Domestic Scrap Steel Recycling – Economic, Environmental and Social Opportunities (EV0490)

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Executive Summary

Steel plays a key role in UK manufacturing, and the modern world is based on and founded by the use of steel. Major industrial sectors such as power generation, infrastructure, automotive, engineering and construction all depend on steel, and these are all sectors which are forecast to grow and will require more steel as they expand. It is clear that the UK steel demand will grow, however production of steel using traditional blast furnace and basic oxygen furnace route is carbon intensive and alternative routes for steel production need to be investigated. If the UK were to recycle all of the scrap steel that it produced it would nearly be able to satisfy the country's steel demand.

The UK consumes approximately 11.9 Mt of semi-finished and finished steel products each year. Currently, the UK produces around 11.3 Mt of scrap steel each year, 2.6 Mt of that is used in domestic steel making which is a mixture of blast furnace – basic oxygen furnace and electric arc furnace production. The remainder of the scrap steel is exported for recycling in other countries with Turkey being the biggest consumer of scrap steel exported from the UK. There is a scope for greater recycling of scrap steel, up to 6.1 Mt, to be used domestically by the current steel production facilities if operating at maximum capacity, which would only be possible with significant investment in downstream processing (e.g. rolling) and greater demand for UK steel and or increasing the export of semi-finished steel products. Further use of domestically produced scrap steel would require greater UK based electric arc furnace steelmaking capacity.

Electric arc furnaces melt scrap steel to produce crude steel that can then be further refined to make the steel grades that are required by consumers. Greenhouse gas emissions for electric arc furnaces are significantly lower than that of blast furnace – basic oxygen furnace steel production due to avoiding the pig iron production by using fossil fuel (coal) in the blast furnace ironmaking. To increase the electric arc furnace steel production capacity in the UK would require significant investment, estimated costs for an electric arc furnace steel manufacturing site could be over £1bn depending on the scale, location and complexity of any downstream steel production required. Electric arc furnace technology would need to be imported into the UK as there are no UK based manufacturers.

There are a number of potential barriers to enabling increased recycling of scrap steel in the UK which need to be overcome. The business alignment between steel manufacturers and scrap suppliers (merchants) needs to be improved to enable a more efficient industry. The standards used to sort scrap steel in the UK are not sufficient to ensure that the scrap steel received by steel manufacturers is of the quality and consistency required to be easily recycled into high quality steel grades. The technology currently used to assess and sort the different grades and chemistries of scrap steel is not advanced enough, often scrap quality monitoring is completed by visual inspection, leading to poor quality scrap steel being used in the steelmaking process. The transition from the blast furnace ironmaking – basic oxygen steelmaking process to electric arc steelmaking is not straight forward, and there are a number of challenges in knowledge/expertise, energy supply and logistic that the steel manufacturers need to face in order to make the transition, in addition to meeting the customer requirements (e.g. steel grades, quality and price).

If there is to be significant investment in the UK for electric arc steelmaking then any factors that impede investment will need to be overcome. Barriers to investment are mostly fiscal, with some affected by geography. UK steel producers have an operating cost disadvantage when compared with many other steel producing countries for electricity costs, and the cost of electricity becomes more important with the electric arc steel manufacturing process as electricity provides the bulk of the process energy. A similar overhead cost disadvantage is seen for the UK steelmakers for business rates. Business rates in the UK are charged on the rateable value of the company, which includes physical assets. Steelmaking equipment is very expensive and investment into new plant increases business rates even if it serves to increase efficiency or decrease emissions. Greenhouse gas emissions for UK steelmakers are taxed under the UK emissions trading scheme (ETS), which caps the industry's emissions. The UK ETS is roughly in-line with the EU ETS and has been designed to give a seamless changeover in emissions taxes post Brexit. Emissions tax regimes are an investment burden when compared against steelmaking countries where there are no carbon taxes. Finally, significant investment barriers can be associated with geographical physical and economic factors such as land prices, power generation facilities, remediation costs for closing current plant, infrastructure and labour sources.

There are several opportunities that can be exploited to encourage further domestic recycling of UK generated scrap steel. Larger market shares in domestic markets would serve to increase the amount of steel that UK steelmakers could sell, and this could be driven at a government level with steel for major infrastructure projects. Import and export tariffs have been considered an option to protect the UK steelmaking market, however evidence from other countries where this has been tried suggests while it may help the steel industry it may be detrimental to wider domestic manufacturing supply chains. A better way of steering domestic steelmakers to use more UK generated scrap steel might be to introduce an end to end supply chain carbon tax, this would not prevent international trade in steel or raw materials but it would promote supply to the lowest carbon supply routes which are often domestic. Improved sorting technologies for scrap steel will be important for increased scrap steel recycling in the UK, the research and development of these technologies is expensive, government subsidies could help to speed up the availability of the technology. Recognising and developing circular supply chains (where scrap steel from steel users is directly returned to steel makers) will help to reduce the amount of sorting required for scrap steel, increasing the efficiency of the steel recycling process. An improved relationship between UK recycling companies and steelmakers will increase the business alignment and understanding required for increased recycling, and this could be carried out through the establishment of a joint body of UK recyclers and steelmakers. Developing and implementing appropriate scrap quality monitoring tools are also needed to achieve this.

Research and development will be required if there is going to be significant increase in domestic scrap steel recycling. More advanced scrap sorting technology will need to be developed which can scan, identify and sort scrap steel at faster speeds, this will give advantages in lessening the reliance on non-scientific methods for scrap sorting and better control of residual chemical elements in recycled scrap. Development of technology to pre-treat scrap before it is recycled would be helpful for advanced steel grades which require extremely low residual elements. The amount of residual elements in recycled steel increases with the number of times that the steel is recycled. Research into alternative iron sources such as direct reduced iron or hot briquetted iron can help to reduce the amounts of residuals by providing a pure iron source for steel during recycling. Lastly, increased research into scrap recycling through the electric arc furnace process itself will lead to an increased understanding of how to use scrap steel in the electric arc furnace process, leading to better quality output from the electric arc furnace steelmaking process.

There is no single intervention that will encourage more domestic recycling of domestically produced scrap steel, and a range of interventions will need to be pursued. There is a significant opportunity for the UK to lead in the production of green, net-zero or low carbon steel if increased electric arc furnace steel production is pursued.

This study is focused on scrap steel recycling with some touches on scrap aluminium, and an in-depth assessment on the UK scrap aluminium recycling is recommended to be carried out in the future. UK has a big opportunity/investment possibility to establish a green aluminium industry, based on the abundant supply of scrap aluminium, to meet the continuously growing domestic demand of high quality aluminium products, and to increase exporting value by exporting high quality products instead of low value mixed scrap. Significant efforts are needed to invest heavily in process technologies from scrap sorting through melting/casting to downstream processing (e.g. rolling). Government could play a critical role to provide policy incentives to promote upcycling, and create an attractive environment (electricity price, business rate) to attract investors to invest in the UK aluminium industry, and even provide financial support to the UK aluminium industry for investment in new, green technologies.

Contents

1. Introduction

WMG (Warwick Manufacturing Group), an academic department at the University of Warwick, has been commissioned by BEIS to undertake research into the economic, environmental and social opportunities around options with scrap metal, particularly steel. This report will consider the current state of scrap steel use in the UK, the technology required for recycling greater amounts of scrap steel, the barriers to recycling larger amounts of domestically produced scrap steel, the factors affecting investment in further steel recycling technology and the opportunities that exist to encourage greater recycling of scrap steel.

The UK exports approximately 8.7 Mt of scrap steel and produces around 7.3 Mt of crude steel per year. Currently the UK uses around 2.6 Mt of scrap, which can be increased to ~3.5 Mt at the current level of crude steel production. This is scope to use up to 6.1 Mt scrap steel in domestic production using existing blast furnace – basic oxygen furnace and electric arc furnace (EAF) steel making plants at full capacity, however, this requires investment in downstream capacity and or increasing the export of semi-finished steel products. To use more than that would require installation of new electric arc furnace production facilities or conversion of existing blast furnace – basic oxygen steelmaking facilities to electric arc furnace manufacturing.

There are significant environmental benefits to electric arc furnace manufacture of steel. The carbon emissions from electric arc furnaces are much lower than the unabated blast furnace – basic oxygen steelmaking. Electric arc furnaces combined with electricity produced by renewable sources and domestically sourced scrap steel presents a real opportunity for the UK in terms of low or zero carbon steel production.

The report highlights a number of options that could be pursued to support greater recycling of domestically sourced scrap and support the UK steel industry's future. The opportunities should not be considered in isolation, there is no single solution, but do present a methodology to a clear future for UK scrap steel recycling and production.

2. Definitions and Assumptions

To complete the report a number of definitions and declarations has to be made.

Definitions:

- Crude steel refers to the first solid steel upon solidification of liquid steel, which includes both ingots and continuous casting products (Semis). Crude steel is also sometimes referred to the liquid steel, which goes into the production of steel castings. The latter is used in this report. Crude steel can be either partially or completely composed of recycled steel.
- Crude steel production – production of crude steel is defined as the manufacture of liquid steel from raw materials. This process is typically completed in either a blast furnace (BF) ironmaking – basic oxygen furnace (BOF) steelmaking production route (i.e. BF-BOF integrated route) or an electric arc furnace (EAF) process. In the BF-BOF integrated route, hot metal (or pig iron in solid state) produced from coke and iron ore in the BF will be first converted to primary liquid steel in BOF with addition of scrap steel (up to 25~30% depending on hot metal quality etc), and further refined to the final liquid steel prior to casting. In the EAF process, scrap steel (up to 100%) with other iron materials (e.g. DRI – direct reduced iron, HBI – hot briquetted iron, hot metal/pig iron) will be first converted to primary liquid steel, and then refined to final liquid steel prior to casting. Then liquid steel is cast into ingots (via conventional solidification process) or slab, bloom and billet (via continuous casting facilities).
- BF-BOF integrated process – the BF ironmaking – BOF steelmaking process route. The BOF can use up to 25~30% of scrap steel without additional investment.
- EAF process – the production of crude steel in an EAF. The EAF process uses electricity to melt scrap steel for the production of crude steel. It can use up to 100% scrap steel.
- Mini-mill – Mini-mills are typically based on the EAF processes that can handle between 200kt and 400kt of liquid steel per year. Often located close to the market for the steel produced and focussed on a smaller number of products than an integrated works. In recent years, the so-called "mini-mill" has evolved into (scrap-based) EAF enterprise comparable to the BF-BOF process route in terms of capacity and products.
- Semi-finished steel products – these are classed as slabs, blooms, billets or ingots. They are products that are further processed into the types of product required by end users.
- Steel processing – the slab, bloom, billet or ingot is processed into a finished steel product usually by re-heating, hot- and or cold-rolling (or forging), and annealing. The act of turning a slab, billet or bloom into a finished steel product is defined as steel processing.
- Finished steel products – at the end of steel processing steel is in the form of uncoated plate, strip, bar, section, rail, rod or wire. These are defined as finished steel products.
- Steel producer – a company which produces steel via either the BF-BOF integrated production route or EAF route or both.
- Steel stockholders – businesses that hold finished steel products from any supplier for resale to steel users.
- Steel scrap – steel that has reached the end of its service life which is removed from its product or application or generated during the steel manufacturing processes from liquid steel production to steel processing. It is also called "scrap steel".
- Steel recycler – a company which collects scrap steel either directly from manufacturers or via disassembly / shredding of products containing steel.
- Steel recycling – This refers to re-melt scrap steel via either the BF-BOF integrated route or EAF route into liquid steel, and cast into a slab, bloom, billet or ingot before being processed into a finished steel product.

