supply chain (upstream scope 3 emissions) by 2040. The company is also committed to help its customers reduce their upstream scope 3 emissions.

One possible way to achieve a reduction in downstream scope 3 emissions for Schaeffler and upstream scope 3 emissions for its customers is the refurbishment of products. Since 2004, the Schaeffler Aerospace division has made significant reductions to CO_2 emissions through the Maintenance, Repair and Overhaul (MRO) of engine bearings. The refurbishment of a bearing can save up to 81 per cent of CO_2 compared with the manufacturing of a new bearing, which is comparable to the emissions of an average refrigerator over 2.5 years.

The refurbishment and recycling of used bearings require co-operation between the producer of the bearings and either the Original Equipment Manufacturer (OEM) or the end customer, or both. When the engine bearings have signs of use, such as scuffs, dents and marks, refurbishment is possible and economic. Restoring used bearings back to their original 'in condition as new' can be done quickly and cost-effectively. However, the rolling elements are not refurbished at present, but instead recycled, remelted and used as raw material for other industries.

In the area of goods and services, the use of steel accounts on average for well over 60 per cent of the emissions in the supply chain. Encouraged by the success with the refurbishment (MRO) of engine bearings, Schaeffler is now looking for additional ways to reduce the emissions of the steel used to produce bearings. Specific avenues that Schaeffler is looking at involve working with Rolls-Royce in the following areas:

- Optimising the recycling route.
- Specific recycling, including preservation of the alloying elements.
- Waiver of crude steel and use of advances in steelworks technology.
- Use of green steel and availability of relevant grades used by Rolls-Royce.
- Investing in ceramics and enhancements to steel components to improve load capability, minimise weight, reduce heat and optimise the aero-engine.

Both companies are heavily invested in thinking about future engines, including future potential design to enable a radical change. A sustainable long-term reduction of the CO_2 emissions from motors can come from their improved efficiency and design of their components.

Schaeffler has a long tradition of continuously improving the energy efficiency of the bearings that it produces. For example, the company's new aircraft engine ball bearing system was nominated for the German Aviation Innovation Award in the category 'Emission Reduction' in 2019. This system combines several highly sophisticated technologies, and by reducing friction achieves a significant reduction of 15 kW in the energy losses of the main shaft bearings.

The new ball bearing system also enabled improvements in the design of the engine to achieve a further reduction in operational emissions by downsizing several oil system components, which could save at least 1 kW more and ~16 kg of component mass. These reductions can be translated to both kerosene and CO_2 emissions reductions. Based on data from the test bench, the yearly savings would amount to ~23,500 tons of kerosene and 74,000 tons of CO_2 emissions for a fleet of 1,000 engines.

However, the implementation of such a new technology in aircraft engines requires a long approval process, which sometimes can hinder their quick application. For this reason, it is important to invest in innovation now to have these solutions in place, approved and ready for scale-up as soon as possible to support progress to the UK's net zero target for 2050.

4.5 Partial offshoring

Relocating the emissions-intensive part of the supply chain where iron ore reduction occurs (ie ironmaking) could be advantageous for the UK since importing iron ore is necessary (given the UK's lack of iron ore deposits), and securing cheap, abundant renewable energy may be a challenge. It must be clarified that offshoring is not proposed as a carbon avoidance mechanism in the context of production-based emission accounting (as opposed to consumption-based) but to optimise renewable resources in a market-based economy.

Separating iron and steelmaking becomes possible under the DRI-EAF route due to the intermediary product that is produced, sponge iron, which can be traded as hot briquetted iron (HBI). H_2 and DRI production account for around 60 per cent of energy consumption of the H2-DRI-EAF route (Devlin & Yang 2022); to manufacture H2-based DRI competitively, cheap renewables and iron ore are necessary. As demonstrated through case studies on transnational steel supply chains across Australia and Japan (Devlin & Yang, 2022) and South Africa and Europe (Trollip, et al., 2022), partial offshoring could deliver significant energy and cost savings. Under this structure, EAF steelmaking would remain in the UK to feed value-adding downstream processes.

