

Steel Arising



Opportunities for the UK in a transforming global steel industry



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Opportunities for the UK in a transforming global steel industry

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The authors of this report, based at the University of Cambridge, are part of a group that, for ten years been, has been funded by the UK's Engineering and Physical Sciences Research Council to undertake research into mitigating the climate change impacts of Industry, with a particular focus on the strategy of Material Efficiency. A previous report "A Bright Future for UK Steel" in April 2016, argued that there could be a bright future for a reborn UK steel industry, focused on recycling steel to high quality and integrating the steel makers with their downstream

supply chain. This new report builds on the earlier one with an expanded analysis of the opportunity for UK innovation and leadership.

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Cover image:

Sculpture of Solfar or Sun Voyager by the sea in the center of Reykjavik, Iceland. Designed by Jon Gunnar Arnason in stainless steel in 1971

Executive Summary

The global steel industry is transforming from using iron ore to recycling scrap. Global arisings of steel scrap are likely to treble in the next thirty years and we will never need more blast furnaces than we have today. The extent and speed of this global transformation depends on two competing forces: on the one hand, today's recycling technology cannot currently produce the highest qualities of high-volume steel economically; on the other, recycling has the critical advantage that it reduces the greenhouse gas emissions released in producing steel to around a third of those from primary production. As the steel industry turns from ore to scrap and action on climate change accelerates, what opportunities does this create for steel in the UK?

UK consumers currently demand around 15 million tonnes per year of steel in final goods. Although the UK's steel production has fallen to well below this figure, it manufactures goods containing around the same annual total. However, the UK largely exports its steel products and manufactured steel goods at low value, while importing most high-value final goods containing steel. Only one sixth of UK final consumption of steel goods is currently made with steel produced in the UK, and that is mainly lower value components for construction.

Despite this weak current position, the UK has four comparative advantages by which it could profit in the ongoing global transformation of steel production.

Firstly, as a mature steel economy, the UK currently generates around 10 million tonnes of scrap per year. This is mainly exported with little value-added at present, but if recognised as a strategic resource could be the feedstock for expanding domestic production.

Secondly, due to its active policies on climate change, the UK already has a comparably low emissions electricity grid, with potential for further improvement. Recycling steel in the UK today leads to a reduction in emissions of more than two-thirds compared to global average primary steel. This benefit will increase with more renewable generation capacity, and will be strategically important as global pressure to mitigate climate change increases.

Thirdly, with a long history of successful innovation in materials and materials processing technologies, the UK has a significant

advantage in developing technologies for high-quality, high-volume production from scrap to allow much more complete substitution with primary steel. There is a clear opportunity for technology innovation in this space that has not previously been exploited because steel scrap supplies have to date been completely absorbed by the lowest grade products. However, it is a certainty that global scrap supplies will treble, because all the steel made in the past will be recycled.

Finally, because of its relatively weak supply-chains, compared to the near European neighbours from which it imports most high-value steel goods, the UK is in a strong position to innovate with new business models and technologies that add more value to less steel. This is both commercially and environmentally attractive.

In order to exploit these advantages, businesses within the UK steel supply chain must seek new forms of vertical integration. While steel-makers produce undifferentiated globally-traded commodities, they face a race to the bottom, and cannot exploit the opportunities for value creation that would be found if they delivered completely fabricated buildings or car body parts, for example, rather than commodity feedstocks.

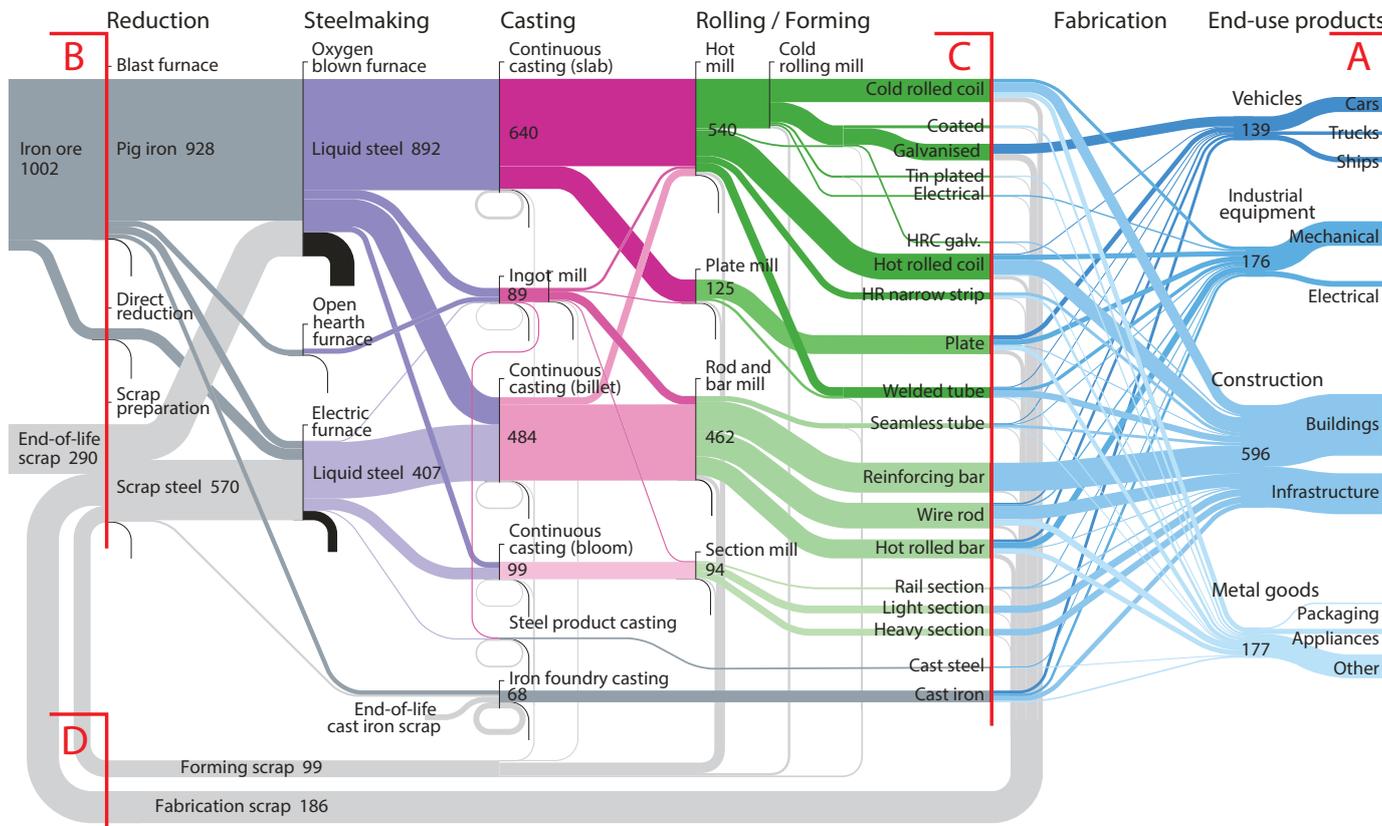
The UK government could support businesses in exploiting these advantages by combining steel energy and climate policy, by setting emissions reduction targets based on consumption rather than production, and by pulling the levers of technology, waste, trade and procurement policy to create the most favourable conditions for business innovation in adding most value to the least steel made by recycling.

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Global steel production and stocks

Figure 1: The “flow” of steel through the global economy in 2008 (units of million tonnes/year)



Steel is the world’s most used metal; we make over 200kg of liquid steel each year for every person on the planet. Figure 1 illustrates the ‘flow’ of steel through the world economy in 2008, with the width of each line proportional to the mass of steel produced. Since 2008, the volume of steel production has increased, but the proportions of the flows are broadly similar.

Four key points are marked on the figure:

- A. More than half of all steel is used in construction, with the other major uses being the manufacture of vehicles, industrial equipment and final goods.
- B. Roughly two thirds of today’s liquid steel is made from iron ore, with the rest made from scrap, but at present more than half of this scrap comes from the manufacturing process itself, rather than from end-of-life goods.
- C. The steel industry makes the intermediate products shown, and sells most of them through stockists to a complex downstream supply chain.
- D. A quarter of all the finished steel made each year (including half of all sheet steel) never makes it into an end-use product but is cut off and recycled. This is because final users want components (such as car doors) and not intermediate products (coils of strip steel).

Figure 2 shows predicted lifespans for new products made from steel. On average, steel goods last for 35-40 years, and are then scrapped. Apart from ~10% of steel used below the surface (for oil pipes or building foundations, for example) most end-of-life steel can be collected for recycling.

Figure 2: Life expectancy global end-use steel applications in 2008

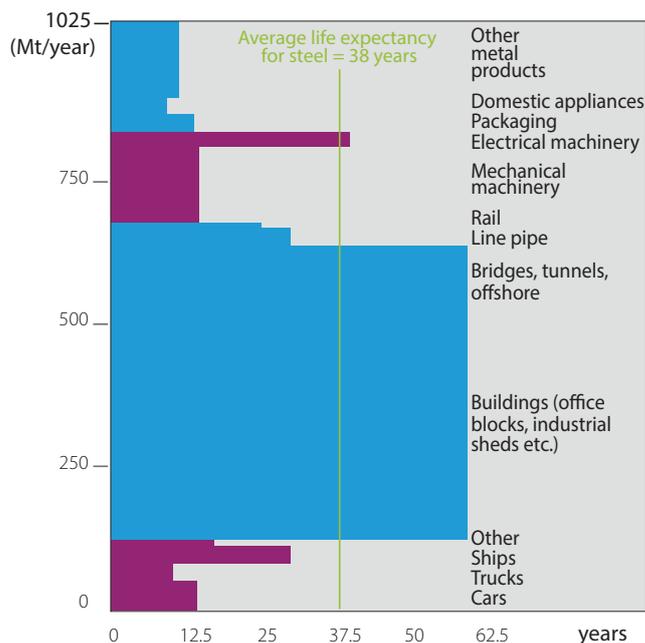
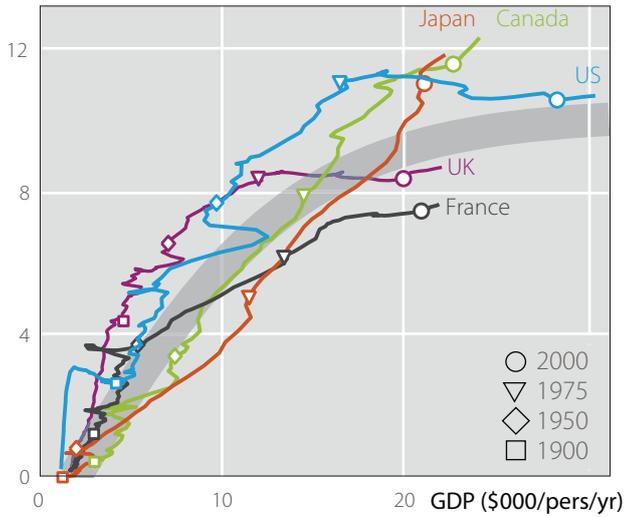


Figure 3: The stock of steel (tonnes/pers) rises with GDP/pers



Steel is traded globally. It is difficult to predict future demand from the history of production in any country. However, figure 3 shows estimates of the accumulated stock of steel in different countries. As countries become richer, their requirement for steel becomes predictable: once we have a stock of around 12 tonnes of steel per person, we need no more. Demand for steel after this 'stock-saturation' is for replacement not expansion.