- Steel reuse – where steel is reused and repurposed without being melted down for recycling.
- Steel plate – a flat rolled product from slabs or ingots of greater thickness than sheet or strip; typically greater than 10 mm thick
- Steel strip – a coiled flat rolled product from slabs, typically less than 10 mm thick

3. Current State of Scrap Steel Use and Scrap Steel Recycling in the UK

This section presents an overview of the current scrap steel use and scrap steel recycling market in the UK. The section shows the quantities of scrap produced and used in the UK; indicates the primary transportation modes; it discusses the industry, how scrap is categorised and used; the section finishes with a description of the UK steel industry's current capacity to recycle scrap steel.

3.1 Overview of Scrap Steel Consumption and Production in the UK

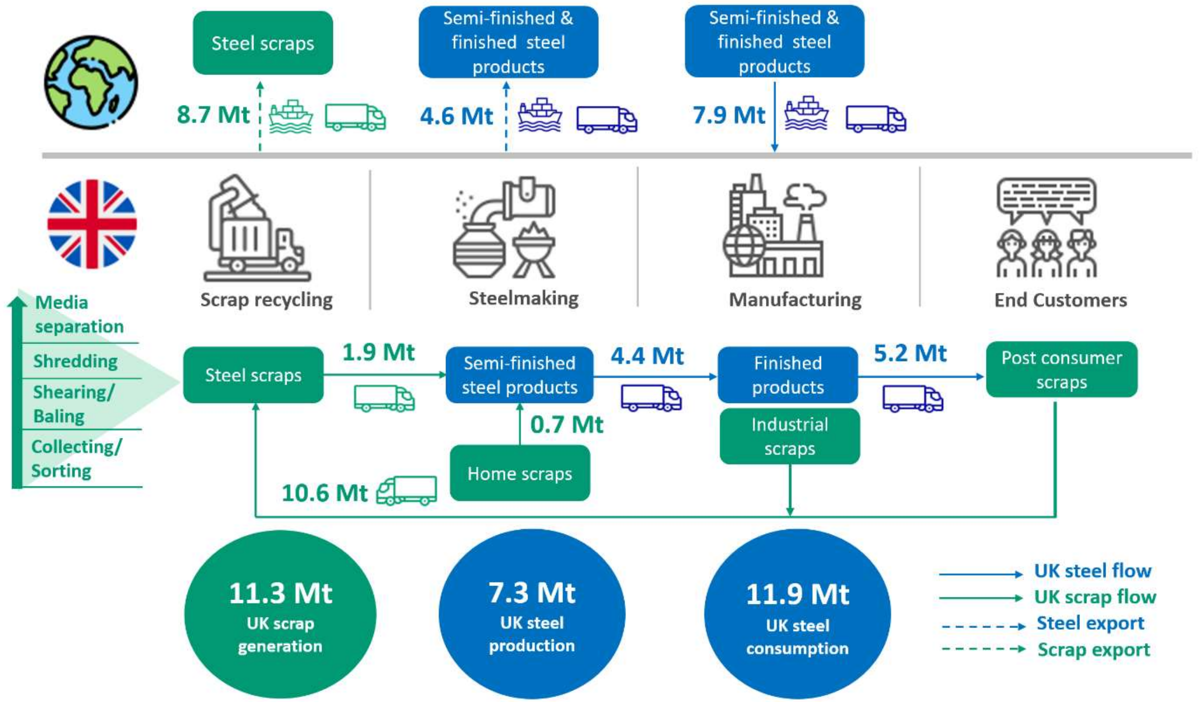

Figure 1: Steel production and movement in the UK [1]

Figure 1 shows the production, scrap generation, transportation and consumption volumes for steel in the UK. In 2018 the UK steel industry [2, 3]:

- Produced 7.3 Mt of crude steel, out of which 5.7 Mt via BF-BOF and 1.6 Mt via EAF route
- Consumed 11.9 Mt of steel, a 4.6 Mt deficit between consumption and production (consumption figures are based on steel consumption per capita)
- Generated 11.3 Mt of scrap steel
  - 8.7 Mt of scrap steel was exported
  - 2.6 Mt of scrap steel was used in the manufacture of steel products in the UK, that is, the UK steel industry used 0.7 Mt internally generated scrap and 1.9 Mt purchased scrap
- Exported 4.6 Mt of semi-finished and finished steel products
- Imported 7.9 Mt of semi-finished and finished steel products
- Steel manufacturers recycled approximately 0.7 Mt of internally generated scrap (home scrap).
- Employed 32,000 people, with further employment in the supply chain
- Contributed £1.6 bn to the UK economy

Current scrap steel consumption by the UK steel manufacturers is estimated to be 2.6 Mt in total, including:

- CELSA 1.1 Mt

- Liberty Steel 0.3 Mt
- British Steel and Tata Steel combined 0.8 Mt
- Other UK based steelmakers and foundries 0.4 Mt

3.2 Scrap Steel – Industry, Categorisation and Use

Metals recycling in the UK is highly regulated and recyclers, irrelevant of company size, must hold the correct licences. Metals recycling in the UK is a pyramid industry and involves companies of all sizes. Metals recycling companies carry out different functions such as collection, weighing, sorting, baling, shearing, shredding, separation, distribution and trading. Smaller recycling companies often supply larger operators, with the larger operators more likely to be those that trade internationally. The UK's biggest metal recycling companies are EMR (European Metal Recycling Ltd) and SIMS Metal Management [4].

Scrap is generally sorted by the recycler before delivery to the steelmaker. Scrap steel is sorted into either ferrous or non-ferrous categories and further sorted according to a scrap steel grading system. The different grades of scrap steel are regularly reviewed to consider new sources of scrap, and the grades are agreed by the Cast Metals Federation, UK Steel and the British Metals Recycling Association (BMRA). There is no single internationally standard for scrap steel, however, the UK standards for scrap steel are aligned with other (EU, US, Japanese) standards. Most scrap exports to Asian normally refer to the ISRI (US) scrap specifications in the contract. The main difference between the UK standards and other national standards is that UK standards do not have a limit on residual elements and other national standards have more detailed guidance on scrap steel grade. Magnetic separation is used to distinguish between ferrous and non-ferrous steel. Further sorting is carried out by eddy current separators, use of sensors, heavy media separation, shape, size, air separation and visual inspection. For both recycler and steelmaker, there is a heavy reliance on visual inspection and hand sampling for quality control, some hand-held XRF is used to check the composition of the sorted steel ("spot check") which relies on the competence of the operator [5-7].

The quality of the scrap is important to the steelmaker as cleanliness and composition have an effect on the quality and type of steel that can be produced from the scrap steel. Also the quality of the scrap has a significant impact on primary steelmaking in terms of energy efficiency, productivity, waste generation and costs, and scrap with high Fe content and low sterile content is always preferable. High quality steel can be (extremely) difficult to make with some grades of supplied scrap steel presenting particular problems. The difficult scrap categories are typically grades 1, 2 and 7A, as they are not always clean and can have higher levels of residual chemical elements in them such as copper, tin, phosphorus, sulphur and silicon. Residual chemical elements need to be controlled by proper scrap sorting to get them to the levels required to produce correct steel grades; residual elements can also be controlled by dilution with DRI (direct reduced iron) or pig iron in steelmaking and or using chemical reactions when the steel is in a liquid state to change the chemical balance as necessary [8].

Table 1 shows the estimated proportions of the grades of scrap steel that are produced in the UK. The grades that provide the highest quantities of scrap are 3B – Fragmented (old light steel arisings fragmentised into pieces not exceeding 200 mm in any direction) and 1 – Thick Old (predominantly 6 mm thick, prepared in a manner to ensure compact charging, may include hollow sections and wire rope [7].

Table 1: Estimated proportions of steel scrap types produced in the UK [9]

Scrap Category	Scrap Category Proportion (%)
0A - Demolition	10.5
1 - Thick old	21.5
2 - Thin old	14.7
3B - Fragmented	28.5
6A - Cans & incinerated	7.6
7A - Turnings	1.1
8A - Manufacturing off cuts	10.4
9A - Old cast iron and rail	4.2
9D - Brake discs and wheel drums	1.0
12A - New cast iron	0.5
Total	100

Figure 2 shows how scrap steel in the UK is generated by the steel makers and the manufacturing sectors, how the scrap is categorised in the UK and then further categorised for export. Approximate tonnages are shown for the categorised UK and exported scraps.

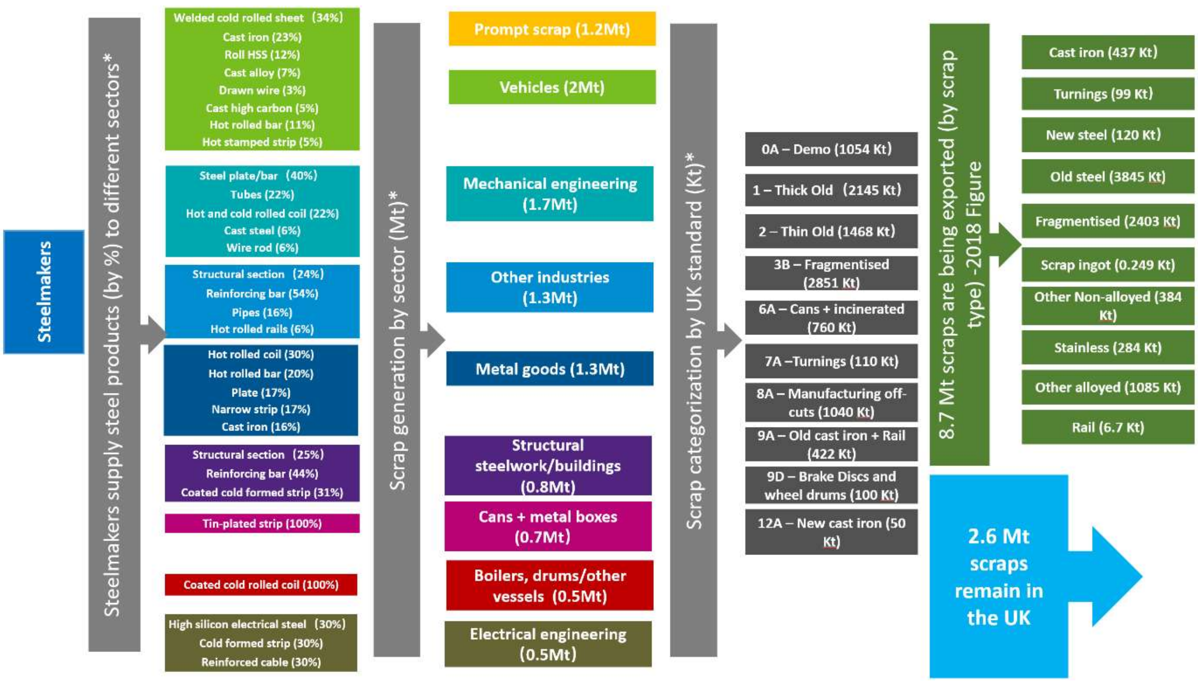

*Figure 2: UK scrap steel flow diagram (*figures are normalised to 10 Mt)*

3.3 UK Scrap Steel Export Overview

Of the 8.7 Mt of scrap steel that was exported, a large proportion went to Turkey, the world's biggest importer of ferrous scrap. In 2018 Turkey imported a total of 20.7 Mt of ferrous scrap, approximately 2.1 Mt of that came from the UK. Other countries which imported scrap steel from the UK are Spain, Egypt, India, Indonesia, Bangladesh, Pakistan and Belgium. The remaining 2.6 Mt of scrap is consumed domestically by the UK's crude steel manufacturers: Tata Steel UK, Liberty Steel, British Steel, Celsa Steel UK, Sheffield Forgemasters, Outokumpu, and foundries. Figure 3 shows approximate ferrous steel scrap exports from the UK to different countries for 2018 and 2019, showing Turkey as the biggest consumer of UK ferrous scrap steel [10, 11].