Offshoring of the UK steel industry is unlikely to receive meaningful political support given the current geopolitical context post-Brexit, post-COVID, and mid-energy crisis, which have exposed the weakness in global supply chains and the risks associated with import dependency. However, given open trade routes and potentially emerging transnational trade agreements that offer preferential treatment to low carbon materials and technologies, **relocating certain aspects of the iron and steel production offshore** could improve the environmental and economic viability of the decarbonised green H_2-DRI-EAF route.

Whilst a strong GDP is not incompatible with very low or zero domestic steel production, it is essential to the manufacturing value add of many developed economies. Steel product manufacturing is diverse in the UK, maintained across many market segments. Hence the supply chain reliance is broad, and many parts of the economy will be affected if steel manufacturing is completely offshored (RUSI, 2023). Maintaining a baseline production capability of various steel products may be essential in the UK context, strengthening the case for partial offshoring whereby only the emissions-intensive ironmaking is relocated to locations where green H2-based direct reduction of iron is cost-competitive. The end of "large-scale" steel production in the UK will not necessarily pose a threat to national security. Still, maintaining resilience amongst volatile supply chains when the region is especially vulnerable post-Brexit is imperative.

4.6 Biomass use

Another approach that could be used in the steel industry to reduce CO_2 emissions is **using biomass to substitute fossil-based carbon**. Biomass resources, including agricultural residues (straw, corn stalks, sugarcane bagasse), wood and forest residues (sawdust, bark, timber harvesting, logging residues) and industrial waste, can be used to produce a renewable, carbon-rich substitution for coal in steelmaking (Mousa, et al., 2016; Suopajärvi, et al., 2017). This type of biomass-based reducing agents has the potential to completely replace coal in the BF. Although the gross emissions of biochar-based BF ironmaking would increase by 50 per cent (compared to conventional coal-based production), considering the burden-free classification of biochar, net CO_2 emissions could be reduced to just 50 kg CO_2/t molten iron (Nogami, et al., 2004). Substituting coal with a mix of biomass (30 per cent) and coal briquettes (70 per cent) has been successfully trialled in an EAF by Liberty Steel to reduce direct emissions from Charge Carbon additions. Using coal as a reductant in EAF steelmaking at low volumes is ideal for replacement by biomass. The low tonnages of Biomass for charge carbon in an EAF mean biomass availability is not a barrier to adoption.

However, the sustainability and availability of biomass supply significantly limit this decarbonisation measure. In a study of the suitability of bioenergy integration into iron and steelmaking, the UK was found to have insufficient sustainably sourced biomass resources for steelmaking (Mandova, et al., 2019). The concerns around the viability of biomass integration were also iterated in an optimisation study for the trade and use of biomass resources across the UK and EU steel sectors (Mandova, et al., 2018), which showed that industrial biomass demand could be met.