This saturation, combined with the life-expectancies of figure 2, gives a basis for anticipating future demand: developed economies maintain stocks; developing economies expand their stocks to reach comparable levels. Following this logic, the upper line in figure 4 anticipates global demand for steel production over the next 30 years. The figure demonstrates a possible split between production of steel from iron ore and from scrap if most future scrap arisings are recycled. Total demand will increase, but if most old steel is recycled (in Electric Arc Furnaces) future growth could be met entirely through increased production from scrap.

Figure 4: Global steel output: primary and recycling (Mtonnes)

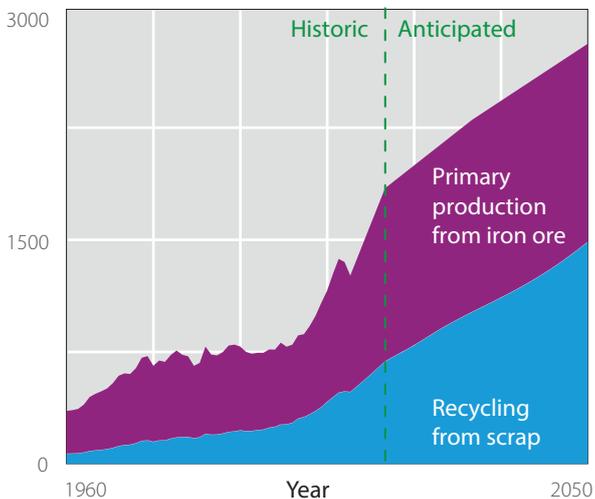
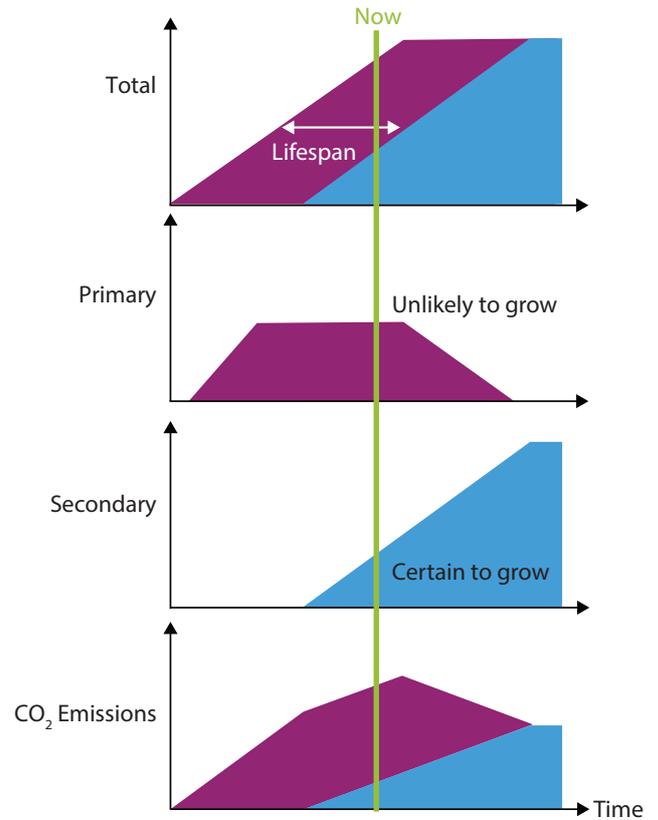


Figure 5: Simplified representation of future steel industry



The simplified pictures of Figure 5 illustrate a possible future for the global steel industry based on this logic.

Global steel demand will eventually reach a limit when steel stocks stabilise. Thereafter, the requirement for primary production could diminish to (nearly) zero, as future requirements are met by recycling. As a result, we can anticipate that the world already has all the blast furnaces it will ever need, but our need for steel recycling will grow substantially from the present. Steel recycling causes significantly less greenhouse gas emissions than blast furnaces. The balance between blast furnace and electric arc furnace production is therefore a critical driver of future emissions as illustrated in the last schematic of figure 5.

It will be difficult for European producers to compete in a global market for steel made by blast furnaces, particularly as the newest assets are in lower-labour cost countries (China and India). The situation will be made worse as Chinese requirements for blast-furnace steel reduce before their blast-furnaces expire, and in the face of planned new blast furnaces in India which will add 10% to current global capacity within the next five years. Producing commodity steel products using older blast furnaces in a region with high labour costs will be commercially challenging.

The economics of scrap steel

The analysis on the previous page demonstrates that the amount of scrap available for recycling globally is going to increase significantly in the next thirty years. How will this influence the structure of the global industry and is there an opportunity for comparative advantage in the UK?

The structure of the global industry will evolve depending on the relative prices of steel made from ore or scrap and the degree to which recycled steel can substitute for new steel. These features are explored here and used to develop a stylized model of future industry structure.

Iron ore, steel and steel scrap are traded globally in sufficient volumes that **short-run prices** are determined by market activity and are highly volatile. Steel prices reflect the immediate balance of supply and demand. Supply is constrained by current global capacity. Prices rise if demand increases ahead of capacity, but when demand falls, prices fall below their long run levels until sufficient plants close. Demand for steel is partially influenced by competition with cement which is the only material available in the same quantities, but is driven largely by economic development. Figures 6 and 7 show the

Figure 6: Profitability, capacity and output of global steel

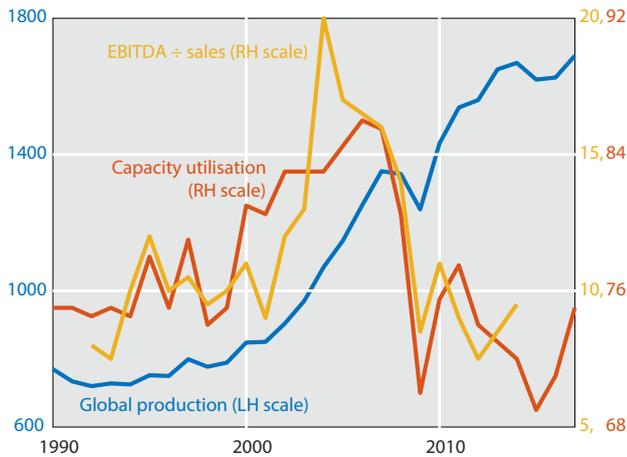
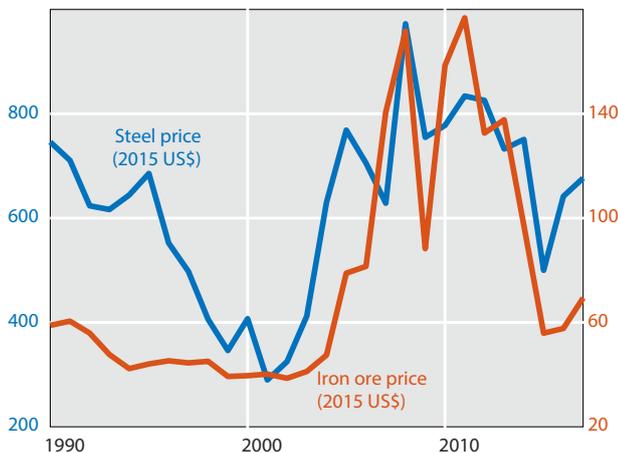


Figure 7: Real steel and iron ore prices track closely



effect of surging Chinese demand in the past two decades: as demand increased, capacity utilisation increased along with profitability (EBITDA). Once capacity was constrained, prices rose rapidly until new plants were brought on stream to meet expanded demand. Prices then fell to below previous long-run levels leading to the crisis of 2016.

Iron ore is subject to derived demand, with volumes and prices tracking steel demand as shown in Figure 7: the mining industry adjusts capacity and with abundant global supply of ore, **long-run prices of iron ore** appear to be relatively steady while their short run volatility reflects rapid resolution of supply and demand exacerbated by inventory holding.

Prices for steel scrap show a different behaviour. Volumes of “Home scrap” generated within the steel industry, and “New scrap” from downstream manufacturing equal about 20% of global steel production as shown in Figure 1. These are the most valuable forms of scrap: their metallic composition is known and they are often bought back by the steel industry in long-term contracts, and have relatively constant long-run prices. At higher prices, more end-of-life scrap is collected and returned for recycling.

The future structure of the global steel industry will largely be determined by the economics of scrap. However, there is in addition a **technical constraint** on the extent to which scrap can be substituted for ore. When scrap prices are low, easy-to-collect scrap will be recycled, in particular from construction and demolition. This source of scrap tends to have large pieces with well controlled composition. At higher prices, scrap will also be sourced from mixed waste streams, with higher levels of contamination. Imperfect control of metal composition in scrap steel collection and limits to today’s technologies for adjusting the composition of liquid steel restrict the degree to which recycled steel can be substituted for primary steel.