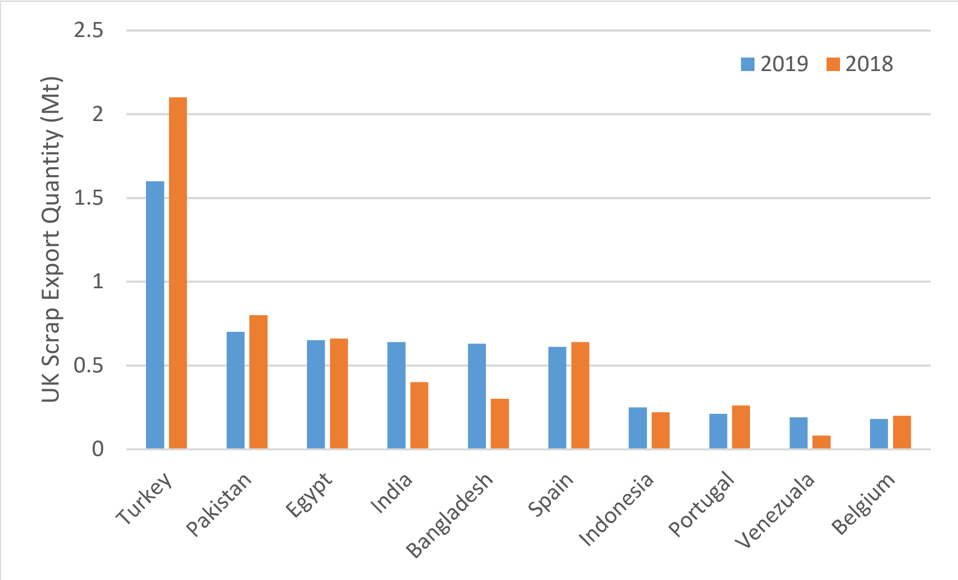

Figure 3: UK scrap steel exports by country for 2018 and 2019 [10]

3.4 Current Scrap Steel Recycling Capacity

At present there is approximately 2.5 Mt of EAF steelmaking capacity (produced 1.6 Mt crude steel in 2018) and 8.5 Mt of BOF steelmaking capacity (produced 5.7 Mt crude steel in 2018) in the UK. All the UK EAF steelmaking plants use 100% scrap and the BOF plants use close to 20% of scrap in metallic charge (but with the potential of up to the practical limit 25% scrap in metallic charge without additional investment). One ton of scrap steel in steelmaking can be assumed to yield approximately 0.91 tons of crude steel. [12] Another opportunity to increase scrap usage is to use up to 150 kg scrap per ton hot metal in the sintering – blast furnace ironmaking steps, which has not been explored by the UK BF-BOF integrated steelmakers yet.

The current scrap steel recycling capacity can be estimated for two scenarios: at current productivity (~7.3 Mtpa crude steel) and at full capacity (11.0 Mtpa crude steel). If the UK crude steel production is kept at 7.3 Mtpa, the maximum scrap consumption can increase from the current 2.6 to 3.5 Mtpa without additional investment in such as scrap preheating and downstream processing (e.g. rolling). This capacity increase comes from the increased scrap use in BOF steelmaking (e.g. from 20% to 25% scrap charge, ~0.2 Mt) and the scrap usage in the sintering-BF ironmaking steps (~0.7 Mt).

Assuming all the BOF furnaces produce at full capacity (5 Mt at Tata Steel UK, 3.5 Mt at British Steel), with the practical maximum scrap usage (25%), the maximum consumption of scrap steel in BOF furnaces is 2.3 Mt. The opportunity to use scrap in the sintering-BF ironmaking steps is 1.1 Mt. The maximum consumption for existing EAF plants is 2.7 Mt. Therefore, the UK steel industry can use up to 6.1 Mt scrap steel in BOF, EAF plants and foundries. It should be pointed out that this will need significant investment in downstream processes such as rolling capacity or increasing the export of semi-finished steel products.

As a summary, the UK generates 11.3 Mt scrap steel per year, 8.7 Mt of which is exported and 2.6 Mt is consumed in the UK steel industry. The scrap usage in the UK steel industry can increase to 3.5 Mtpa at the current UK crude steel output and without additional investment. The maximum scrap recycling capacity in the UK steel industry is estimated to be 6.1 Mtpa, however this requires significant investment in downstream processes or increasing the export of semi-finished steel products. Even under the scenario of maximum scrap recycling capacity, it leaves a deficit of 5.2 Mt of scrap steel per year that cannot be consumed by the domestic steel industry. The pathway that the UK steel industry can make full use of the domestically generated scrap steel is to build new scrap-based EAF enterprises and or to convert the BF-BOF capacity to scrap-based EAF capacity.

4. EAF Technology Compared to Basic Oxygen Steelmaking

4.1 EAF Process vs. Basic Oxygen Steelmaking (BOF) Process

BOF process:

- Hot metal (pig iron) is produced in a blast furnace ironmaking from iron ore, coke and limestone.
- The hot metal is transferred to a vessel called a convertor or basic oxygen furnace (BOF). Filling the convertor is called charging. Convertors are often charged with a mixture of scrap steel and then hot metal.
- High purity oxygen is blown into the iron at very high pressure to lower the carbon content (i.e. decarburising), turning the liquid iron into primary liquid steel. Fluxes, such as lime and dolomite, are also added to absorb impurities.
- Once the temperature and chemistry of the primary liquid steel is correct, it is then tapped into a steel ladle with a basic refractory lining.
- The chemistry of the primary liquid steel can then be further adjusted / refined in the ladle using additions which cause chemical reactions in the liquid steel.
- The steel is then poured from the ladle into ingot moulds (note, no UK BF-BOF producer makes steel ingots) or continuous casters to produce semi-finished steel products depending on the required final product.

EAF steelmaking process in general utilises scrap steel (up to 100%) and or DRI (direct reduced iron), HBI (hot briquetted iron) and hot metal/pig iron to make steel. Please note that UK is currently lacking the facilities to produce DRI and or HBI. The EAF process in the UK uses 100% scrap:

- Scrap steel is loaded into baskets. The steel is loaded in layers, separating heavier grades of scrap with lighter grades. The baskets have clam-shell doors at their base, the baskets are used to load, or charge, the EAF. The scrap baskets are sometimes pre-heated to heat the scrap before it is loaded into the EAF.
- The scrap from the baskets is then charged into the EAF, the layers from the baskets of scrap should also be present in the EAF once it is filled. The roof of the EAF is moved out of the way for the charging process. Fluxes can be added using buckets and or via injection.
- After charging the EAF is closed. The scrap is then melted using electrodes which are introduced through the furnace lid, oxygen is blown into the molten steel to reduce the carbon content and affect its temperature.
- Once the chemistry and temperature of the liquid steel are correct, the steel is tapped into a ladle where the steel chemistry can be altered similar to the integrated process route.
- The steel is then poured from the ladle into ingot moulds or continuous casters to produce semi-finished steel products depending on the required final product.

Figure 4 shows the differences between EAF and BOF steelmaking routes [13].

Figure 4: BOF (top left) and EAF (top right) steelmaking processes. Applications for the different types of steel produced are shown at the bottom of the diagram [13].

The EAF process can produce steel from 100% scrap feedstock. BOF can practically use up to 25% scrap feedstock in the convertor without additional investment.

It is clear from the process descriptions that the type of scrap steel charged into the EAF will have an effect on the steel produced. Control of the scrap charged into the EAF is important, residual elements in the scrap can be difficult to control meaning high quality steels with stringent requirements on impurities can be more difficult to manufacture using the EAF process than the BOF process. Steriles in the scrap have negative impacts on energy consumption, productivity, waste generation and costs of the steelmaking process. EAF can, in theory, be used to manufacture all steel grades that BOF can produce, however, it is known that the BOF process is in an advantaged position to produce steels for certain applications such as automotive strip steel where low residual elements are very important. On the other hand, EAF is established to produce high alloy speciality steels.

4.2 EAF Investment Factors and Costs

The exact costs of investment in EAF technology are very difficult to report due to the complexity of the investment. The purchase of EAF technology alone is not necessarily enough to start new semi-finished or finished steel products from scrap steel.

Investment in new EAF capability is affected by a mixture of practical and fiscal factors:

- Scale of production – larger scales of production require bigger facilities, increasing the cost of investment in equipment, staffing and energy requirements.
- Location – if the new EAF is positioned on a site that already has the supporting energy and transport infrastructure then the investment is significantly lessened, while the investment is significantly higher if the EAF is being positioned on a new site. New sites will require purchase of land; they will need new or extensions to existing road, rail or sea transport connections; they will need to be connected to reliable sources of power and they will need to be positioned close to a population centre that can provide or house the plants workforce.

- Downstream production requirements – the EAF produces crude steel that needs to be refined and processed to produce semi-finished or finished products ready for use. The investment can be scaled up or down depending on the type of downstream equipment required for the end product.
- Decommissioning of existing equipment – where EAFs are replacing existing iron making –BOF steelmaking equipment, existing equipment may need to be decommissioned.
- Business rates – business rates in the UK will be discussed in greater detail in a later section. Business rates for steel manufacture in the UK are charged on the rateable value of the plant in question, the greater the value of the associated site and equipment, the greater the effect of business rates will be on any return on investment.

Estimates for EAF mini-mills alone vary from £100M to £350M [6, 14, 15], with costs for new whole plants (EAF, steel processing equipment and all supporting infrastructure) ranging from £0.8 bn to £5 bn [16, 17]. Big River Steel, the flagship EAF steelmaker in the US, is estimated to cost ~US$2 bn to achieve a capacity of 3.3 Mt per year. Steel Dynamics is investing around US$1.9 bn to build a 3 Mtpa EAF flat product steel mill near Sinton, Texas.

There are no manufacturers of EAF equipment in the UK, so EAF technology would need to be imported before installation. EAF manufacturers include SMS (Germany), Inteco (Austria), Primetals (Austria), SAMA (Italy), Tenova (Italy), HC Furnace (China) and Steel Plantech (China).

4.3 EAF / BF-BOF Emissions and Energy Consumption Comparisons

Energy plays a significant role in the production of steel, representing between 20% and 40% of the total cost for steel production. Table 2 shows the energy sources and representative percentage proportions of supply for the BF-BOF and EAF process routes. The table shows that BF-BOF uses significantly more coal than EAF and that the EAF's primary energy source is electricity. The EAF requires the energy only to melt the scrap and fluxes whereas the BF-BOF route requires additional carbon based energy for the reduction of the iron ore. Coal is used in EAF steelmaking as an additional source of chemical energy and contributes to foaming of chemical slag [18, 19]

Table 2: Energy sources and proportions for BF-BOF and EAF steel manufacturing routes (world average) [18, 20].

Energy Source	BF-BOF Route	EAF Route
Coal	**89%**	**11%**
Electricity	**7%**	**50%**
Natural Gas	**3%**	**38%**
Other Gases and Sources	**1%**	**1%**
	24.5×10^9 J	2.25×10^9 J

The difference in energy consumption means that carbon dioxide (CO_2) emissions from the BF-BOF process are significantly higher than for the EAF process. Table 3 shows a direct comparison of CO_2 emissions between the BF-BOF and EAF steel manufacturing processes, the table includes all possible downstream processes after crude steel manufacture. Table 3 shows that the EAF process reduces CO_2 emissions for steel making by as much as 75%, although this will vary with different downstream operations. The table also shows the criticality of the blast furnace to CO_2 emissions, the blast furnace itself releasing almost five times the tCO_2/t of steel than an EAF. Average greenhouse gas emissions per ton of steel stands at approximately 1.8t/t for the BF-BOF integrated process route in the EU countries. It should be noted that one of the low values for CO_2 emissions in the EAF process in Table 3 is because the emissions from the electricity generated to power the EAF are not included, if this electricity is generated from fossil fuels and is included then the CO_2 emissions will be much higher. Direct CO_2 emissions from the EAF process result from fuel, carbon from electrodes and scrap that is oxidised in the electric arc furnace, and CO_2 sources for slag foaming [21, 22].