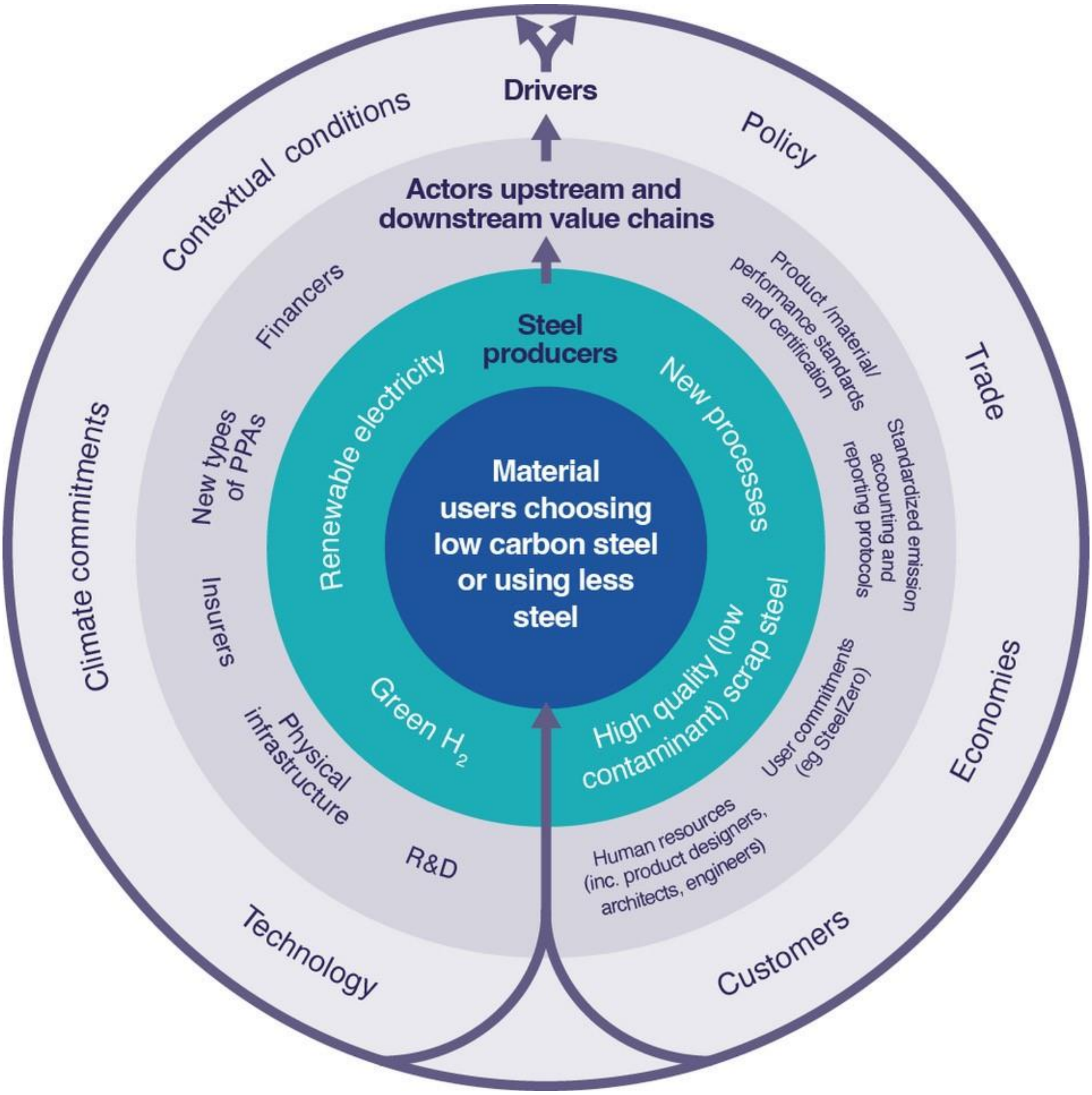
However, the UK would partially rely on imports from France, Germany, and Poland. Whilst existing biomass satisfaction from pulp and paper mills, heat and power producing plants, and sawmills was considered, future demand in a low carbon bioeconomy was not, eg to produce biofuels. Maximising biomass use in steel production across the UK and EU decreased emissions by 42 per cent. However, it was only enabled with a carbon tax of 140 EUR/t, which increased steel production costs by 50 per cent. The economic viability of biomass use in steel production will be a significant barrier to uptake.