The competing forces of these economic and technical constraints are illustrated in the **stylized model** of figure 8. The model assumes long-run pricing and that the costs of labour, energy, capital and other inputs are fixed. Unused scrap is accumulated in an inventory. Global demand follows

Figure 8: Stylised model of the global steel industry

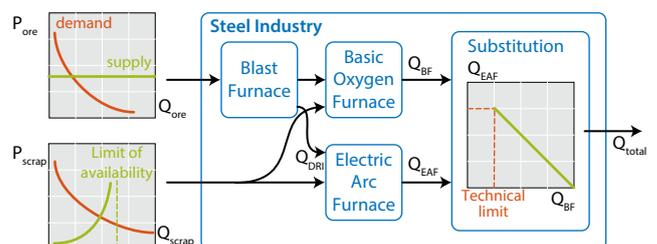


Figure 9: Model predicted volumes (Mt/yr)

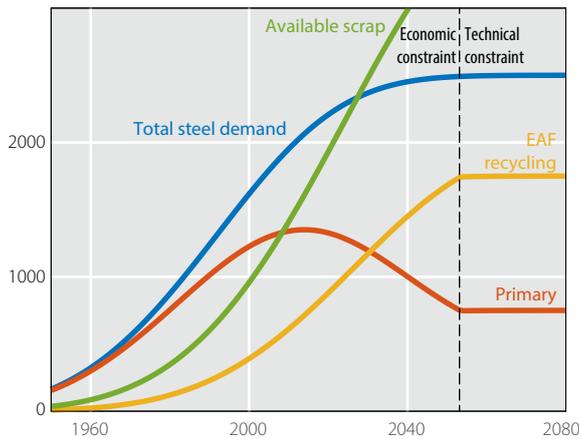
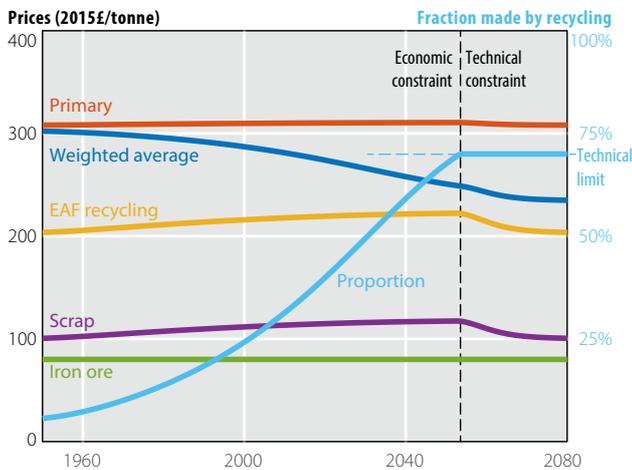


Figure 10: Model predicted prices and proportions



a pattern derived from the analysis on page 3. Steel made from scrap in electric arc furnaces is assumed to be a perfect substitute for steel from the primary blast furnace route up to a technical limit and the relative proportions of the two forms of production is found by cost minimisation. Cost and price data have been estimated from several sources to be approximately representative of 2014-15 but model outputs are intended more as indicators of trends than as quantitative predictions.

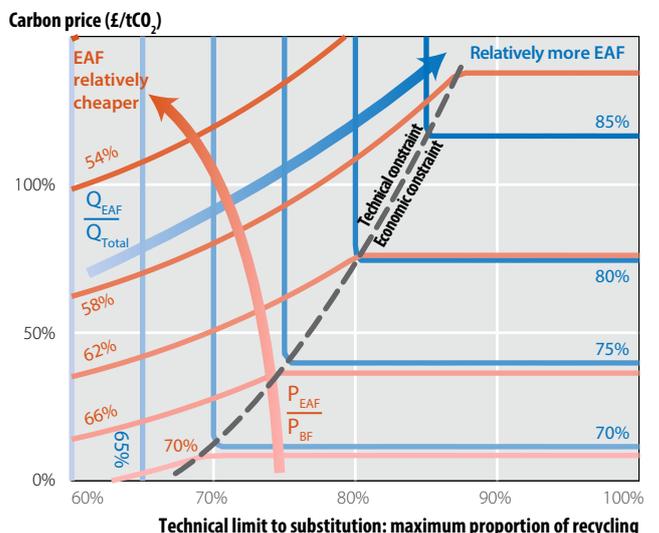
Figure 9 shows that, as expected, the increased availability of scrap drives a global shift from blast furnace to electric arc furnace production. Despite being perfect substitutes, the prices of primary and recycled scrap are not the same: if one further tonne of steel is made by recycling, the weighted average price reduces by the difference in primary and recycled steel, but increases as the price of scrap rises with increased demand. As a result, the shift to recycling does not match the availability of scrap and the figure demonstrates an accumulation of unused scrap. Eventually, Figure 9 shows that the technical limit of figure 8 constraints the growth of recycling: in this case, 30% of demand must be met by primary production due to quality limits in recycled steel.

Figure 10 shows how this development affects prices. As more scrap becomes available, electric arc furnace capacity increases and scrap prices rise as demand approaches the limit of scrap availability. However, once the technical constraint on substitution is reached, scrap prices fall due to excess supply.

As scrap availability increases, growth in global recycling will be constrained by price up to a technical limit of substitutability. Additionally, in future, the prices of all forms of steel will increasingly be affected by action on climate change. Recycling steel produces around a third of the CO₂ emissions of primary steel. Figure 11 presents a sensitivity analysis performed with the model to show how innovation to improve the technical limit to substitution and action on climate mitigation (represented as a price on CO₂) will affect the future structure (in 2050) of the global steel industry. The proportion of recycling rises and the relative price of recycled steel falls as the technical limit to substitution improves and the price of carbon increases. However, for any carbon price, the proportion of recycling will increase with the technical limit only to the point that the economic constraint dominates, and any further increase in recycling would raise average prices.

The indicative model is for the global industry, but raises key questions about the future of steel in the UK which are pursued in the rest of this report: to what extent could the UK's demand for steel intensive goods be met by recycling our own scrap? How could climate policy influence the UK's steel strategy? Can the UK profit through technology innovation in recycling quality? Could high quality recycling lead to profitable innovation in steel supply chains and what strategic actions can UK actors take to support a strong and transformed future domestic steel industry? These questions set the agenda for the rest of this report.

Figure 11: Sensitivity of proportions of production and relative price of recycled steel in 2050 to technical limit and carbon price

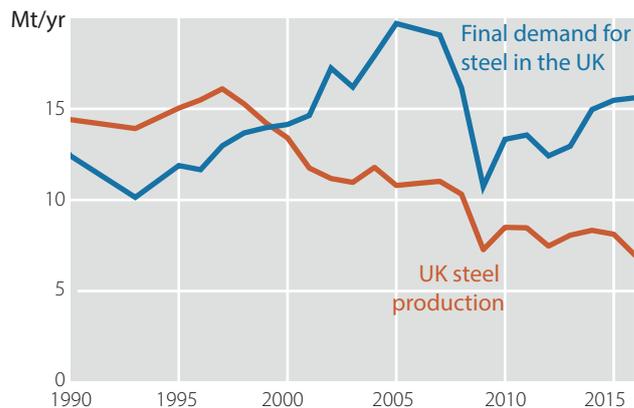


Steel supply and demand in the UK

To what extent could the UK's demand for steel intensive goods be met by recycling our own scrap? The evidence on this page addresses this question by comparing volumes of end-of-life steel and demand for new steel goods in the UK and by examining the national and international supply chains in which steel is created, transformed and purchased in the UK.

Figure 12 shows that since 1990, the UK's production of steel has continued the long decline that has followed peak output in the late 1970's. Output today is about half that of 1990, and comes mainly from the blast furnaces of Tata Steel in Port Talbot and British Steel in Scunthorpe and the electric arc furnaces of Celsa Steel in Cardiff and Liberty Speciality Steels in Rotherham. This decline is unrelated to our demand for the buildings, infrastructure, vehicles, equipment and goods in figure 1. The UK's total demand for steel in finished goods has varied between 10 and 20 Mt since 1990 and since around 1960 has averaged around 15Mt per year. As our production has fallen, our dependence on imports has increased.

Figure 12: UK Steel consumption grows while production falls



In order to examine the destiny of the UK's steel production and the origins of its consumption, Figure 13 presents a snapshot of a comprehensive new analysis prepared for this report. The figure shows how UK final demand is met from imported goods and domestic manufacturing and how

Figure 13: Production, Consumption, Import and Export of steel, components and final goods in the UK in 2016