Table 3: Direct tCO_2/t emission comparison between BF-BOF and EAF manufacturing routes (world average) [21].

BOF Process Steps	Direct CO_2 emission (tCO_2/t)	EAF Process Steps	Direct CO_2 emission (tCO_2/t)
Coke plant	0.794	Electric Arc Furnace	0.24
Sinter plant	0.2		
Pellet plant	0.057		
Blast furnace	1.219		
BOF plant	0.181		
Bloom, slab and billet mill	0.088	Bloom, slab and billet mill	0.088
Hot strip mill	0.082	Hot strip mill	0.082
Plate mill	0.098	Plate mill	0.098
Section mill	0.084	Section mill	0.084
Pickling line	0.004	Pickling line	0.004
Cold mill	0.008	Cold mill	0.008
Annealing	0.049	Annealing	0.049
Hot dip metal coating	0.059	Hot dip metal coating	0.059
Electrolytic metal coating	0.046	Electrolytic metal coating	0.046
Organic coating	0.003	Organic coating	0.003

Figure 5 shows an overview of the CO_2 emissions, amount of residual elements and scrap consumption for different mixes of BOF / EAF steel production. The figure shows that as the amount of scrap consumed in steelmaking goes up, the amount of residual elements accumulated in each recycling cycle increases, in particular for the 100% scrap-based EAF steelmaking. The amount of residual elements makes production of some steels very difficult, reinforcing the need to sort the scrap steel and minimise the amounts of other waste products in the scrap [6, 23].

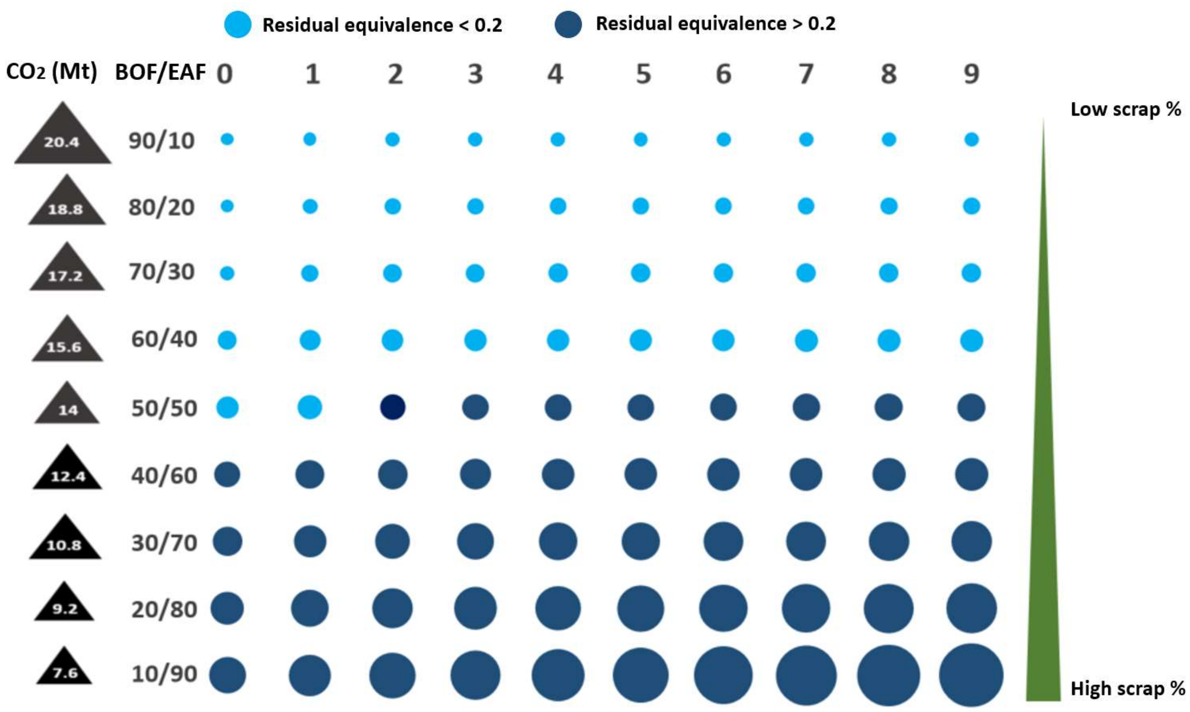

Figure 5: CO_2 emissions, residual element and scrap consumption for different mixes of BOF and EAF steel production. The figure is modified according to the data in reference [23].

5. Barriers to Recycling More Scrap Steel in the UK

This section will discuss the barriers to recycling more scrap steel domestically in the UK.

5.1 UK Steel Recycling Capacity

UK steel manufacturing is currently limited in the amount of scrap steel that it can recycle, Table 4 shows the current scrap recycling consumption in tons per year for each of the UK's major steel manufacturers and other UK steelmakers and foundries. Current total scrap consumption in the UK is approximately 2.6 Mt per year, this is a mixture of purchased scrap and internally arising scrap.

Table 4: UK scrap steel recycling capacities [5, 24]

Steel Manufacturer	Current Scrap Steel Consumption (tpa)
Liberty Steel	300,000
Celsa Steel UK	1,100,000
Tata Steel UK	500,000
British Steel	300,000
Other UK steelmakers and foundries	400,000

There is some unused capacity for scrap usage by the UK steel manufacturers. If all EAF plants were running at full capacity, BOF plants were utilising the maximum amount of scrap (the practical maximum 25%), and the sintering-BF ironmaking use up to 150 Kg scrap per ton hot metal, the UK steel industry would be possible to use up to 6.1 Mt of scrap steel in current steel manufacturing systems. However, this requires significant investment in downstream processes (e.g. hot rolling) and or increasing the export of semi-finished steel products. The volume of scrap that can be incorporated into the BOF process is limited by the impact of scrap or hot metal (made from iron ore and coal) on crude steel costs, technical setup of furnaces and the steel products being produced [12].

The majority of steelmaking capacity in the UK is by the BOF process, around 8.5 Mtpa, compared to a maximum EAF steel production capacity of 2.5 Mtpa. The most scrap steel that the BOF process can consume is 25% of the total mass of metallic materials charged into the furnace. This naturally limits the amount of scrap that current steel manufacturing can consume [12, 15].

The only way that it would be possible to get close to a scenario where no, or very little, scrap steel was exported and scrap steel was consumed internally would require establishment of new scrap-based EAF enterprises and or replacement of BF-BOF plant with EAF plant assuming that the UK steel demand remained at the current level (approximately 11.9 Mtpa). This would represent a very significant/fundamental change to the UK steel industry, with investment into new plant and decommissioning of old integrated plant.

5.2 Relationship Between Recycler and Scrap Steel Users in the UK

Scrap is an internationally traded commodity similar to iron ore and its derivatives. ~600 Mt of scrap steel are bought and sold every year and prices are monitored by global indexes. Figure 6 shows the scrap steel procurement process for UK steel manufacturers. UK steel manufacturers purchase scrap on a monthly basis. Monthly purchases of steel are made as purchasing is driven by scrap price, which fluctuates, as well as production demand.

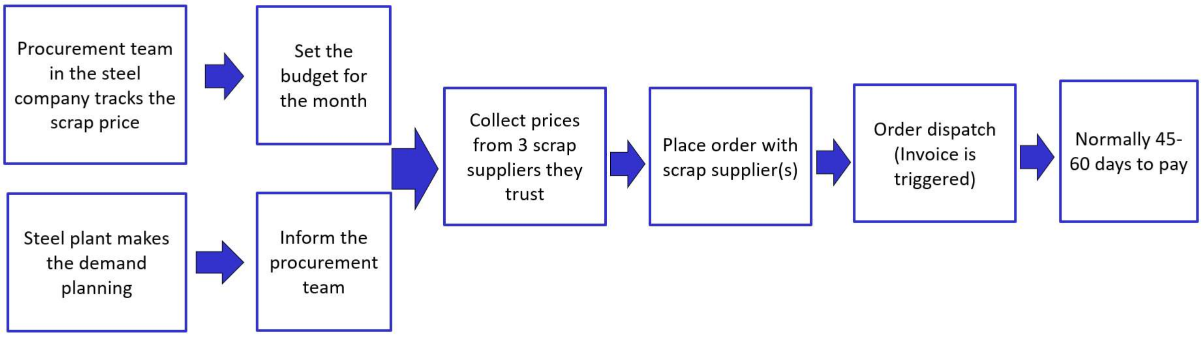

Figure 6: Scrap steel procurement process in the UK steel industry

Payment terms between domestic and international scrap customers (steelmakers) are different, depending on the types of export. Deep Sea exports (via large vessels) are made on a Letter of Credit basis, and international buyers of UK scrap pay immediately on despatch from the port (on transfer of title). UK steel manufacturer payment terms are between 45 and 60 days after the order (scrap steel) is dispatched to the steelmaker meaning that a UK steelmaker pays usually in slower time than an international buyer. It is always preferential for a seller (scrap dealer) to be paid quickly, making export of steel more appealing to scrap merchants [5].

A lack of business alignment between UK scrap suppliers and steel manufacturers is cited by both sides. The reasons for the lack of business alignment are not clear, but may be related to the perceptions below:

- It is perceived that either the steelmaker or the recycler may try to gain an advantage in price negotiation if either side's technical difficulties are fully understood. For example, technical conversations on requirements and difficulties (on both sides) may give advantages to the other side in price negotiation.
- It is perceived that steel manufacturers are not prepared to pay for the grades of scrap steel that are harder to achieve, showing a lack of will to help scrap companies improve their capabilities, a particular example would be clean scrap steel via improved sorting. However, it is not easy to evidence this perception. The reality could be the steel manufacturers probably do not need cleaner scrap at higher costs in the current manufacturing systems.
- The perception of how and why steelmakers downgrade scrap that is deemed as unacceptable. Also there may be a mismatch between the supplier and buyer's aspirations in terms of the value potential of the scrap steel. The subjective nature of quality check (without objective measurement) and physical nature of the materials have created opportunity for quality issues in the past. These reflect the importance of appropriate scrap quality monitoring/control tools which are currently lacking.
- Slow payment terms.
- A perception that some scrap steel grades essential to EAF manufacture are bulked out with other grades, in particular thick old and demolition (heavy melting) grade scrap.

In order to improve steel scrap recycling in the UK, better relationships (ideally strategic relationships) between steel manufacturers and recyclers will be needed. Better relationships will mean that the technical conversations around requirements and difficulties can take place [5, 15]. Proper scrap quality monitoring/control tools can also help build up the business alignment between the scrap supplier and the steelmaker.

5.3 Technical Barriers to Further Recycling

There are several technical barriers which need to be overcome to enable further domestic recycling of steel scrap:

5.3.1 Scrap standards

Scrap recyclers currently sell scrap metal under the UK standards. The UK standard focuses on size, source and safe practices, as opposed to the chemical composition of the scrap. For the steelmaker this means that the levels of residual elements in the scrap steel are not clear. Recyclers can provide scrap steel that meets the UK standards but it may not suit the needs of the steelmakers. The standards for scrap steels could be further improved by incorporating chemistry requirements.