5. How could demand-led innovation support steel industry decarbonisation?

Typically, 'demand' in the steel industry is considered to be the end-user of the final steel-containing product, but this definition is narrow. We broaden this definition to include the whole steel industry value chain, creating a more holistic view of demand-led innovation (refer to Fig 3). For instance, automotive manufacturers who are keen to reduce the embodied emissions of their products create demand for automotive manufacturing components that are made of low-CO_2 steel, which then incentivises intermediate product manufacturers to use low-CO_2 steel instead of more carbon intensive steel. This translates into demand from steel producers for low carbon production technologies (such as Electric Arc Furnaces) and inputs (eg renewable electricity and green hydrogen) and transition financing.

This demand from the steel manufacturers, in turn, creates demand throughout the value chain, including the production of supporting infrastructure (eg solar panels, wind turbines, electrolysers, and upgraded power grids). The causal sequence is cyclical: the more significant the product demand, the greater the demand for raw and intermediate materials and supporting financing, physical and administrative infrastructure. This drives up the supply of low-CO_2 steel, leading to greater demand as supply chains become more efficient, economies of scale are realised, and costs decline, as explained in the technology learning curve example in Section 2.3 of the technical report (Markkanen, 2023). For low-CO_2 steel production to operate successfully at a large scale, actors across the whole value chain must be aligned, working in parallel and in collaboration with each other to implement and sustain the low-CO_2 steel production ecosystem.

Figure 3: Steel demand ecosystem



Source: Developed by the authors drawing on available literature

The first movers in demanding low-CO_2 steel products have been in the automotive sector, such as Volvo (2022) and BMW (2022), who have sought to be the "first" in fossil-free vehicle manufacture. Yet the steel industry's demand markets are far more diverse; global steel consumption in 2021 totalled 1,839 Mt (WSA, 2023b), split between buildings and infrastructure (52 per cent), mechanical equipment (16 per cent), automotive (12 per cent), metal products (10 per cent), other transport (5 per cent), electrical equipment (3 per cent) and domestic appliances (2 per cent). Stimulating demand for low-CO_2 steel in all steel-consuming industries, especially construction, is vital to create economies of scale to reduce the per unit manufacturing cost of low-CO_2 steel.

The building industry has already made meaningful progress. Lifecycle assessment standards and certifications for low carbon buildings governed by the UK Green Building Council (UKGBC, 2023) and Building Research Establishment (BRE, 2023) (who implement BREEAM) support demand for low embodied carbon assets. Collective action industry groups are also emerging and growing, such as the UK's Better Buildings Partnership (BBP, 2023) for property owners who seek to construct more sustainable commercial buildings. In May 2022, the UK's first Net Zero Carbon Buildings Standard was launched to determine a single, agreed methodology to account for built asset emissions, championed by UKGBC, BRE, BBP, the Royal Institute of British Architects, and the Carbon Trust, among others (NZC Buildings, 2023). The following case study also provides an example of how collaboration across the supply chain could support low carbon innovation through product standards.

Case study 3: Tata Steel – Innovation in construction products

Tata Steel UK (TSUK) produces ~3.6 million tonnes of steel a year, primarily for the automotive, engineering, packaging and construction sectors. More than 50 per cent of TSUK's steel is destined for the construction sector.

TSUK is committed to sign up to the Science Based Targets initiative (SBTi) and aims to be a net zero steelmaker by 2045. The company is also seeking ResponsibleSteel certification for its primary UK steelmaking site at Port Talbot in South Wales. It is also engaging with its downstream supply chains to support the design, adaptation or development of new products to help their customers reduce their environmental impact.

For several years, TSUK has worked with the automotive sector to improve productivity and material efficiency by driving standardisation in developing vehicle platforms, with excellent results. However, the construction sector supply chain has been slower to adopt new practices, and driving change in this sector has been challenging. In order for the construction sector to achieve similar progress to that made in the automotive sector, change is needed in three main areas:

1) Collaboration and standardisation, ie developing standard ways of reporting and costing buildings, shared data templates or passports, and common designs.
2) Finding ways to demonstrate the ability to manufacture safely offsite with rapid onsite manufacturing style assembly.
3) Demonstrating the benefits of designing and building with the waste hierarchy truly reflected in any building assessment from cradle to cradle (reduce, reuse, recycle).