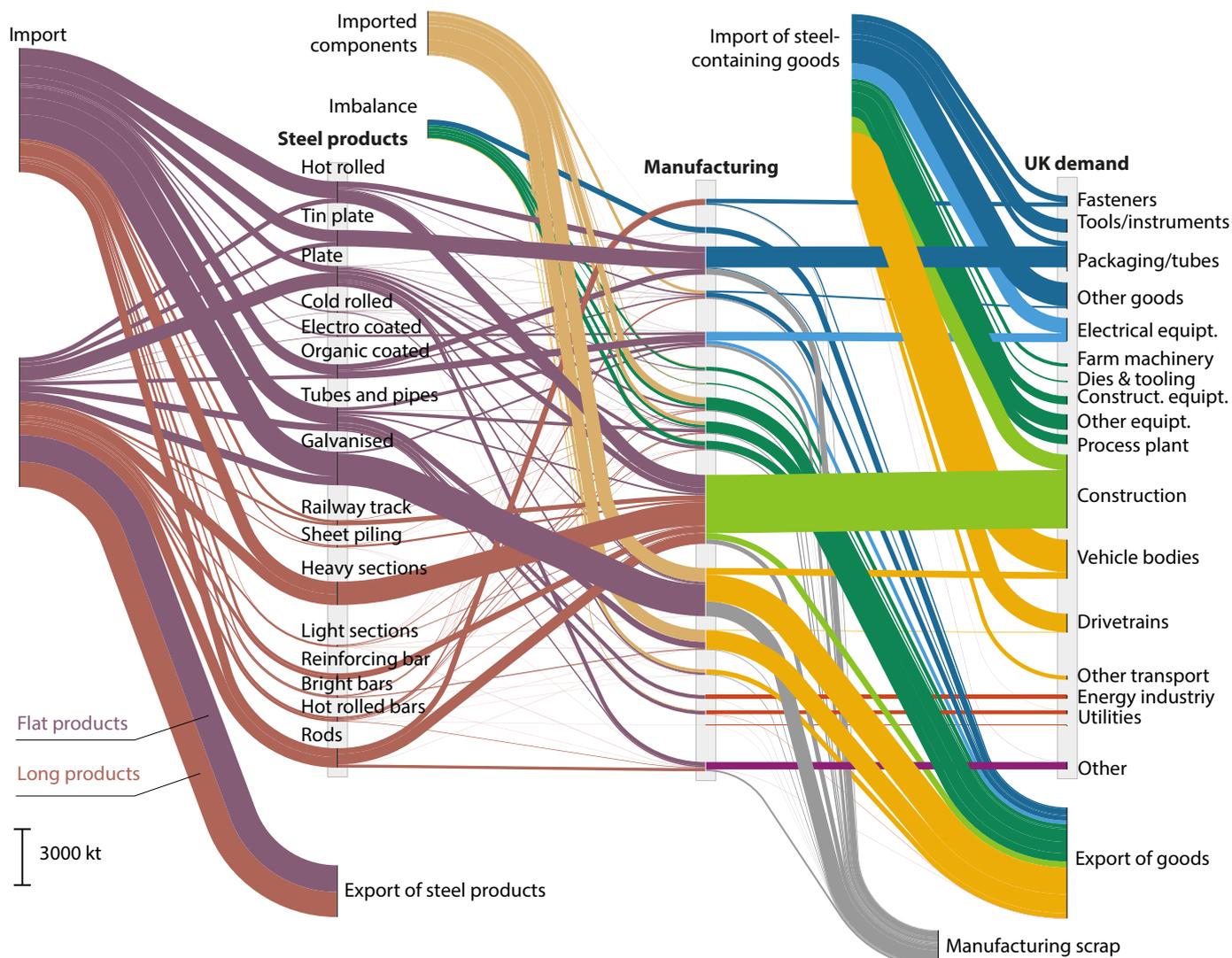
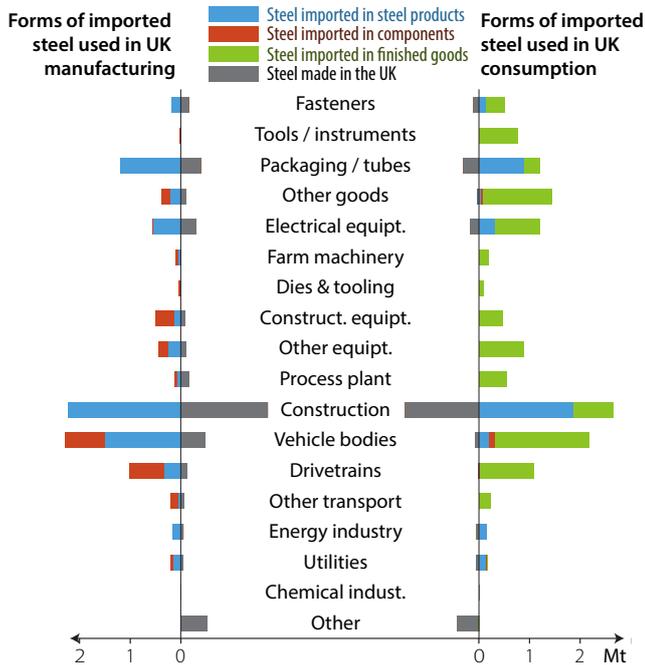


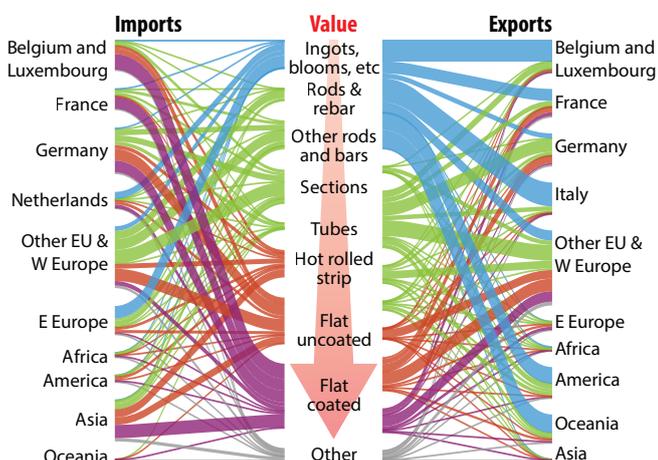
Figure 14: Forms of imported steel in UK manufacturing and final consumption in 2016



domestic manufacturing relies on domestic and imported components and steel. The figure reveals how much of domestic manufacture is itself exported, largely as cars and equipment even though UK production of these goods would be sufficient to meet domestic demand, most of which is instead imported.

Tracing the origin and destinations of steel across this map, Figure 14 reveals that, except for steel used in construction or pipelines, most UK manufacturing involves the conversion of imported steel products (the intermediate goods, such as bars and plate produced by the steel industry) and most UK consumption is imported as finished goods. This suggests a significant structural weakness in UK supply chains, which is underlined by the summary of trade in Figure 15: the UK largely

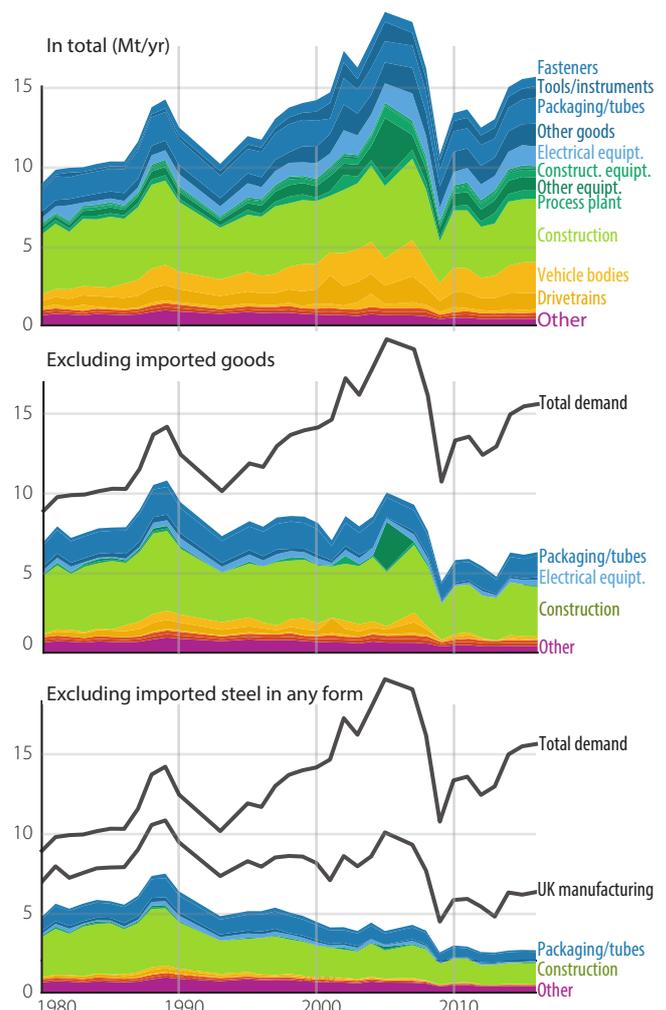
Figure 15: UK steel imports and exports



exports low value steel products (ingots or blooms) while it largely imports those of higher value (strip products). The UK mainly trades steel with European countries with comparable labour costs but even though UK steel production is equal to half of our final demand, we do not currently meet our own needs for high-value goods, because we are producing and exporting at the lowest value.

Figure 16, which compiles a summary of 36 annual snapshots of the form of Figure 13, shows that since 1980, domestic manufacturing with domestically produced steel has met an ever-shrinking fraction of our relatively steady demand for steel in final goods. This figure reflects the widely understood shift of the UK economy away from production towards services, but also clearly delimits an opportunity arising from the global transformation towards steel made by recycling. If the UK expands its capacity to transform its own scrap into high quality steel, this new supply of steel could be connected to a renaissance of UK manufacturing targeting evolving domestic consumption for high-value goods.

Figure 16: UK demand for steel in 2016



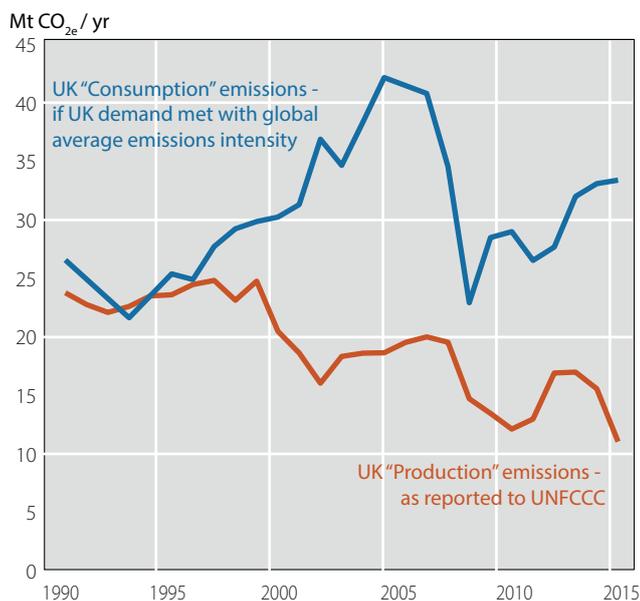
Steel and UK Climate Mitigation

How could action on climate change influence the UK's steel strategy? This question depends firstly on the way in which UK policy takes responsibility for emissions associated with steel production, secondly on the emissions intensity of producing steel from iron ore or scrap, and thirdly on the UK's future balance between primary production and recycling.

Globally, the steel industry emits 25% of all industrial greenhouse gases – more than any other industrial sector. Our choices about the future of the sector are therefore central to our choices about mitigating climate change. Concern about climate change is growing: the 2015 Paris Agreement aiming to limit warming to no more than 1.5° above pre-industrial temperatures has had widespread approval although the consequent requirement that net global emissions reduce to zero by 2050 is far beyond any current planning. Within the UK, the commitment of the UK Climate Change Act to cutting domestic emissions by 80% from 1990 to 2050 is less severe, but nevertheless requires a dramatic reconfiguration of the economy within thirty years. This period is shorter than the asset-life of many steel plants so today's strategic decisions about steel should account for the likelihood that as public concern over the impacts of climate change grows, these mitigation targets will be translated into increasingly demanding laws and regulations.

The UK's Climate Change Act addresses our production emissions only – those which are released from within UK borders. This leads to a clear anomaly in planning for a low carbon industrial future. Figure 17 takes the data from Figure 12 on UK production and consumption of steel and translates them into emissions figures. The figure clearly demonstrates the illusion of current UK policy: closing steel plants in the

Figure 17: UK steel emissions - production and consumption



UK apparently leads to a reduction in our emissions, while in reality our emissions are linked to our demand for steel, and may be higher if the emissions intensity of steel production in other countries is greater than that in the UK. UK policy could deliver a more effective contribution to global mitigation if instead it promoted lower emitting forms of steel production, and reaped the benefit of the required innovations.