5.3.2 Quality control technology

Regular monitoring and control of scrap quality in terms of yield and residual levels are not practically implemented by scrap merchants and steelmakers. Quality control of scrap steel currently relies heavily on visual inspection of scrap, sometimes aided by spot checks with hand-held XRF measurement, which is not suitable for modern steelmaking. Better, large scale, fast measurement techniques are required which need to be developed and built to a sufficient scale. The technology needs to be available to both the steelmaker and the recycler, ideally with technical development that is led by both parties [5, 15]. There are technologies available to the market place to assist with the provision of better quality scrap that are not currently used as recyclers cannot see the fiscal benefits to using them. The technologies include techniques such as XRT, XRF, LIBS and AI-aided sorting [24, 25].

5.3.3 Implementation of Value In Use (VIU) model for steelmaking

”Value in Use” is the specific value that an asset can generate when in use. Use of the VIU model would move steelmakers away from simply monitoring the cost of scrap to calculating the value of the steel that can be made from each ton of scrap purchased. VIU drives steelmakers away from buying the cheapest scrap that is available to seeing the benefit of buying more expensive, better quality scrap. Better quality scrap has effects on overall yield, electrical energy consumption, productivity, waste generation, electrode consumption, slag generation rate, and flux and alloy consumption. Implementing VIU should also have the effects of improving the relationship between the recycler and the steelmaker as well as making steel manufactured from domestic scrap more competitive [26]. The major UK steelmakers do have their own VIU models, however, proper application of VIU model does require characterisation of the scrap materials such as Fe yield, impurity levels and dirt as accurate as possible.

5.3.4 Transitioning from BOF to EAF steelmaking

There are significant practical technical challenges that steelmakers need to overcome if a BOF site is converted to an EAF site, these include as a minimum:

Switching energy sources – EAF relies on electricity for power, power supplies to existing plants need to be upgraded or changed to make ready for EAF production.

Raw material sorting, storage and movement – BOF plants have large storage areas for blast furnace burden. The switch over to storage of scrap means repurposing of these yards to handle scrap, representing a significant investment and process change.

Expertise – BOF and EAF production are significantly different and require different expertise to manage, operate effectively and produce similar quality of steels while maintaining market share and customer service. BOF plants need to acquire these skills during the changeover process. This is a significant reskilling and recruitment challenge.

6. Factors Affecting Investment in Further UK EAF Plant

Investment into EAF steelmaking facilities will be necessary if the UK is going to recycle scrap steel beyond current capacity and use it to produce low or zero carbon steel. The capital expenditure costs of EAF are large (typically $2 billion for a plant with capacity of 3.0Mt per year), and there are a number of factors that need to be taken into account which affect the operating costs and return on investment for steel manufacturers. This section discusses the major factors that could prevent or compromise investment into EAF plant in the UK.

6.1 Industrial Electricity Pricing

Energy pricing in the UK is comparatively high compared to other steel manufacturing countries. Exactly how much higher than other countries depends on the source of information. According to UK government's Department for Business, Energy and Industrial Strategy (BEIS) published data, in 2019 the industrial energy price (including taxes) in the UK was 11.53p per kWh, in the Netherlands it was 7.57p per kWh, in the USA it was 4.95p per kWh and in Turkey it was 7.02p per kWh. Using this data source, the UK's industrial energy costs are 48.8% higher than the IEA median for industrial electricity [27].

UK Steel completed a sector specific analysis of the energy costs for steel manufacture, comparing UK steel manufacture with France and Germany. The data presented is different as it uses data sourced directly from steel manufacturers as opposed to the aggregated IEA data collected and presented by BEIS. Another source of discrepancy is that steel manufacturers are energy-intensive industry users who pay different rates to industries that use lower amounts of energy. Figure 7 shows energy prices in MWh for steel producers in France, Germany and the UK for 2019/20, the prices are broken down into policy costs, network costs and wholesale electricity costs. It can be seen that UK steel makers pay 80% more than French steel makers and 62% more than German steel makers. Figure 7 shows that UK steel makers pay proportionally higher policy, network and wholesale costs than that of French and German steel makers [28].

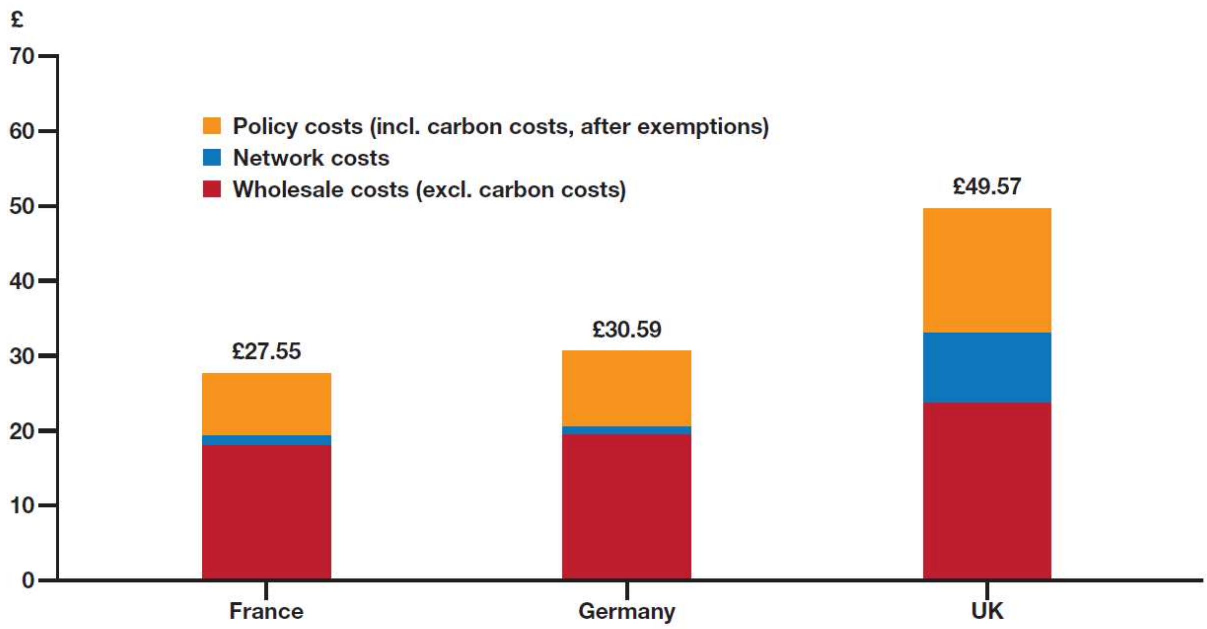

Figure 7: Energy prices (MWh) for steel producers in France, Germany, and the UK (2019/20) [28]

EAF steel manufacture is estimated to use between 300 kWh and 550 kWh of electrical power per ton of steel produced. Assuming a medium value of 425 kWh, a UK based EAF producing 800 kt of steel per year could have electricity cost of £16.9 M per year, whereas the equivalent EAF operating in France would have an electricity cost of £9.4 M per year [28, 29].

The most recently updated information by UK Steel [30] indicates that the difference in energy prices for steel producers between the UK and France/Germany has changed, as shown in Figure 8, that is, UK steel production sites are paying 62% and 86% more than their main competitors in France and Germany, respectively. The difference in energy prices between the UK and German steelmakers has significantly increased.

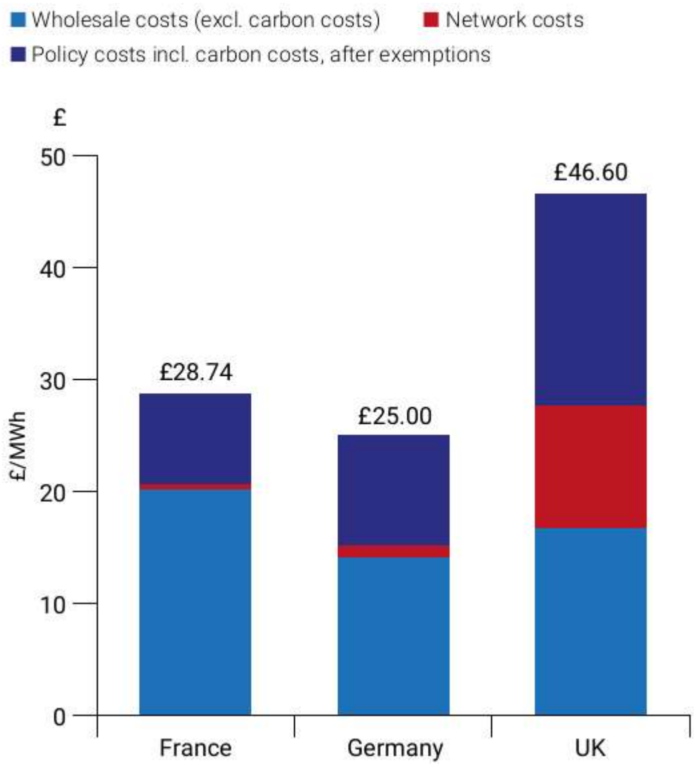

Figure 8: Energy prices for steel producers in France, Germany and the UK (2020/2021) [30]

6.2 Business Rates and Taxes

All UK industries pay business rates. Heavy industries pay business rates based on the rateable value of the companies, and the value is calculated on a number of factors including the size of the premises occupied and the value of the equipment used. For the steel industry this includes items such as EAF, blast furnaces, coking ovens, ship-lifts and building berths, turbines and generators, boilers, washeries for coal and silos [31].

Business rates in the UK are 5 to 10 times higher than in other EU countries and represent a significant burden on UK manufacturing as a whole. 14p in every pound of tax paid by business is paid in business rates. For the steel industry this presents a counter intuitive scenario where investment in lower carbon manufacturing, such as the switch to EAF steel production, is more of a tax burden than continuing to use older, less efficient and less environmentally friendly equipment [12, 32].

Multi-national manufacturers perceive business rates as a barrier to investment since they have a direct effect on a site's profitability, often making investment economically unviable.

UK steel manufacturers pay VAT on the scrap steel that they buy (UK VAT is currently 20%). In other countries the VAT contribution may not be as much or a factor at all. As an example, in Turkey, scrap steel is VAT exempt giving an immediate purchasing advantage over UK steel manufacturers, essentially Turkish steel manufacturers can purchase the same amount of scrap steel as a UK steel manufacturer but for 20% less immediate cost (UK steel manufacturers can reclaim the VAT at the end of the tax year) [33, 34].

6.3 Greenhouse Gas Emission Costs

UK steel manufacturers participate in the UK Emissions Trading Scheme (ETS), which came into force after Brexit. The UK ETS scheme provides continuity from the EU ETS which UK manufacturers had to work to until Brexit. The UK ETS is a “cap and trade” scheme where a cap is set on the total amount of greenhouse gases that can be emitted, the cap is reduced over time, forcing overall emissions to fall. At the time of writing this report (January 2021), full guidance for the UK ETS had not been released [35].

Under the UK ETS steel manufacturers will be allocated an amount of CO_2 that is acceptable for them to emit, beyond this they will need to trade allowances with other manufacturers that are emitting less than their allowance. Carbon trading uses different prices depending on the initiative being used to control emissions, currently the UK carbon price is set at US$ 23.23 (£16.98) per ton of CO_2, for comparison the EU ETS is currently US$ 30.14 (£22.03) per ton of CO_2 [36].

Steel plants are major emitters of CO_2, and the EAF process alone emits 0.24 tCO_2 per tonne of steel made. A UK based EAF plant producing 800 kt of steel per year would produce 192,000 tCO_2 per year, and an equivalent BOF process would produce 1.96 Mt of CO_2 per year. It is clear from these figures that the EAF route produces much lower emissions than the BOF route, and both routes are potentially costly to a steel manufacturer in terms of CO_2 emissions although EAF production has an obvious advantage in terms of emissions trading [21].

