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STEELING FOR A SUSTAINABLE FUTURE:

HOW THE UK STEEL INDUSTRY COULD COMPETE THROUGH SUPPLY CHAINS

UKRI Engineering and Physical Sciences Research Council

Research Project

Critical Technological Assessment of the Viability of Future UK Steel Production

The 'Future Viability' project brought together academics across multiple disciplines to critically evaluate the technologically viable steel manufacturing routes, which can maximise the use of the abundant supply of steel scrap and produce high quality steel grades, to meet the UK economic development and realise the transformation to a low carbon steel industry.

This research project was funded by Engineering and Physical Sciences Research Council (EPSRC) (Project Reference: EP/S013318/1). The key research collaborators included Advanced Steel Research Centre, Supply Chain Research Group (WMG, University of Warwick) and industrial partners – Tata Steel, Liberty Speciality Steel and British Steel.

The Supply Chain Research Group focuses on the end-to-end supply chain management, which aims to provide recommendations for practitioners to address operations challenges and achieve increased sustainability and productivity. We hope you find this report insightful, and welcome any questions or feedback you may have. You can reach the team at SCIP@warwick.ac.uk.

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Executive Summary

What will the future of the UK steel industry look like? The industry will find out over the next 30 years. In the era after the Economic Recession, steel has been traded as a low cost commodity in the global market due to oversupply of steels from some emerging countries. This has pushed UK steelmakers ever closer to breaking point, in particular regarding declining sales and shrinking industry size. However, the launch of the 'Net Zero Emission' law in June 2019 provides both challenges and opportunities. Producing steels through the BF-BOF (Blast Furnace-Basic Oxygen Furnace) integrated route generates a huge amount of CO_2 emissions, making steel the most carbon intensive product in the UK. Selling such products at a steadily low price does not bring any benefits to the steel industry, especially when the operating costs are relatively higher in this country compared to those of international rivals.

To support the shift towards the low carbon economy by 2050, adopting a scrap-based steelmaking route is inevitable in the near future, as turning recycled scrap into new steels via EAF (Electric Arc Furnace) produces only small amounts of onsite emissions. Despite ongoing research on technological development, it is time for steelmakers to rethink how they could make the U-turn to increase profitability, productivity and sustainability through supply chain (SC) innovation.

This report provides an overview of the current state of the scrap steel SCs in the UK and lays out possible strategies and enablers for future growth. An SC assessment was conducted to uncover operational issues in the areas of new product introduction, plan and source (procurement), make (production), deliver and return (recycling). To prepare firms for a more sustainable future, we provide a set of strategies.

To improve the current SCs, firms should:

- Adopt a 'process approach' to build an E2E (End-to-End) SC integration
- Establish circular SCs to enable the material flow
- Implement SC finance solutions, such as reverse factoring, to facilitate the cash flow
- Deploy digital technologies to support the information flow

To support future transformation, firms should:

- Consider different scrap sortation models
- Renovate the business model to add more value with less steels

We understand that our recommendations are not a panacea. Our intention is that this report should explain the role of supply chain management (SCM) in the steel industry and provide guidance that prepares firms to be more profitable, productive and sustainable through effective SCM practices.

Introduction

The UK steel industry is now facing more tremendous challenges than ever. In the era of post-financial crisis, steelmakers have been struggling to make profits in the world commodity market due to fierce competition from low-cost countries. Internally, historical data indicates that the UK annual consumption of steel is around 11.9Mt, in which 5/6ths of demand is supplied by the import of high value steel products (strips) from the EU, while the UK produces and exports some low value semi-finished (ingots and blooms) and finished steels [1]. On the other hand, as the most emission-intensive industry, steelmakers are under extreme pressure to be carbon neutral by 2050.

The inherent recyclability of steel makes it a renewable asset, meaning steel scraps are great alternative sources to iron ores and coals used in steelmaking, as they only produce a small amount of onsite emissions [2]. As the UK is a mature steel economy, domestic arising steel scrap will be able to fulfil the total steel consumption in the next 20-30 years if all steels are made with recycled scrap. This presents great opportunities for the UK steel industry to gain a competitive advantage through technology and business model innovations, in which SCM plays a critical role [1]. It is without doubt that businesses in the (scrap) steel SCs will have to rethink the SC network design and operating model.