The future emissions intensity of the two main routes to producing steel – primary production from iron ore and recycling scrap – will determine the best pathway to delivering steel in a low carbon future. The primary steel industry today has limited scope for mitigation by energy efficiency, due to its successes in the past. Figure 18 shows how the global average energy intensity of steel making has halved since the last major innovation in the 1960's (the basic oxygen furnace described on page 4) due to global efforts to reduce costs. A third of steel-making costs are in purchasing energy and as a result the average energy intensity of steel making is now within 10% of best practice and best practice is just double the unattainable absolute theoretical limit. No other industry operates so close to its theoretical performance limit. As a result, the emissions of making new steel from iron ore have similarly converged to a global average of 2.1 tonnes of CO₂ per tonne of crude (liquid) steel. The largest variation in emissions performance arises from the fraction of scrap charged to the basic oxygen furnace, and as this has been maximised in the UK, domestic blast-furnace emissions per tonne of liquid steel are lower than the global average (as shown in the upper two bars of Figure 19.)

Primary steel makers today, who recognise the serious implications of future greenhouse gas emissions, have made extensive efforts to identify technologies that will allow primary production to continue with reduced emissions. These centre on carbon capture and storage (separating CO₂

Figure 18: Energy intensity of global steel production

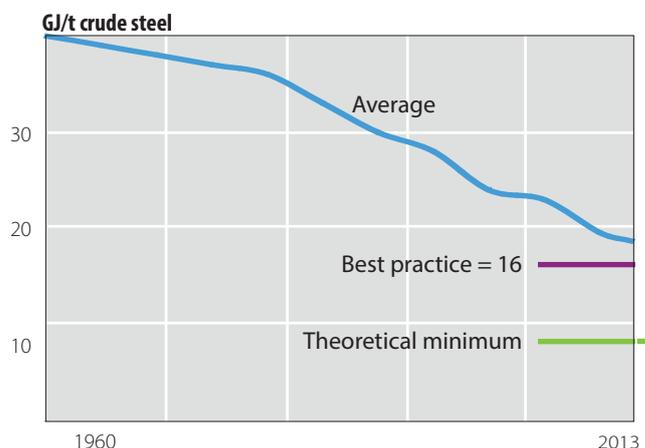
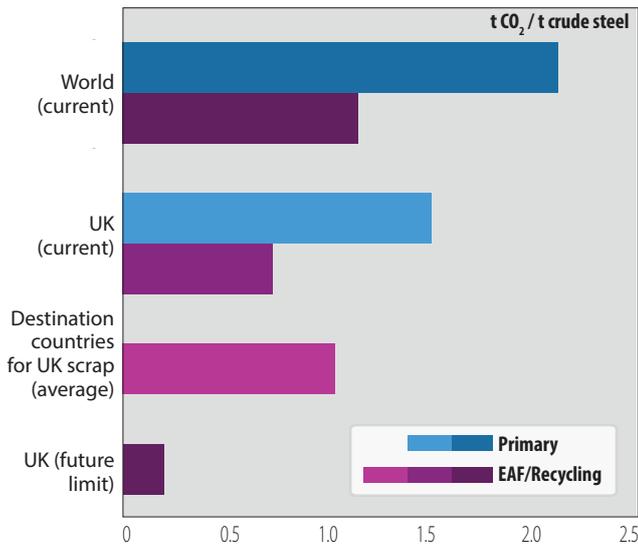


Figure 19: CO₂ emissions for steel production

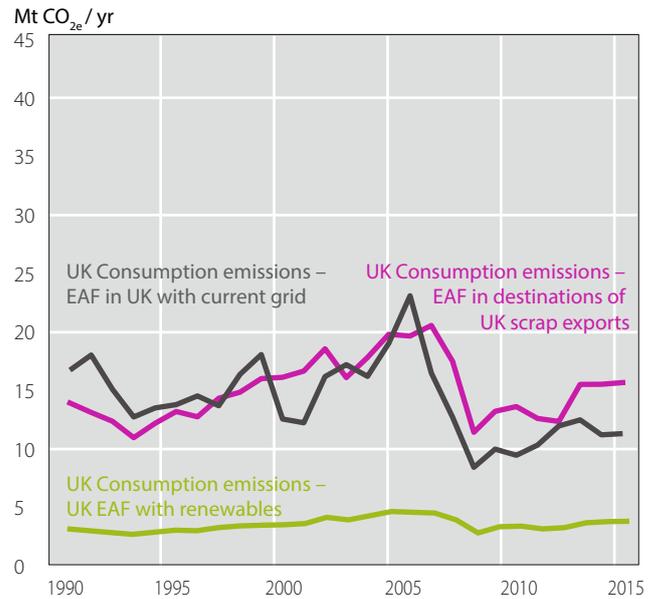


from other exhaust gases, compressing it and pumping it far underground into long-term storage), and carbon capture and utilisation in which a large external supply of electricity may allow the conversion of CO₂ into other forms, for example as a pre-cursor for plastics. Both of these options are important development projects. However, both are energy intensive so viable only if there is an excess supply of low carbon electricity, and both require major capital investment in plant and infrastructure. It is unlikely that these technologies will operate at a significant global scale within the time-scales required by the Paris Agreement or the UK Climate Change Act.

As with primary production, the energy-intensity of steel recycling is close to a limit, but the emissions associated with electric-arc furnaces vary according to the emissions intensity of local electricity generation. It takes approximately 2 MWh of electricity to process a tonne of scrap steel in an electric arc furnace, and Figure 19 demonstrates how this requirement translates to emissions per tonne of steel. The figure shows (in purple) the emissions intensity of steel making with current UK and world average electricity intensities (365 and 574 gCO₂/kWh respectively), the weighted average intensity of Turkey, India, Spain and Pakistan (where 65% of UK scrap steel is currently exported for recycling, 517 gCO₂/kWh) and a nominal future UK figure of 100 gCO₂/kWh if steel recycling could be powered by renewables in the UK.

Figure 19 also shows that global emissions would be lower if UK final demand were met by UK blast furnaces rather than those elsewhere. However, the lower bars in the figure show how much lower these emissions could be if UK recycling of its own scrap could deliver sufficiently high-quality steel to satisfy domestic demand in a closed loop. Figure 20, using the same scale as Figure 17, demonstrates how these idealised emissions

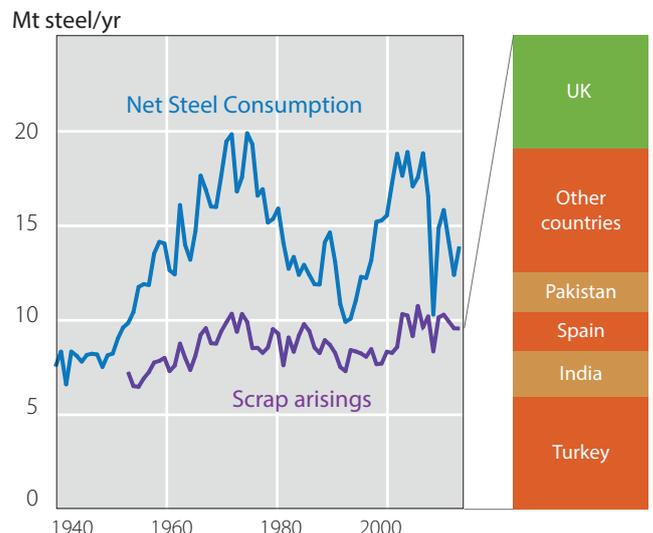
Figure 20: UK Iron and Steel emissions by various measures



intensities for recycling could have transformed recent UK steel consumption emissions, presenting a clear incentive to future development. Figure 21 shows how UK scrap arisings currently lag consumption, so will surely rise, and includes a breakdown of the destination of UK scrap today.

Is it possible to exploit the strategic resource of UK steel scrap to supply domestic consumption? The answer depends on whether we can develop technologies to make high quality steel from recycled scrap and whether we can develop innovative business models to allow downstream steel supply-chains to thrive in the UK. These two questions are addressed in the next two sections.

Figure 21: UK steel consumption, scrap and scrap destinations



Innovation for higher quality recycling

Can we develop technologies to make high quality steel from recycled scrap? Most recycling of end-of-life steel today is to produce reinforcing bars for construction, products that require high strength but have no aesthetic requirement. In contrast, in America, around half of all domestic steel demand is made by recycling domestic scrap. To explore whether recycling could supply more of our future demand for steel, we need to examine the causes of contamination that currently downgrade the quality of recycled steel and the opportunities to control the composition of liquid recycled steel.

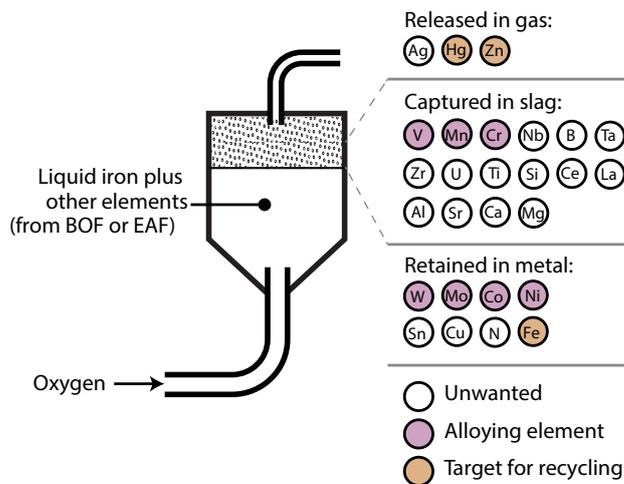
The word “steel” describes not one metal, but a whole family of alloys based on iron. Pure iron is a soft metal that would have few practical uses – you can tie a knot in a bar of pure iron. Instead steel-makers add small amounts of carbon and other metallic elements in precisely measured quantities to achieve the strength and other properties of today’s steels. It is currently possible to control steel composition precisely, only because the blast furnace and basic oxygen furnace of primary production create pure liquid iron, so that alloying is a matter of adding other pure elements to the pure iron.