The burden of greenhouse gas emissions taxation on EAF investment in the UK becomes clear when analysed against competitor countries. In the EU steel manufacturers will pay for emissions under the EU ETS legislation, currently slightly more expensive than UK ETS trading prices. Lower carbon trading pricing offers an advantage as it reduces the overhead costs of emissions compared to countries with higher carbon trading prices. Non EU/UK countries have different rules, some paying significantly more and some paying significantly less or no emissions taxes at all. As examples, Chinese manufacturers pay as little as £3.92/tCO_2 (depending on the province) and Turkey currently has no tax on CO_2 emissions [36].

6.4 Geographical Considerations for Investment

New EAF steel plant needs to be positioned in a suitable location and be near to a number of services in order to make them possible. It should not be assumed that current steel making sites have all of the services required to support EAF manufacture.

Geographical factors include:

- Power sources – EAF steel manufacture is mostly electrically powered and requires a constant, direct supply of electricity. BOF steelmaking has a lower reliance on electricity and a much higher reliance on gas and coal as power sources. Ideally new EAF plant would be situated next to a power station that could provide an uninterrupted supply or in a place where has adequate electric power supply. Existing power supplies at BOF plant may not be able to support EAF manufacture on top of the power draw from other plants. As an example Tata Steel’s Port Talbot steelworks has a power station which uses by-products from steelmaking to generate power, the plant provides a maximum of 225 MWh, a single 300t melt in an EAF can use as much as 165 MWh, over 50% of the total power produced at the plant. It should be noted that if the Port Talbot steelworks is converted to an EAF plant, the power plant would not be able to operate because of no supply of gas by-products. [29, 37].

- Road, rail and sea connections – Scrap supply to a new EAF plant requires significant transport links, the capacity of the transport links needs to increase with the quantity of scrap being transported to make it cost effective. Sensibly, new EAF plant would need to be placed near to a rail transport node or sea-port to minimise the amount of road travel for the scrap steel.
- Labour – Large/modern steel plants are not labour intensive in terms of labour cost, steel plants do however require a significant number of workers when operating. Tata Steel's Port Talbot plant directly employs 4000 workers and supports a further 12,000 in its supply chain. Any new steelmaking plant would need a ready supply of labour that could be drawn on. Further to this, steelmaking requires skilled labour and would ideally need to draw upon an already trained and educated workforce wherever possible [38, 39].
- Remediation – Closure of large industrial sites incur remediation costs associated with their use, size, location, risk to water source, geology and future use. Steel plants fall into the highest remediation category, incurring costs of at least £305,000 per hectare. Remediation costs might drive a steel maker to convert a current site to EAF steel making instead of building a new site [40].
- Land prices – Industrial land prices vary greatly across the UK and would have to be considered for any investment into a new EAF plant. Steel manufacturing requires large areas of land, Tata Steel's Port Talbot steel works has a footprint of approximately 650 hectares. Table 5 shows 2019 industrial land prices per hectare for the different regions in England. The difference in land price across the different regions is significant with the highest land prices in the South East (£1.55M/ha) and London (£5.08M/ha), and the lowest land prices in the North East (£0.19 M/ha) and North West (£0.47 M/ha) [41].

Table 5: 2019 industrial land prices (£/ha) for different geographical regions of England [41].

Region	£/ha
East Midlands	494,865
West Midlands	631,833
East	845,700
Yorkshire and The Humber	488,810
North East	190,417
North West	467,179
South East	1,554,104
South West	686,892
London	5,083,333

The factors shown mean that siting a new EAF plant is not simple, in many ways it would make sense to site new EAF plant on an existing site as this may already have good transport links and a ready supply of skilled labour, however there may not be the correct amount and type of power available. New sites for EAF plant could be more easily positioned next to new or existing power generation sites, potentially near sources of green energy to reduce emissions, but this may reduce the ease with which skilled labour can be accessed and could mean that transport links need to be extended to meet the new site. The variation in land prices will have an effect on the location of any new manufacturing site, as new sites could be very expensive to acquire and might drive a decision to put a new plant on an already owned, existing site.

7 Opportunities to Encourage Recycling of Domestic Scrap Steel

This section will discuss different interventions that could be used to encourage greater recycling and utilisation of scrap steel in the UK. The interventions are explained discreetly but no single intervention should be treated as a solution that on its own would encourage more recycling of scrap steel. As discussed earlier in the report, to dramatically increase the amount of steel recycling in the UK it will be necessary to build more EAF capacity. This will require measures to change the availability of scrap and the market for steel in the UK.

7.1 UK Steel Demand

In 2018 the UK used the equivalent of approximately 11.9 Mt of crude steel and produced 7.3 Mt of crude steel. At the current steel output (~7.3 Mt per year), the scrap usage can increase from 2.6 Mt to 3.5 Mtpa without additional investment. At full capacity and in the current configuration, UK steel manufacturers can consume up to 6.1 Mt of scrap steel and produce approximately 11 Mt of crude steel, which requires significant investment in downstream processing such as rolling and or increasing the export of semi-finished steel products. The difference between the steel produced at maximum capacity and consumed is around 0.9 Mt. If the UK is to recycle most of the scrap steel that it produces, it will not be enough to simply make more steel, and UK steel manufacturers will also need to have greater shares in domestic and foreign markets [3, 12].

The amount of steel consumed is related to population size. The UK's population is forecast to grow steadily to over 70M by 2029, an increase of 5% in the next 9 years. The infrastructure required to support the extra population will drive steel consumption to higher levels. Other trends that will increase the need for steel in the UK include electrification of transport, building low carbon power generation (which requires more steel) and the increased use of steel in construction. The UK government has forecast the need for 3 Mt of steel for major infrastructure projects over the next 10 years, with an estimated value of £0.5 bn [42, 43].

One way of ensuring that UK steel manufacturers have a larger portion of the domestic steel market place would be for the UK government to mandate that a significant, set percentage of the steel used in all planned major infrastructure, power and defence projects is manufactured and sourced from the UK steel manufacturers. Proper measures must be taken to ensure that this intervention will not increase domestic steel prices. This would provide a guaranteed market for UK providers to sell steel into, making investment into new steel making facilities possible. As an intervention a mandated market share would have to be in addition to current steel demand in the UK, not as a replacement for current demand. This would not necessarily require an increase in the total UK steel demand, but a displacement of internationally traded steel into UK markets. The extremely high levels of capital investment required for a new steel plant mean that the return on investment takes many years. Measures to increase market share could not be short term, they would need to be planned and monitored over long periods of time [12].

7.2 Import and Export Tariffs

Imposing tariffs on the import of finished and semi-finished steel products and export of scrap steel from the UK is a potential means to drive more domestic recycling of scrap steel. This is not a measure that could be carried out in insolation, and without an increase in processing capacity it would lead to stockpiling of scrap steel, therefore using tariffs could only work with an increase in steelmaking capacity.

The most recent examples where import tariffs have been used to defend the steel industry were in the USA. In 2018, the US government imposed tariffs on steel imports from the EU, Canada and Mexico with the intention of pushing US manufacturing to use domestically produced steel, protecting the industry and increasing employment. The tariffs encouraged steel producers in the US to increase the prices for their products, soon after the tariffs were introduced US steel prices exceeded global steel prices (50% higher than European steel prices and 80% higher than Chinese steel prices). This had a negative effect on US manufacturers who had been using imported steel, weakening their competitiveness by pushing their costs up and resulting in loss of business as consumers looked for cheaper alternatives. The exact effects of the 2018 tariffs on US manufacturing are yet to be seen, however the last time that import tariffs on steel were imposed by the US (in 2002) 200,000 jobs were lost in dependant manufacturing sectors due to domestic steel price increases. US supply chains are heavily dependent on imported steel. In 2016, 40% of the steel consumed in the US was imported, this dropped to 26% in 2019 after the tariffs. Modern supply chains are global, tariffs on imports can act to break supply chains up, having a negative impact on overall productivity [44-46].

The effects of tariffs on the export of scrap steel to encourage it to remain in the UK are harder to distinguish. It is likely that tariffs on the export of scrap steel would drive down the price of scrap steel in the UK making it more appealing for UK steel manufacturers to buy and encouraging them to invest in EAF production. On its immediate merits this would seem like a good idea, however without the increased capacity to use the cheaper scrap steel that would become available the tariffs would likely lead to stockpiling of scrap as foreign buyers turned to other sources and scrap remained in the UK unused. It is clear that this would be detrimental to the UK recycling industry, it could lead to recycling companies turning their attention to other more profitable areas of recycling and the potential of less scrap steel being available in the domestic supply chain due to a lack of profitability. A counter argument to this is that recyclers would increase their prices for scrap steel in order to account for the cost of the export tariff, making them less competitive internationally and making scrap prices in the UK more expensive for steel manufacturers (costs would increase to account for a potentially smaller market place). A further adverse effect of export tariffs is that it would encourage law breaking and dysfunctional behaviour that would make it more difficult for reputable operators in all stages of the supply chain to stay competitive [5, 12, 15].

7.3 Through Supply Chain Carbon Emission Taxation

Current carbon emission taxes are charged to individual companies, the taxes start at the point where a raw material enters a company site and stop at the point where a finished product exits a company's site. This is a simple and practical way of taxing companies as it makes emissions calculations relatively easy. As a means of measuring and taxing the actual emissions of a supply chain it misses some aspects of production.

Current taxation allows manufacturers to stop calculating carbon emissions at the end of their production processes, ignoring the emissions created further up and down the supply chain. If emissions taxation were to consider the environmental cost of different transportation modes, as well as including where materials were sourced, it might encourage more domestic production.

Current taxation process promotes the concept of offshoring carbon – in order to reduce emissions that are expensive (via carbon taxation) in one country, manufacturers make the products in a country where emissions are cheap (via less or no carbon taxation). While this lessens the cost of carbon emissions for a country, it does not solve the harmful emissions problem, but it simply moves it abroad and the overall carbon emissions for making a product either stay the same or worsen.

A large portion of UK scrap steel is exported to Turkey, where it is recycled in EAF process into semi-finished or finished product, and a significant portion of this is then exported to other countries where it is further processed into finished products. Turkey does not currently have a tax on carbon emissions, so has no incentive to control Turkish steel industry emissions [36].

A further addition of carbon emissions through the export of steel scrap is caused by international shipping. International shipping is a major source of carbon emissions, transporting 85,000 tons of scrap steel to Turkey emits approximately 9640 tons of CO_2 (2.64 tCO_2 / nautical mile). Transport emissions would be reduced by using road, or shorter coastal shipping for domestic recycling [47].

A carbon tax on products that takes into account their entire supply chain as it stretches across international borders, would ensure that carbon emissions from shipping and countries which have no or little carbon emission taxation are taken into account. It would make products that are manufactured in more carbon intensive supplies chains more expensive, and this cost difference could be enough to encourage more domestic recycling of scrap and would represent a more responsible approach to carbon emissions taxation.

A refinement of this option may be to use tax or payment rebates for using locally sourced, greener, raw materials for steel making. This would have the same effect as carbon taxation on a supply chain but has the advantage of not being seen as a tax and being less contentious.

7.4 Subsidies for Improved Scrap Sorting Technologies

Reducing the amount of unwanted and accumulated residual elements in recycled steel is key to producing high quality steel products from scrap steel. As shown in Figure 5 as the number of recycling loops increases, so do the amount of unwanted residual elements in the steel. It is therefore extremely important to sort recycled material before it gets to the steel recycler.

There are two main causes of impurities for recycled steel:

- Other waste products being mixed into the steel from fragmentation or shredding processes. A commonly cited example of this is copper from wiring becoming mixed into steel during the shredding process of vehicles.
- Sorting of one type of steel from another. Current sorting techniques are inadequate and lead to highly alloyed grades of steel being mixed with other grades, increasing the amounts of unwanted residual chemical elements to be managed.