These challenges are all addressed in the SEISMIC project (Specific, 2022), which was set up in 2020 to develop a platform-based construction approach. This approach enables standardised building components to be used in construction at scale and offsite, across unrelated projects. For example, a component designed in the same way can be used for a school, a hospital or a prison. It also enables faster adoption of new technologies and manufacturing solutions as they become available.

The SEISMIC approach was initially developed in response to the Department for Education aspiration to improve the construction of schools, focusing on the design of a standardised, lightweight steel frame and universal connector block. A second phase of the project involved designing and constructing core components to work with the frame system, including wall, floor, ceiling and roof cassettes, offering an 'all-in-one' solution for customers.

The SEISMIC approach was designed to meet the UK government's Construction 2025 targets, which it already exceeds, making it possible to complete a building 75 per cent faster than traditional methods allow, and with a 70 per cent lower carbon impact and 47 per cent better value. These achievements have been enabled by the consortium structure of the project, with three manufacturers working independently on the same building. The demonstrator building shows this to good effect, incorporating systems from the McAvoy Group, the Elliott Group and TSUK.

Multiple global initiatives also exist to stimulate demand for low carbon industrial materials, including the Clean Energy Ministerial's Industrial Deep Decarbonisation Initiative (IDDI) (Clean Energy Ministerial, 2023). The IDDI is a collaboration of national governments co-led by the UK and India, which works to stimulate demand for low carbon industrial materials by standardising carbon accounting methods, establishing ambitious private and public procurement targets, and incentivising project investments. The following case study profiles a similar initiative called SteelZero, which is a broad-based collaborative initiative between industry stakeholders from across the value chain as well non-profit organisations. The initiative seeks to accelerate decarbonisation within the steel industry by promoting adherence to standardised net-zero standards.

Case study 4: SteelZero – A demand-side business initiative

SteelZero is a global demand-side steel industry decarbonisation initiative led by the international non-profit organisation Climate Group and run in partnership with ResponsibleSteel, a non-profit multi-stakeholder standard and certification programme.

SteelZero brings together leading organisations across the entire steel value chain to speed up the transition to a net zero steel industry. Businesses that join SteelZero make a commitment to use, buy or specify net zero steel by 2050, with an interim commitment of using 50 per cent responsibly produced steel by 2030. Collectively, SteelZero sends a strong demand signal for net zero steel, shifting global markets and policies towards responsible production and sourcing of steel. The membership in February 2023 was 31 companies – and forecast to grow – including: international construction firms such as Mace Group, Lendlease and Skanska; the automotive maker Volvo Cars; Siemens Gamesa from the renewable energy sector; and the global shipping giant Maersk.

The partnership with ResponsibleSteel is central to the commitment. ResponsibleSteel is the industry's first global multi-stakeholder standard and certification initiative. With members from every stage of the steel supply chain, ResponsibleSteel is developing an independent certification standard to assure businesses and consumers that the steel they use has been sourced and produced responsibly at every stage. For SteelZero members, purchasing ResponsibleSteel-certified steel is one key pathway to achieving their 2030 and 2050 commitments. ResponsibleSteel certification is also playing a crucial role in defining a global standard and definition for 'net zero' steel, which is needed to speed up the global transition to net zero steel, as outlined by SteelZero in May 2022 (Climate Group, 2022).

SteelZero is following the same model as other Climate Group demand-side initiatives, such as RE100, which brings together businesses committed to 100 per cent renewable electricity. When RE100 launched in 2014, the cost of renewable electricity was prohibitive for many companies. Now, more than 300 RE100 members represent an electricity demand greater than the UK or Italy, fast-tracking the global transition to zero carbon grids. Climate Group holds similar ambitions for SteelZero, which is gaining traction. When British Steel announced that it would be adopting science-based targets in 2021, it cited SteelZero as a critical factor in driving this transformative decision. The SteelZero commitment framework has also been partially adopted by a climate-focused European investors group, which is looking at integrating it into their own engagements with their members, showing the strength and reach of the SteelZero initiative all along the value chain. Given that we have less than ten years to halve global carbon emissions to get the world on track to reach net zero by mid-century, this kind of engagement and innovation across the value chain is vital and urgently needed.