In recycling steel, the input material is less pure. The degree of contamination depends both on the source of scrap and the economic incentive paid to the recycling industry to sort it. At present in the UK, scrap is sold in five main categories as shown in table 1. The least contaminated, “home” scrap, is the 20% of annual steel production cut off in manufacturing so is generally not mixed with other metals. Large scrap from construction demolition sites, typically steel girders, is also generally well separated, while the output of car shredders will have a complex composition including many other metals.

Figure 1 shows that scrap steel is recycled by two routes. Around a third of today’s scrap, often the better sorted material from table 1, is added to the basic oxygen furnace to reduce its temperature. Using scrap in this way reduces the emissions per unit of steel produced, but the amount of scrap that can be used is constrained by the available excess heat. Typically, the charge comprises 85% pig iron from the blast furnace and 15% scrap.

Scrap Type	Copper concentration (weight %)
Home / prompt scrap	<0.1
Construction scrap	0.1
Shredded scrap (vehicles)	~0.3
Machine scrap	0.25
Metal goods scrap	0.4

Figure 22: The effect of purifying liquid steel with oxygen

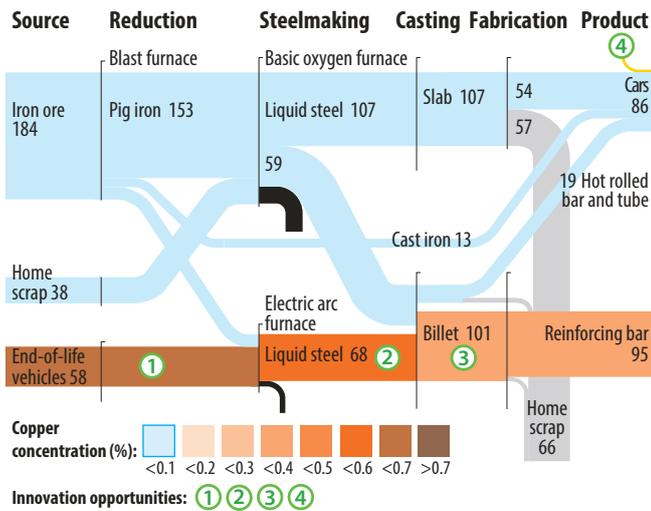


Most scrap however is recycled in electric arc furnaces in which a powerful electric current passes through the scrap to create an intense local lightning storm that burns off unwanted non-metallic material and melts the steel. This process leads to a crucible of liquid metal containing all the metallic elements in the scrap. The liquid is purified by a similar process to that of the basic oxygen furnace: minerals are added to the liquid to attract some unwanted elements into a slag that floats above the iron-based liquid and oxygen is blown through the melt.

The effect of using slag and oxygen to purify steel is summarised in Figure 22. Three elements including mercury and zinc are blown out of the liquid as gas, and captured. Many other elements are captured in the slag which is reprocessed to extract some of their value. Seven elements remain in the liquid. Of these, Tungsten, Molybdenum, Cobalt and Nickel are used as alloying elements so can be accommodated easily. However, nitrogen absorbed from the air causes small unwanted bubbles in the steel, and tin and copper both lead to the unwanted property of hot-shortening: steel containing even small amounts of these metals will show small surface cracks that degrade its performance.

The problem of contamination in steel recycling is illustrated in figure 23. New cars are made from primary steel with no copper contamination, allowing production of high-performance components by ductile forming. Old cars recycled at the end of their life are shredded, leading to a feedstock containing all the copper in their motors and winding. This leads to a low-quality steel which is used mainly to make reinforcing bars for concrete construction. However, even these bars can tolerate copper concentrations only up to around 0.4% where higher-grade applications such as vehicle bodies require concentrations below 0.1%. As the world’s supply of steel scrap expands, we will therefore reach a point that we are unable

Figure 23: Steel in car-making and recycling



to use it all with current technologies. Figure 24 shows that within the next 20-30 years there will be an excess of copper in the scrap supply and potentially around half of likely scrap arisings will be unusable.

The green numbers on figure 23 illustrate four options to address this problem of copper contamination:

1. End-of-life scrap could be processed more intensely, for example with disassembly or higher-intensity shredding to allow better identification and separation.
2. New technologies could be developed to purify the liquid metal from recycled sources.
3. New casting technologies could produce higher-quality products from less controlled steel compositions.
4. New product designs could eliminate copper from recycling scrap, for example by use of aluminium-wound motors.

Figure 24: Copper contamination in steel recycling: likey concentration in arising scrap sources by 2050 and acceptable thresholds for destination applications

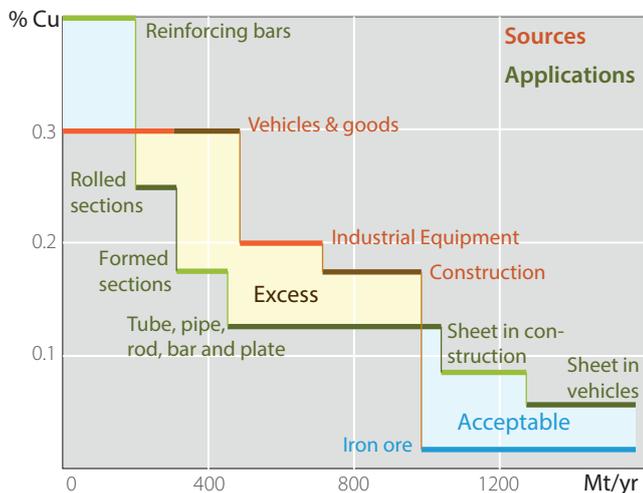
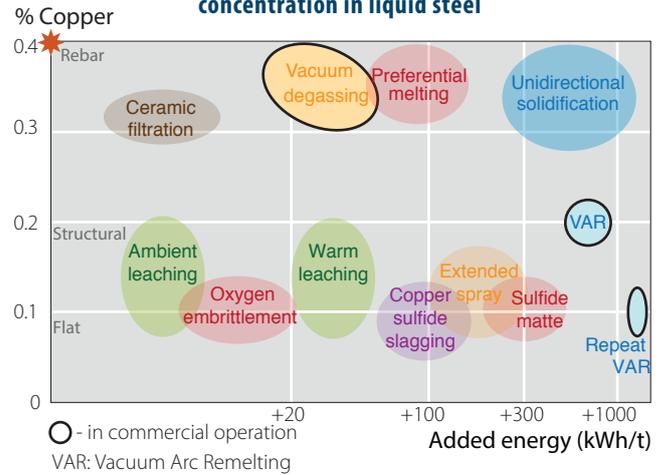


Figure 25: Candidate processes for reducing copper concentration in liquid steel



All four approaches have received attention, but the second is ripe for innovation. Of the three contaminants in figure 22, tin which appears in recycling streams associated with food packaging, is already removed in dedicated factories and nitrogen can be controlled in vacuum refining. The critical concern is copper.

It is already possible to remove copper from liquid steel by vacuum melting: holding liquid steel in a (near) vacuum for a long time allows unwanted metal contaminants to vaporise. This is already a commercial strength in the UK and used for making some of the highest quality steels for aerospace components. The innovation opportunity is to replicate this success at higher speed and lower cost.

Figure 25 illustrates a range of technologies for removing copper from liquid steel. UK scrap arisings have an average copper concentration of 0.4% (indicated by the red star) and the graph contrasts the likely outcome of reducing this concentration against the required additional process energy. Vacuum arc re-melting is particularly effective but at a very high energy cost. Most of the other processes in the figure have been tested only in research laboratories in the past 40-50 years and were abandoned at the time due to lack of economic incentive. However, given the inexorable global surge in steel scrap arisings, the economic incentives for these processes will change. The incentive will increase when, as predicted in figure 24, we have unusable scrap, which will drive down the price of all scrap relative to iron ore.

The UK, with its high volumes of scrap arisings, is well placed to lead the development of these technologies: UK research institutions have a long tradition of metallurgical process innovation, and the Catapult system has created the infrastructure in which new knowledge-intensive processes can be brought to market.

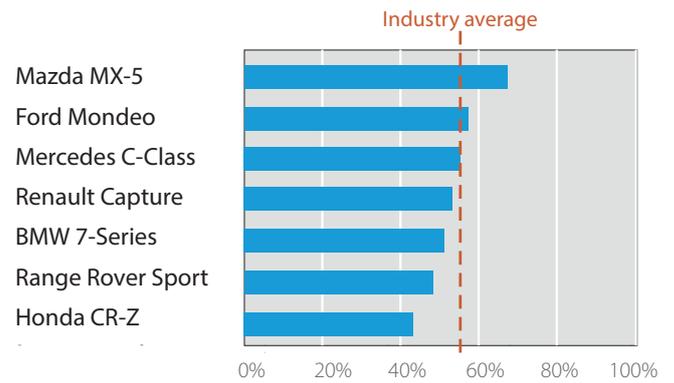
Adding more value to steel in the supply-chain

Making steel from scrap requires about a third of the labour of making it from iron ore. The UK steel industry will therefore employ fewer people as the steel transformation progresses. However, as revealed by figure 1, the steel industry makes intermediate products – plates, coils and bars of steel – that are then shaped, cut and assembled in the supply chains of manufacturing and construction into final products. Is this the best business model, and is it possible to employ more people in these supply chains as employment in steel production declines?

Efficiency gains in steel production over the past century have kept the steel price so low that for many goods made in the UK, the price of labour in downstream manufacturing far exceeds the price of steel, and therefore we use steel wastefully. This is illustrated in figure 26 which shows that on average, the world’s car-manufacturers use just 55% of all the steel they purchase. The steel industry supplies coils of strip steel in constant widths to car-makers, who then cut out irregular blanks from the coils, draw them into the curved and shaped forms of car-body panels, and trim off all the spare material used to prevent tearing and wrinkling while the panel is shaped. For the least efficient panels, such as doors with windows, utilisation can fall to as low as 30%.

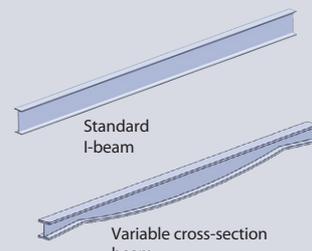
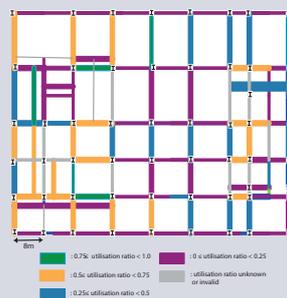
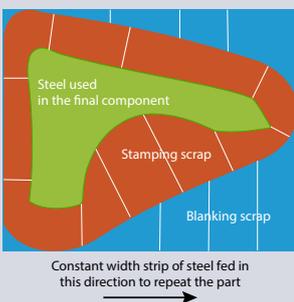
Wasting steel in this way may be economically optimal with current prices if using more steel can reduce the total cost of labour. However, due to the very high emissions intensity of steel-making, this strategy is environmentally harmful. As our commitment to mitigate climate change leads to more stringent actions, making better use of materials will be an early priority for reducing emissions.