The primary means of sorting scrap metal into ferrous and non-ferrous is magnetisation, with some more advanced sensor techniques employed to further sort ferrous scrap steel after that. Technology is available to better sort ferrous steel types and is already used for plastics and non-ferrous metals. Deployment of these technologies to scrap steel would require research and innovation and would be costly due to the scale of implementation. Large scale shredders and sorting equipment are estimated at £90M (for a scale of 1 Mt per year scrap sorting plant) and are a significant investment for a recycling company [5]. This requires a collaborative approach to investment and pricing policy by considering the benefits in the whole supply chain.

Further improved sorting technology is not being developed or deployed by recycling companies because of a number of factors. Firstly, a lack of business alignment between steel manufacturers and recycling companies means that the technical conversations between recyclers and steel manufacturers to fully understand the problem do not take place. Secondly, steel manufacturers do not need much cleaner scrap at higher cost in their current manufacturing system, or it is perceived that steel manufacturers do not want to pay a premium for better sorted scrap steel, which is a disincentive to scrap recyclers to invest in better technology to support the steel manufacturers. Thirdly, advanced fast sorting technology that can distinguish chemical composition of scrap needs to be developed or need significant investment to implement [5, 15].

Research and development subsidies for recycling companies (and steelmakers) could help them to develop and build technology of a suitable scale to provide scrap steel sorted by both composition and grade at a competitive price to steel manufacturers. If a capable technology is already available, the industry should work collaboratively to get it implemented. This would improve the overall capability of recycling companies for both domestic and international scrap steel provision. An intervention like this may also help to improve the relationship between scrap steel users (steelmakers) and the recycling companies, since the technical development would need to be a joint effort.

7.5 Circular Supply Chain

To enable the increased use of scrap steel in the UK steel industry (e.g. by increasing the scrap-based EAF steel production), increasing the amount of clean scrap steel would be needed to produce high quality steel products. This can be achieved through the establishment of a circular supply chain, in which steel manufacturers work with scrap suppliers to collect industrial scraps from the manufacturers that they supply [46]. Empirical evidence suggests that the adoption of circular supply chain brings four types of value to the steel industry, which include:

Environmental value: Using recycled materials in steelmaking enables all firms in the supply chain to reduce carbon emission and landfill waste, which ultimately contribute to the establishment of a green corporate image. In addition, retaining more scrap steel for domestic use reduces the carbon footprints of shipping scrap to overseas markets.

Economic value: Industrial scrap generated from the manufacturing production line is mostly high-quality scrap. Its use in steelmaking is more operationally efficient, avoiding the potential risk of using dirty scrap with high amounts of residual chemical elements (e.g. poor quality of steel products). In addition, profitability can be sustained if steelmakers, scrap suppliers and manufacturers are able to be bonded in a long-term contract which build closer ties. This enables them to align with each other and work towards mutual business objectives – delivering value to end customers at the lowest possible cost.

Information value: Collaboration and coordination are key to the adoption of a circular supply chain, in which the information flow between the firms can be improved as the consequence. This presents an opportunity for steelmakers to track and trace steel products that they supply and understand its performance through feedback from the manufacturers. Moreover, establishing greater supply chain visibility into each party enables steel manufacturers to plan its inventory and production more effectively as they have access to real time information from both the demand and supply side.

Customer value: Sustainability has become a critical factor when manufacturers assess their steel suppliers. Forming a circular supply chain enables steel manufacturers to access premium scrap steel where the chemical composition matches the production requirement more closely, which largely reduce the quality variation of steel products.

In order to support the adoption of circular supply chain in the steel industry, the following areas would need to be improved:

Financial investment: Additional investment such as the set-up of Supply Chain Finance scheme needs to be in place to smooth the cash flow in the supply chain. The adoption of Supply Chain Finance brings banks/non-bank financial institutions (NBFI) into the transaction, who is able to provide 100% payment to the supplier at lower interest rates once the steelmaker approved the invoice. The steelmaker has to clear the invoice with bank within the original due date or extends the payment terms. The immediate advantages for steelmakers are longer supplier payment terms, optimised cash flow and stable supply chain, while key advantages for scrap suppliers include reduction of trade receivables, better cash flow and strong relationship with steelmakers. Moreover, additional investments into scrap sorting and logistics are necessary to support the operation. Scrap suppliers have a strong intention to set up the circular supply chain to deliver premium scrap, but there needs to be a financial incentive for them to do it.

Strategic alignment: Empirical evidence strongly indicates that there is lack of alignment in the current supply chain, in which companies operate in silos. This is due to poor communication, lack of business alignment and low rate of technological innovation. The first critical step for setting up the circular supply chain is to build integration between firms, where they are taking a coordinative approach to plan and manage business activities. This enables them to create swift even supply chain flows (information, material and cash) and manage buffers (inventory and production) effectively.

Digital technologies: The adoption of digital technologies is in a nascent stage in the steel industry, which is a key inhibitor to the supply chain visibility. Poor visibility into external partners significantly affects the decision making in supply chain planning, and potentially increases the supply chain risks and operating costs.

7.6 Improving the Relationship Between Recyclers and Steel Makers

The relationship between UK steel makers and recyclers is key to efficient and productive recycling of scrap. The current relationship is characterised by misalignment, misunderstanding, short term contracts and slow payment terms.

Better, more efficient recycling of scrap steel can be enabled by better control of scrap quality (e.g. appropriate scrap quality monitoring tools), development of new scrap standards, and implementation of advanced sorting technologies. However, another important aspect is that the relationship between recyclers and scrap steel users need to improve. Establishment of a joint body of recyclers and steelmakers, that stretches across the industry with stakeholders from the major scrap companies and steelmakers would enable [5, 15, 24]:

- Improvements in understanding of technical requirements for scrap and where current scrap standards fall short of steelmakers' requirements.
- Recyclers to understand why better scrap quality control is required in terms of steelmaking, providing incentive and justification for investment into new technologies.
- Steelmakers to understand the challenges and the associated costs to overcome the challenges that recyclers have in terms of scrap preparation and sorting.
- Recyclers and steel manufacturers to share and collaborate on research and development on scrap quality control technologies and practical issues such as scale up and analysis speed.

- Build business alignment between recyclers and steelmakers, changing the way scrap is procured, ideally changing it toward a more tactical purchasing method similar to that used for iron ore.

There are no disadvantages to improving the relationship between recyclers and steelmakers. Any improvement in the relationship will help to make recyclers and steel manufacturers more competitive in domestic and global markets.

7.7 Research and Development

As discussed, significantly increasing the scrap usage in the UK steel industry or converting the BF-BOF integrated route to the scrap-based EAF route is a pathway to achieve low or zero carbon emissions for the UK steel industry and use domestically generated steel scrap to manufacture high quality steel products for the UK manufacturing supply chains. Making this transition will require significant research and development as an enabler. If the UK government strategically plan, initiate and financially support the R&D activities, together with the steel community (steelmakers, recyclers, academics and RTOs), it would reduce risk in the transition, place UK steel recycling at the forefront of green steel production as well as support the steel industry. Identified R&D themes include, but are not exclusive to, those listed below:

7.7.1 Advanced scrap sorting technology

Currently UK steel scrap recyclers do not have high drivers to invest in R&D to advance scrap sorting technologies. There are two main aspects for this: scrap steel processed through existing facilities can be easily sold under good payment terms and conditions to international customers who may not have high quality requirements and UK steelmakers currently do not have stringent quality requirements and have no incentive to buy premier scraps at higher price. This scenario will drastically change if the UK steel industry is transformed to the scrap-based EAF steel manufacture.

A typical example where advanced scrap sorting technology would be an advantage is the production of automotive strip steel, residual chemistry levels (e.g. Cu, Sn) need to be very low (<0.15%) and can be easily achieved in the BOF process. However, to produce these steels in the EAF route requires advanced scrap sorting technologies to provide very clean, very low residual scrap for the steelmakers to manufacture automotive strip steel from. Advanced sorting technologies are being developed and implemented in other sectors such as non-ferrous scrap recycling and plastic recycling. Investment in support for the development and implementation of this sort of technology would be well received due to its importance, scale and cost.

7.7.2 Quality monitoring and control tools

Scrap quality monitoring relying on visual inspection and or aided with spot analysis (hand-held XRF) does not meet the stringent requirements of steel scrap quality and can cause disputes in quality between the supplier and the user. Investment in R&D should enable the development and implementation of modern quality monitoring and control tools which are quantitative, having a rapid response and intelligent.

7.7.3 Scrap pre-treatment technology

Advanced scrap sorting technologies and quality control tools can ensure the scrap quality to meet the needs of steelmakers for the production of high-quality steels. However, under certain circumstances where the steel quality requires extremely low residuals, extra pre-treatment for scrap steel is needed. The steel community could be supported to develop novel and cost-effective technologies to pre-treat the steel scrap, in particular to remove residual elements.

7.7.4 Using scrap-based EAF to produce high quality steel

In theory, any steel product that can be produced by the BF-BOF integrated route can also be produced by the scrap-based EAF route. However, it is well recognised that the BF-BOF route is much more advantageous than the scrap-based EAF route to produce certain steel grades such as ultra-low carbon, low nitrogen, low sulphur and clean steels. Research and development is essential to establish the technical routes for the manufacture of those specific steel grades in a cost-effective way via scrap-based EAF route. If a small proportion of steels cannot be made by the scrap-based EAF route economically, efforts could be made to develop alternative steel grades compatible with the EAF route which could meet the customer needs.

7.7.5 Alternative iron sources for scrap-based EAF technologies

As shown in Figure 5, repeatedly recycling will significantly increase the levels of residual elements in steel scrap. An important measure is to use alternative iron sources to dilute the residual levels. The alternative iron sources can be direct reduced iron (DRI), hot briquetted iron (HBI), hot metal or pig iron from BF ironmaking or alternative iron making routes. UK is currently lacking such production capability. UK research and development in this area is also significantly lagging behind international competition. This is evidenced by non-strategy and investment at different levels from government to industry. This may restrain the UK steel industry to achieve net zero carbon emissions by 2050.

8 Economic and Social Importance of UK Steel

Steel is key to every part of the UK's future, it is everywhere we look, it is in most of the products we buy and where it is not in a product it was used to make that product. Steel has forged the modern world.

Today's UK steel industry is a fraction of what it was, it is an industry that has been in decline for a long time. However, the UK steel industry continues to play an important part in the UK's infrastructure, manufacturing, transport, energy, manufacturing and defence sectors, in particular the UK demand for steel has been predicted to continuously grow in the coming decades.

The UK steel industry directly employs around 32,000 people and contributes £1.6 bn to the UK economy, about 0.1% of the UK's economic output and total workforce. The indirect contribution to the UK economy is harder to calculate, conservatively there are a further 96,000 employees relying on the steel industry is its supply chain. The indirect contribution to the UK's economy is related to the UK's construction, manufacturing, energy, rail and defence sectors, all sectors which are heavily reliant on steel from UK suppliers. Table 6 shows the direct employment and economic contribution figures for industries using UK steel, approximately 26.6% of the UK's GDP and 6M jobs are directly dependent on steel for their productivity [2, 48-51].