Customer relationships are crucial in supporting steel industrial decarbonisation, especially when green premiums exist. The main consumer-facing steel-containing products are buildings, vehicles, and food containers, which are stirred by market expectations to decarbonise production supply chains. The demand for low-CO_2 steel can stem from multiple internal and external drivers and is not necessarily the same across different uses and user groups. For example, buyers of top-tier cars may be willing to pay more for a zero-carbon vehicle. However, governments (and, therefore, taxpayers) may be less prepared to pay such a premium for a zero-carbon bridge, tunnel or school. Subsequently, policy and regulation will be critical enablers to shift business-as-usual in steel-consuming industries.

6. Conclusions

Strong demand-side signals are needed to support the effective and efficient decarbonisation of the UK steel industry. These signals must flow through the entire value chain and all sectors that use large quantities of steel (such as construction, transport, appliances, and the intermediate products going into the manufacturing processes). This, in turn, will support the development of low carbon, resource-efficient steel markets. To cultivate and sustain a reinforcing loop between value chain actors who push for sectorial decarbonisation, strategic innovation and policy mechanisms are called upon. We highlight some important ones below.

The following innovations will support the decarbonisation of the UK steel sector:

1. **Circular business models and supply chain collaboration.** Material efficiency in the steel sector can potentially reduce demand by 40 per cent (IPCC, 2022). This can be enabled by minimalist designs (reducing overdesign but also using reduced volumes of higher strength steel for the same application, eg light weighting vehicles), increasing product lifetimes, reusability, and recycling where contaminants are controlled. New business models are needed to enhance closed-loop material circularity in the steel sector to reduce the quantity of material required to serve the same function over the same period. Enhanced digitalisation and collaboration across value chains will support the circular economy.
2. **Build high quality scrap recycling competence.** The scrap-EAF route is a prime short-term opportunity for the UK, given the magnitude of scrap available and existing competence in producing high-quality steel products with almost 100 per cent scrap charging. Investments in R&D for high quality scrap recycling technology is required, to improve the robustness of scrap collection and decontamination. Technology innovation is required to improve steel recycling processes in removing impurities and retaining the iron-bearing material value.
3. **Increase renewable energy capacity and industrial process flexibility.** The anticipated switch from dominant fossil-based thermal energy demand to renewable electricity energy demand brings the challenge of managing variable renewable energy sources. Whilst firmed clean power, such as nuclear, has been proposed for UK's future energy mix (UK BEIS 2020), it is unlikely to play a big role. Hence managing variable renewable energy sources (solar and wind) with energy storage and industrial process flexibility is necessary. In the H2-DRI-EAF process, electrolysis for H_2 production can be flexible if electrolyser technology with rapid response capabilities, such as the Polymer electrolyte membrane (PEM) is selected. In addition, the EAF operates in batches so it does not need to be run continuously. This requires an industrial shift away from 24/7 production but may be necessary to reduce the costs of renewable-powered and electricity-intense steel production.
4. **Scale-up low-CO_2 technologies.** Public and/or private investment in a low-CO_2 steel production project is necessary to validate the technology's viability and build investor confidence. In the EU, 14 projects have been announced for hydrogen-based DRI, and a further eight for H2 injection into the BF, whilst in the, UK the number for both is zero (Energy & Climate Intelligence Unit 2021). The most viable decarbonised ore-based steelmaking route, according to a robust techno-economic model of low-CO_2 steelmaking routes in the UK, is the hydrogen-based DRI-EAF route, with a projected levelised cost of steel 19 per cent cheaper than the BF-BOF + CCS (Richardson-Barlow, et al., 2022). Hence, it makes economic sense to invest in at least a component of the H_2-DRI-EAF supply chain to start growing domestic competence in technology use.
5. **Establish transnational green steel supply chain alliances.** Especially if the UK chooses the option of partial offshoring, transnational agreements with first-moving countries building an export industry for low carbon H_2 and/or HBI must be a priority. In such circumstances, there should be a consensus on the classification of 'low carbon' steel, the emissions measurement methodology, carbon prices and trade relationships.