Figure 26: Material utilisation rates for selected cars



The box below illustrates the waste of steel in car-manufacturing alongside three other examples of inefficient steel use: in constructing steel-framed buildings in the UK, we currently use nearly double the steel required by our own conservative safety codes, because it is cheaper to save labour by using more steel; many products, such as I-beams, are made in constant cross-sections where a variable cross-section would provide the same final service with a third less steel; commercial buildings which could last for 100 years or more, are typically knocked down and replaced in 40-60 years.

Figure 27 suggests that we could in fact provide most of our existing needs with approximately one eighth of the steel we use today: a quarter of today’s steel production never enters a product, as shown in figure 1; most products are over-designed by at least a third; products, such as cars, are larger than required to deliver their basic function – in fact cars continue to become heavier, despite the direct relation between fuel consumption and vehicle size; apart from



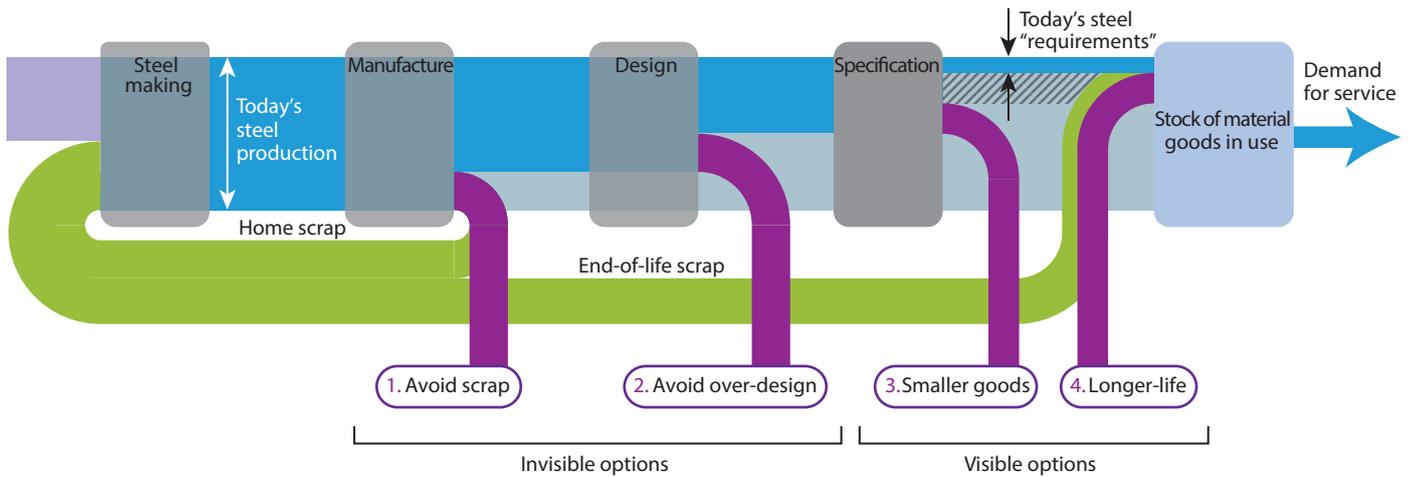
Half of all sheet steel is scrapped during manufacturing: in this example, the car panel doesn’t tessellate, and extra material is needed for grip while it is shaped

Steel framed commercial buildings must meet the safety standards of the Eurocodes, but on average are currently over-specified by a factor of two

Floors deflect most furthest from the walls, so floor beams should have a variable cross-section. Standard I-beams use 30% more steel than necessary, to no benefit

Buildings are designed for 100 years but on average replaced much sooner, and the steel could be re-used, as in this temporary structure.

Figure 27: Four technical options for delivering more value with less new material production



infrastructure, most goods made with steel could be used for much longer before they are replaced. Some of these options will be visible to final consumers so it may require external changes in pricing or preference to drive change. However, for the “invisible” options, where material is wasted without any benefit to the consumer, material could be saved profitably either if managers find means to escape current “lock-in” to inefficient choices, or if technology innovations allow more efficient use of less material. Both strategies are opportunities for UK innovation and leadership.

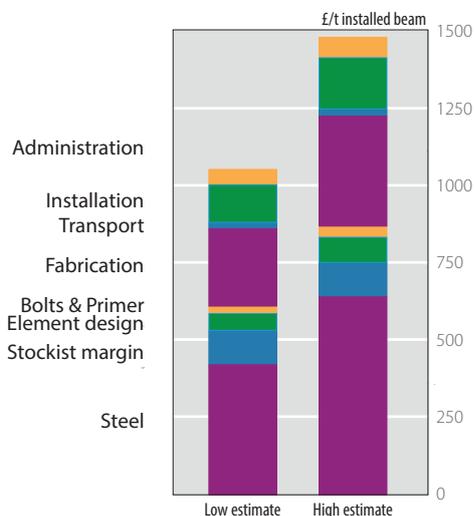
The UK’s trade in steel, illustrated in figures 15 and 16, largely leads to steel leaving the UK with low value (as scrap or as cast blooms and billets) while we import high-value steel, components and products, mainly from Western Europe. This suggests that the UK as a whole is failing to profit fully from its most emissions intensive material: more value is added to steel in downstream manufacturing and construction than in the steel industry. So, if the UK could capture more of this

value by increasing domestic production and reducing our dependence on imports, we could more than replace the jobs that will be lost as the steel industry turns away from primary production.

Figure 28 illustrates this downstream value, in a detailed case study in construction. The figure demonstrates low and high values for the composition of cost of a tonne of fabricated steel beam assembled into a UK commercial office building. Even with the relatively simple geometry of a steel beam, the value of the assembled beam is around three times the value of the steel within it. The processes of downstream fabrication, stock-holding, transport and installation are more valuable than making steel. The UK steel industry currently operates without integration: intermediate commodity-products are sold in bulk to stockholders, so the key determinant of revenue is volume of sales and the steel industry has no interest in ensuring the efficient use of its own emissions-intensive products. However, if instead the steel industry were integrated into its own supply-chain, it could capture around three-times the value per tonne of steel. Furthermore, having internalised the cost of steel, the industry would be motivated to minimise steel wastage while maximising its value.

The UK, which currently has an under-developed downstream supply chain for steel, could exploit the simultaneous transformations created by the switch to steel recycling and the critical requirement to mitigate climate change, to develop the new supply-chains required to deliver maximum service from each tonne of steel. Doing so could lead to the creation of new skilled jobs while adding significantly more value to domestic steel production. More integrated UK steel supply chains could be more responsive to innovation opportunities, could challenge lock-in to existing inefficiencies and could develop skills, technologies and services for export.

Figure 28: Supply-chain costs for installed steel beams



Steel strategy and policy in the UK

The global steel industry is in an inevitable transition to a future based largely on recycling end-of-life scrap. This transformation will be accelerated by action to mitigate climate change and creates opportunities for innovation and growth in controlling steel quality and in delivering more value from less steel. The transformation potentially reveals some key comparative advantages for the UK. What actions are most likely to lead to these advantages being exploited in practice?

The steel industry and manufacturing are viable sectors in the UK. Figure 29 shows that wages in the metals and manufacturing sectors are attractively ahead of national averages and that productivity in both sectors has begun to rise again after the 2008 financial crisis, albeit with some loss of earnings in the metal sector to compensate for global pressure on steel prices.

However, the absence of proactive industrial policy in the UK in favour of a shift to services has weakened domestic supply chains. Figure 30 reveals that UK manufacturing produces final goods containing around 10-15 Mt/yr of steel, which is comparable with total domestic demand. However, only a small fraction of this manufacturing occurs with steel made in the UK, and largely this fully domestic activity is in the lower value sectors of construction and tubes. This confirms the

Figure 29: Wages and productivity in the UK steel sector

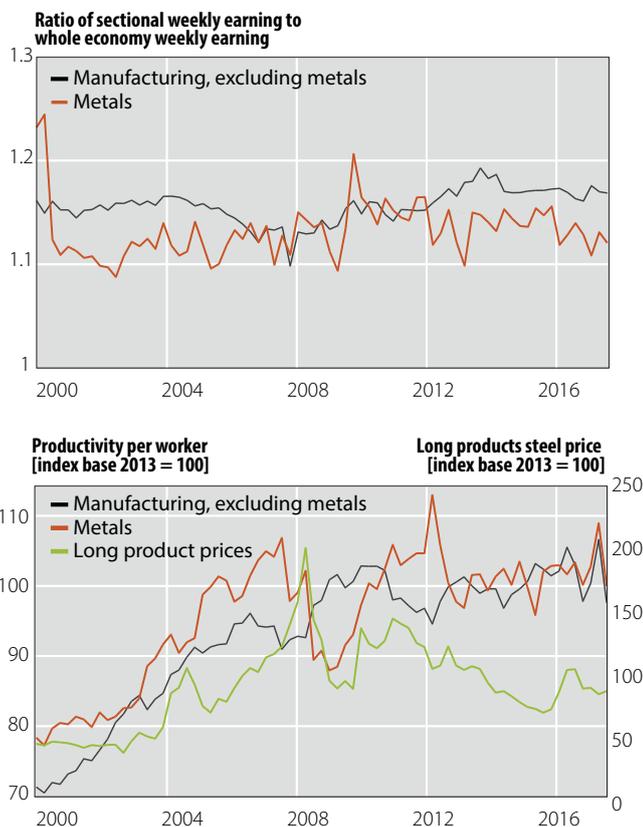
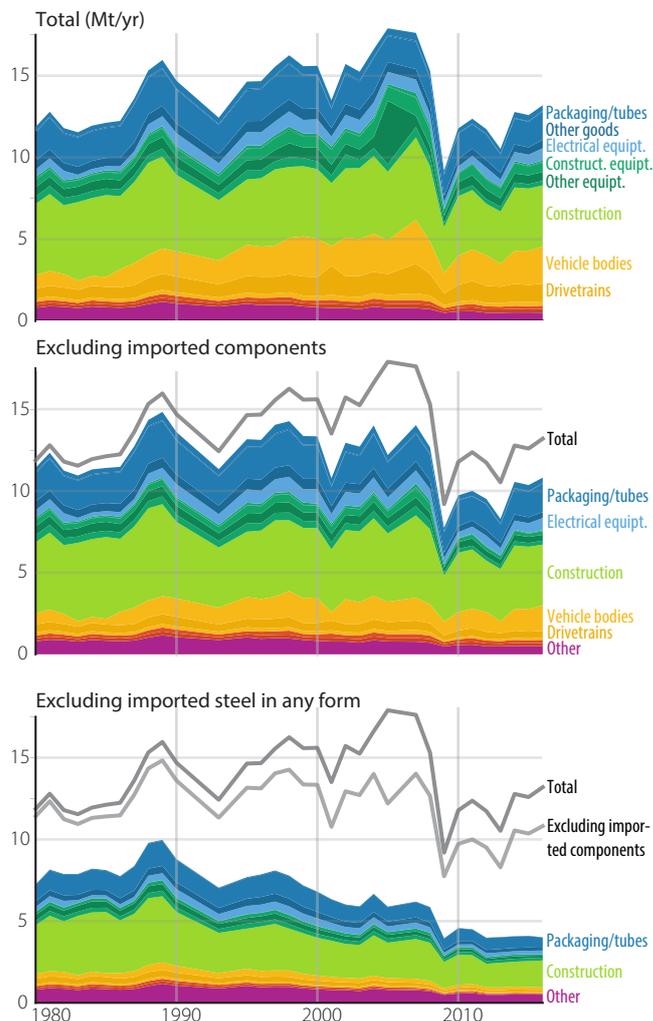