Table 6: Employment and economic contributions of industries reliant on UK steel [2, 48-51]

Sector	Employees	GDP Economic Contribution (%)
Manufacturing	2.6M	9
Construction	2.4M	6
Defence	260k	1.4
Energy	180k	3.2
Rail	600k	7

UK steel manufacture has national strategic importance, although the exact strategic importance is hard to measure. Steel is a foundational material, and the UK economy relies on it in the same way as it relies on plastic, cement, paper and ceramics. Examples of where steel has national importance include the UK defence and energy sectors which rely on supply of specialised heavy castings from UK suppliers such as Sheffield Forgemasters and Goodwins International. The UK transport sector sources steel directly from UK suppliers – 96% of the UK's rail network is manufactured by British Steel and Celsa Steel UK supplies steel into major infrastructure projects in the UK, with steel often travelling less than 500 miles from Celsa's plant to construction sites. Some of the world's biggest manufacturing brands (e.g. Nissan UK and JLR in the automotive sector, JCB in the construction sector) source significant amounts of steel from UK suppliers. [52, 53]

Iron and steel have been at the heart of the UK for almost 200 years. The Bessemer process for steel manufacture was invented in the UK and was recognised as the most important technique for making steel in the 19th century. At its peak in the early 1970s the UK produced 28 Mtpa of steel and employed over 300,000 people. The steel industry has been in decline ever since, but the social impacts of a once massive industry continue, "steel towns" such as Port Talbot and Motherwell were built around steel plants and were an integral part of the town's identity. The loss of steel plants is not just the loss of a manufacturing plant, it is the loss of entire communities and its impacts should not be underestimated. Steel manufacture is highly skilled work, increasing the amount of steel manufacture will drive up the amount of highly skilled work wherever the steel is manufactured, bolstering local economies and supporting communities [54].

The UK steel industry is at a critical point with the opportunity to transform itself to a modern steel industry for manufacturing high quality steel products to meet customer needs in a sustainable (net zero), cost effective manner. This can only be achieved through a combination of the desire of the steel making community, government support and maximised utilisation of the abundant scrap steel supply that the UK uniquely has. If any of these three aspects is lacking it will adversely affect any potential success of this transformation. A modern steel industry in the UK will produce high quality steel products for the UK economy, which will significantly amplify the value of the scrap steel generated in the UK. Otherwise, the UK will fall into a position of exporting its unique scrap source without adding value (which will be the case when the global scrap supply is increasing) and importing steel products at high prices and with greater carbon leakage.

9 Conclusions for Scrap Steel Recycling

The following conclusions can be drawn from the information gathered for this report:

- The UK produces 11.3 Mt of scrap steel per year and consumes approximately 11.9 Mt of new steel products. 8.7 Mt of scrap steel are exported each year. It should be possible to recycle more domestically produced scrap steel to satisfy the UK demand of steel.
- The scrap usage in the UK steel industry can increase from the current 2.6 Mtpa to 3.5 Mtpa at the current UK crude steel output (7.3 Mtpa) and without additional investment.
- It is possible for UK steel manufacturers to recycle greater quantities of domestically produced scrap steel using current plant facilities, this would increase usage of domestic scrap up to 6.1 Mtpa, but would only be possible with significant investment in downstream processing (e.g. rolling) and greater market share for UK steel and or increasing the export of semi-finished steel products.
- If the UK steel industry moved towards majority EAF steel production and away from majority BF-BOF steel production, consumption of much greater amounts of domestic scrap steel would be possible. Theoretically it would be possible to recycle all of the UK's scrap steel into finished steel products using the EAF process.
- The CO_2 emissions (0.24 tCO_2/t) from scrap-based EAF steelmaking processes are significantly less than the unabated BF-BOF steelmaking process (1.96 tCO_2/t on average). EAF steel making combined with renewable energy and recycling of domestic scrap presents a real opportunity to produce steel with low or zero carbon output.
- Investment into EAF plant requires very large amounts of capital expenditure, estimates for EAF range from hundreds of millions of pounds for mini-mills into billions of pounds for entire steel plants and infrastructure. Steelmakers in the UK have a number of headwinds which provide significant barriers to investment. These include electricity pricing, business rates, greenhouse gas emission taxes and geographical considerations. Interventions in these areas would make investment in EAF steelmaking in the UK much more likely.
- There is no single opportunity to encouraging greater recycling of domestically produced scrap steel. There are however some initiatives which should be supported above others. It is clear that to recycle more domestic steel scrap UK steelmakers will need to have better global and domestic market shares as well as other derived benefits to encourage investment in new capability. Any intervention that builds the relationship between recycling companies and steelmakers in the UK will be positive: it will enable research and development into better facilities and equipment, and it will build business alignment and put scrap merchants and steelmakers in a more competitive position. Support for research and development will help both the steelmakers and recycling company.
- Taxation as a means to encourage and drive greater recycling of domestically produced scrap is difficult and must be applied in a way that does not affect other parts of UK manufacturing chains. Evidence gathered shows that tariffs on scrap steel and finished product imports and exports are detrimental to domestic supply chains as they push raw material costs up, driving production costs at downstream manufacturers up. The use of a carbon tax on an entire supply chain might encourage scrap to be used domestically as it would place a tax on products manufactured or processed in countries without current carbon taxation, and it has the advantage of enabling global supply chains to still be used without being seen as deliberately protective and potentially prevents increases in product price as it does not directly impose barriers to international trade. The "Carbon Border Adjustment Mechanism (CBAM)" has been discussing in EU in recent years, however, CBAM is not legally binding yet at the time of writing this report (January 2021). It is worth comparing the "through supply chain carbon emission taxation" that we proposed here with CBAM in the future.

10 UK Scrap Aluminium Recycling

10.1 UK aluminium industry

Cheaper imports from China and higher energy costs are often cited as the main reasons for the closures of aluminium smelters in the UK. Only one primary smelter in Fort William (Alvance British Aluminium) remains in operation in the UK, producing around 50,000 tonnes of aluminium each year, generally cast in 10 tonne ingots. The company also operates smelting facilities, which also includes two neighbouring hydroelectric stations and a complex of on-site bio-diesel units. Primary aluminium production is mainly in China, and the UK has to be self-sufficient in secondary aluminium (scrap aluminium).

There are fourteen secondary smelters (refiners) in the UK, the vast majority of which are located within the Midlands and the North West of England. Outputs from these refiners are ingots (to specific alloy specifications) supplied onto further processing plants for producing end-market products. Many of the wrought alloy processors are integrated as subsidiaries of large, global aluminium companies (e.g., Novelis UK Ltd, Norsk Hydro) and the ingots from secondary smelters are used internally within their own production processes.

The UK major market segmentation for aluminium is transport manufacturing industries (35.6%), construction industries (26.4%), equipment manufacturing industries (18.1%), packaging industries (15.0%) and others such as chemistry and pharmaceuticals (4.9%). [55]

Both exports and imports of aluminium are high in the UK. The value of industry imports is at an estimated £2.1 bn in 2020-21 with annual growth rate of 2.3% to satisfy approximately 93.1% of domestic demand. The domestic aluminium industry revenue is estimated to be £1.3 bn in 2020-21, £1.2 bn of which is export sales. [55]

10.2 Scrap aluminium recycling

Total aluminium recycled in the UK was 800,000 tons in 2019, additionally 450,000 tons of scrap aluminium was exported to outside Europe. Meanwhile, ~150,000 tons of scrap aluminium were also imported into the UK, which is high purity scrap for specific use. The predicted aluminium recycling opportunity is 1.6 Mt per year in 2030. The main reasons are quoted that changing applications will result in 30% of all Aluminium in service, reaching the end of life by the year 2030, and light-weighting (by using aluminium alloys) is a dominant trend in automotive. Out of the fourteen aluminium recyclers in the UK, Novelis is the biggest recycler (~200,000 tons per year), Hydro is the second largest (~100,000 tons per year), and the rest are much smaller. [56, 57]

Scrap aluminium collection is an established industry. Two collectors are specialised in scrap aluminium only, supplying 30,000 tons of scrap aluminium per year in total. The majority of scrap aluminium is supplied from the same scrap merchants as scrap steel. Modern scrap sorting can result in over 95% series segregation for re-melting feed stock. Organics, dried and physical shaken off are sent for fertilizer; plastics can be electrostatically sorted; steel can be extracted by magnetism; and non-ferrous copper can be removed using eddy currents. Scrap aluminium can be sorted into “Aluminium Alloy Series” by X-ray Florescence (XRF). LIBS (laser-induced breakdown spectroscopy) is also reported to enable elemental analysis and separate multiple alloys at high accuracy. Strict sorting of scrap into tight alloy grades could enable recycling of alloys into specific product types. However, the scrap aluminium in the UK has not been sorted into tight alloy grades yet. Only one large recycler has implemented XRF technology in their own processing step, while the rest recyclers (refiners) rely on scrap suppliers.

Scrap aluminium price is determined by London/Shanghai stock markets. Similar to scrap steel trading, the payment for domestic purchase is in general 3 months, however, the seller is paid while the scrap is loaded into ship for exports. The transport of scrap aluminium is by lorry in the UK and EU and by ships to other countries (e.g., India), at almost same costs. [56, 57]

10.3 Opportunities and Challenges

There is sufficient scrap aluminium generated within the UK, which is 1,100,000 tons per year now and projected to be 1.6 Mt in 2030. Recycling scrap aluminium can save 95% of energy consumption compared to primary aluminium production, significantly reducing the industry carbon footprint. If the energy is from renewable sources, the UK has a big opportunity to establish a net zero green aluminium industry.

Proper sorting could significantly increase the value of the scrap aluminium for either exporting or domestic use. A significant barrier to aluminium scrap re-use in high grade applications is the incompatibility of different grades in differing use, particularly with respect to their silicon content. As a result, the value of mixed scrap aluminium (without proper sorting) is only 15% of the price of the alloys that made from the scrap while the properly sorted scrap can be 50 to 60% of the alloy price. [56] UK currently exports to outside EU ~450,000 tons of scrap aluminium without proper sorting. Significant added value (up to 45% increase in value) will be obtained if all the scrap aluminium is properly sorted to grades before selling. For recycling within the UK, proper sorting will enable the production of high-quality aluminium alloy at lower costs and less environmental impact, that is, reduced aluminium loss, energy consumption and emissions.

In order to sort the mixed scrap into grades, the scrap collectors (scrap merchants) and scrap recyclers need to invest significantly in modern scrap sorting technologies. Modern technologies such as XRF and LIBS are either on the market or under development. So far only one large company in the UK has implemented the XRF technology in their processing route.

The UK aluminium industry does not have adequate process routes, for example, an integrated route from scrap sorting through scrap melting/casting to downstream processing (rolling) to final products. This integrated route may need half billion pounds of investment. Currently the large companies re-melt the scrap aluminium into ingots, send the ingots to their forming plants in Europe mainland, and then sell back the final products to the UK. This is also reflected by the fact that the UK imports much higher value of aluminium than that of exporting. This limits the capability of the UK aluminium industry to produce high quality aluminium alloys to meet the customers' requirements in the UK.

The UK has some established research centres in aluminium; however, significant efforts are needed in research and development in scrap aluminium recycling, process, and product development by using scrap aluminium, and decarbonising the industry to achieve the net zero target, preferentially under the joint force between industry, RTOs, and academics.

The UK Government could play a critical role to rebuild the UK aluminium industry from various aspects, for example, 1) to create a fair and attractive environment to attract investors to invest in the UK aluminium industry. This has been discussed in previous sections for scrap steel utilisation, such as policy incentives to help the industry in electricity price, business rate, etc; 2) to provide financial support to the UK aluminium industry for investment in new, green technologies; and 3) to consider policy incentives to promote upcycling (e.g., increasing the standard of proper sorting of scrap aluminium within the UK).

10.4 A brief Summary

The UK has a big opportunity/investment possibility to establish a green aluminium industry, based on the abundant supply of scrap aluminium, to meet the continuously growing domestic demand of high-quality aluminium products, and to increase exporting value by exporting high quality products instead of low value mixed scrap. Significant efforts are needed to invest heavily in process technologies from scrap sorting through melting/casting to downstream processing (e.g., rolling). Government could play a critical role to provide policy incentives to promote upcycling, and create an attractive environment (electricity price, business rate) to attract investors to invest in UK aluminium industry, and even provide financial support to the UK aluminium industry for investment in new, green technologies. This study is focused on scrap steel recycling with some touches on scrap aluminium here, and an in-depth assessment on the UK scrap aluminium recycling is recommended to carry out in the future.

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