The following policies will support the decarbonisation of the UK steel sector:

1. **Targeted procurement policies.** The vast quantities of steel-containing products purchased by downstream sectors must meet the demands of private and public sector clients, including the embodied carbon value. The UK Government, which funds the majority of infrastructure projects in which large quantities of steel are consumed, should lead the way in mandating low-CO_2 steel, measured by emission factor and/or recycled content. Procurement policies may also mandate a minimum amount of UK-produced steel to protect local industry against cheap imports, alongside anti-dumping policies. The struggle to compete against cheap steel imports is not unique to the UK. It is also felt by the US and EU steel sectors. We must provide steel manufacturers with assurance of demand to invest in decarbonised technology and practices.

2. **Consistent, cross-border carbon pricing.** A consistent, effective carbon price for all steel producers is necessary to level the playing field. The current effective carbon price (levied carbon price minus compensation) paid by BF-BOF steel producers in the UK is less than that paid by EAF steel producers (Allwood, et al., 2019). Given the global nature of steel markets, domestic climate policies must also consider trading partners to (i) assure market competitiveness and (ii) reduce the risk of carbon leakage. One carbon policy solution would be to impose comparable penalties to those of the UK carbon price also on imported products based on their embodied carbon content through a UK Carbon Borden Adjustment Mechanism (CBAM). It has been argued that a CBAM would benefit the UK steel sector by increasing steel import prices (UK Steel 2022). Positively, for consumers of steel further down the value chain, the added costs burdens of a CBAM would likely be minor; at £100/t CO_2, the average car could cost an extra £150-200 to produce, that's two per cent of the selling price. However, because of the necessary phasing out of free ETS allowances, a CBAM would decrease the competitiveness of UK exports of steel and steel-containing products in jurisdictions that do not have comparable carbon prices. Revenue from carbon pricing schemes should be fed into industrial decarbonisation support.

3. Fair and visible lifecycle emissions accounting
To support carbon pricing, strong industrial regulations must be enforced for embodied carbon certification within steel products, and a standard global emissions accounting method agreed upon that covers the entire product lifecycle. Lifecycle analysis methodologies and inventories must be consistent across the global market, especially regarding boundary definition and input data for emissions accounting tools. Alongside transparent embodied carbon declarations, publicly-available supply chain information should be mandated and normalised in annual company reports.

4. **Cap industrial electricity tariffs**. A fair price on electricity is required to enable today's scrap-based EAF steelmaking facilities to regain market competitiveness and future electricity-intense steel production to obtain an investable business case. The recent subsidies available to UK steel producers under the Energy Bill Relief Scheme, which capped electricity prices at £211/MWh for businesses for six months up until March 2023, were insufficient in effectively addressing the high electricity costs and providing long-term certainty for industry (The Guardian 2022). With larger shares of renewably sourced power replacing fossil-fuelled power in the national grid, an electricity market reform is called upon. An analysis of UK steel production economics showed that a reliable renewable electricity price of £50/MWh would make scrap-EAF production cheaper than relining a blast furnace. With a carbon price of £70/t CO_2, the H_2-DRI-EAF route will also become cheaper (Green Alliance 2022). Reliable, affordable, and renewable electricity supply is essential for the successful decarbonisation of the UK steel sector.

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