Figure 30: UK manufacturing with steel in 2016



overall view of trade shown earlier as figure 15: the UK mainly exports lower value steel products, components and goods while importing those of higher value.

Despite this current weakness, this report has demonstrated several important comparative advantages for the UK as the global steel sector transforms towards recycling:

- The UK is a mature steel economy, so has the necessary resources of annual scrap arisings which will soon be of comparable volume to total final demand for steel in goods. The UK is one of the first countries in the world to reach this position.
- UK energy and climate policy has led to significantly faster action than other comparable countries, and the emissions intensity of electricity generated in the UK has reduced rapidly. UK recycled steel is therefore among the least emissions intensive steel made in the world, and this will improve as UK deployment of renewable electricity generation continues to expand.

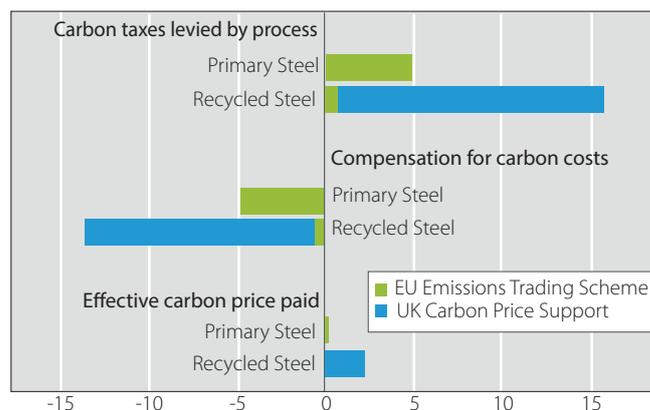
- Steel recycling for high quality products needs technological innovation, but that is a core UK strength. The UK has a long history, stretching back to Henry Bessemer, of successful innovation and deployment of new technologies in material processing, and retains world-leading research institutes and infrastructure for further development.
- The relative weakness of current steel supply chains in the UK enables easier innovation in an emerging, transformed sector, based on adding more value to less steel. There is relatively less inertia to change in the UK compared to countries with a stronger industrial infrastructure linked to the high-carbon practices of the past.

A critical opportunity for **UK businesses** in the steel sector to exploit the opportunities of the global steel transformation is to pursue vertical integration. The steel industry globally is configured to trade commoditised intermediate products and it is difficult for UK producers to compete in undifferentiated over-capacity commodity markets. However, upstream integration between the steel scrap supply chain and recycling, and downstream integration between steel producers and component manufacturers offers significant opportunities for innovation. This arises from internalising the costs of scrap, which is generated as a result of the trade in commodity products, from innovating in the delivery of efficient designs without over-specification, and from new business models based on service and closer-connection to final customers. Integration between steel producers and fabricators for construction for example, which could be through purchase, partnership or joint-venture, could reveal opportunities related to delivering steel-framed buildings with half today's mass of steel, and no loss of performance. Integration between steel-making and blanking and drawing could raise average material utilisation in the car-making industry beyond best practice, while saving cost and reducing embodied emissions.

Government policy could support UK players during the global steel transformation across many fronts:

- Connecting steel to energy and climate policy could avoid the risk of incumbent bias revealed in the effective carbon pricing shown in figure 31. The figure shows that compensation offered to primary steel producers in the UK currently leads to a lower total carbon charge than that paid by steel recyclers powered by the current national grid. Instead a uniformly applied carbon price linked to ongoing aggressive electricity de-carbonisation targets, would support the move towards world leadership in low emissions steel recycling.

Figure 31: Carbon prices and compensations (£/t CO₂)



- Climate policy should be re-stated to account for the emissions driven by UK consumption, not its production, to avoid the artifice of UK industrial closure appearing to be a climate success. The possibility that the World Trade Organisation rules may be re-negotiated due to other international pressures further creates the opportunity to support domestic ambition for emissions mitigation by enforcing border rules of comparable severity on imports.
- Waste policy could be developed to support improved collection rates for end-of-life steel goods, better separation and control of scrap composition, and could ensure that the strategic resource of the UK's steel scrap is preferentially recycled domestically rather than exported at minimum value. The success of UK waste policy in reducing the emissions of landfill methane by waste separation could be replicated to add significant value to UK scrap steel streams giving a comparable reduction in national emissions.
- Technology policy could support research and innovation in up-cycling steel, through a specific focus on reducing copper contamination, while creating favourable conditions for supply-chain integration and innovation in the downstream uses of steel.
- Significant government purchasing contracts could follow the example of many European neighbours in using evaluation based on total return to the UK, not just on least initial outlay, to support the development of domestic industries.
- In response to changing international trading conditions, industrial strategy in the UK could specifically support the re-establishment of critical sectors (such as equipment manufacture or closed-die forging) that were past UK strengths and have been lost due to the recent shift towards a service economy.

Notes

Pages 2-3: Figure 1 is from Cullen et al. (2012); Figure 2 from Cooper et al. (2014); Figure 3 is developed from Müller et al (2011); Figure 4 is from Allwood and Cullen (2012)

Pages 4-5: Global steel production data from WorldSteel; Capacity and profitability data from Brun (2016); Ore and steel prices from World Bank online database adjusted according to US ILO Consumer Price Index. The economic model in figure 8 was created for this report, using constant iron ore price, and a scrap supply price as described in the text comprising constant prices for home and new scrap up to 20% of current production, and with prices rising with a constant elasticity of supply for end-of-life scrap up to a limit defined by final steel goods production 35 years previously and a maximum collection rate of 90%. Primary and recycled steel are assumed to be perfect substitutes up to a technical limit, beyond which only primary steel can currently meet quality requirements. The balance between BF and EAF production for each year is found by minimising total supply costs, allowing for the interchange of flows shown in figure 8.

Pages 6-7: The results on these pages arise from a new model of the flow of steel through the UK. This model was based on UK steel production statistics and import/export of steel products (ISSB, 1980-2016) to estimate the sales of steel to UK manufacturers. Final UK steel demand was estimated by subtracting manufacturing scrap (manufacturing yield losses estimated by Cullen et al., 2012) to UK steel used by manufacturers and also by estimating the import/export of steel-containing goods from UK trade statistics (HMRC, 2018). The classification of types of steel products and their allocation to end-use product categories is uncertain due to differences in the classification of steel products used by UK steel statistics (ISSB, 1980–2016) and worldsteel statistics for the UK (World Steel Association, 1980–2017), and due to only direct sales from UK steel producers to UK manufacturers being reported by ISSB, 1980–2016. This allocation was obtained by conciliating the classifications of products and sectors from UK steel statistics (ISSB, 1980–2016) with worldsteel statistics for the UK (World Steel Association, 1980–2017), informed by global allocations of steel products into end-use sectors (Cullen et al., 2012) where no specific UK data was available.

Pages 8-9: Consumption emissions in figures 17 and 20 derived from steel consumption data in figure 12 with emissions intensity for each steel production route estimated from UK steel production figures (ISSB, 1980–2016) and data on UK electricity generation and UK steel energy uses (IEA, 2017a,b). Emissions intensities for primary steel production in figure 19 were estimated from the latest global and UK primary steel production data from world steel (World Steel Association, 1980–2017) and their energy requirements from the IEA energy balances (IEA, 2017a). Emissions intensities for steel recycling in figure 19 were obtained from the latest electricity grid emissions reported by the IEA (IEA, 2017b) assuming an average requirement of 2 MWh/t of recycled steel. The estimate for destination countries for UK scrap in figure 19 is the average emissions intensity for the four largest destinations for UK scrap (Pakistan, Spain, India and Turkey) weighted by the share of UK scrap exports in 2016. Energy intensity for steel production in figure 18 was taken from Allwood and Cullen (2012), based on WorldSteel data. Figure 21 is based on data from the ISSB annual statistics publication.

Pages 10-11: Figure 22 is adapted from Nakajima (2010); figures 23 and 24 are developed from Daehn et al. (2017); Figure 25 and Table 1 are developed from Daehn et al. (2019).

Pages 12-13: Figure 26 developed from Horton et al. (2017) based on data from the Euro-Car-Body conference between 2009 and 2015; Figure 27 is developed from Allwood (2018); and figure 28 from Dunant et al (2018). The examples in the box at the bottom of page 13 are taken from a large collection of case studies of the technical potential for material efficiency in Allwood and Cullen (2012).

Pages 14-15: Figure 29 arises from the model developed for pages 6-7. Figure 30 is from Skelton and Allwood (2017); Some of the policy suggestions are expanded from the review by Söderhokm and Ejdemo (2008)

Supporting data, code and figures: further details of the analysis behind this report can be found in Lupton et al. (2019)

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