This report provides an overview of the UK scrap steel SCs based on a recent assessment study, in which areas for improvement have been identified throughout the entire SC. This leads to the development of a set of recommendations for optimising the current SCs (short-term) and supporting future transformation (long-term). In this report, we focus on three areas:

- Mapping the current landscape of the UK scrap steel SCs
- Identifying the operational issues through an SC assessment study
- Developing the strategies and enablers for future growth

About our methodology

To develop a holistic overview of the UK scrap steel SCs, we have engaged with senior management from companies in the steel and metal recycling industry. A four-stage research design was developed for this study.

Stage 1: Case study identification
Five companies were selected to cover a broad scope of SC activities (e.g. steelmaking and scrap recycling).

Stage 2: Scoping study
Through site visits, workshops and semi-structured interviews, the business overview, organisational structure and SC context were defined.

Stage 3: Situation analysis
SC mapping activity was conducted with a group of relevant stakeholders from each case company to identify key SC players, operating processes and managerial challenges in the current scrap steel SCs. Follow-on semi-structured interviews with individuals were conducted to identify factors that both enable and inhibit the SC sustainability.

Stage 4: Validation
Research findings were presented to case companies and the wider community in the steel industry for feedback.

Current landscape of the UK steel industry

Steels in the UK are produced via two basic routes: BF-BOF (Blast Furnace-Basic Oxygen Furnace) and EAF (Electric Arc Furnace). BOF has a long history as a dominant steelmaking technology worldwide, which produces steel using raw material inputs (i.e. iron ores and coals). EAF has become an alternative to BOF in recent years due to its 'greenness' – operating using recyclable steel scrap. The two technologies offer different competitive advantages (Figure 1) [3].

- Scrap consumption – EAF takes up to 100% scrap whereas BOF takes up to 25-30% scrap depending on other production factors
- Tolerance to high residual scrap – EAF only takes 'clean' (low residual) scrap whereas BOF can take 'dirty' (high residual) scrap
- Primary material consumption – EAF uses a small amount of primary (virgin) materials whereas BOF takes up to 75% of primary materials
- CO_2 emission – BOF produces much higher CO_2 emissions than EAF due to the consumption of coal in ironmaking
- Energy consumption – EAF consumes more energy (electricity) than BOF; however, the total energy consumed by the scrap-based EAF route is at least 50% less than that by the BOF route
- Product range – BOF can produce a wider range of steel products than EAF

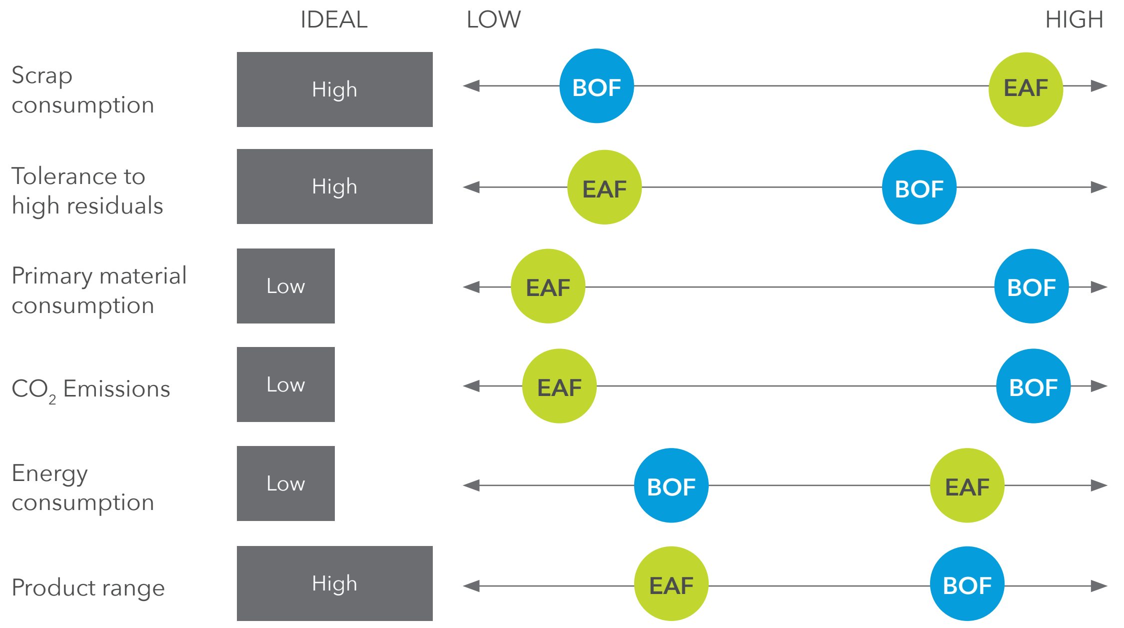
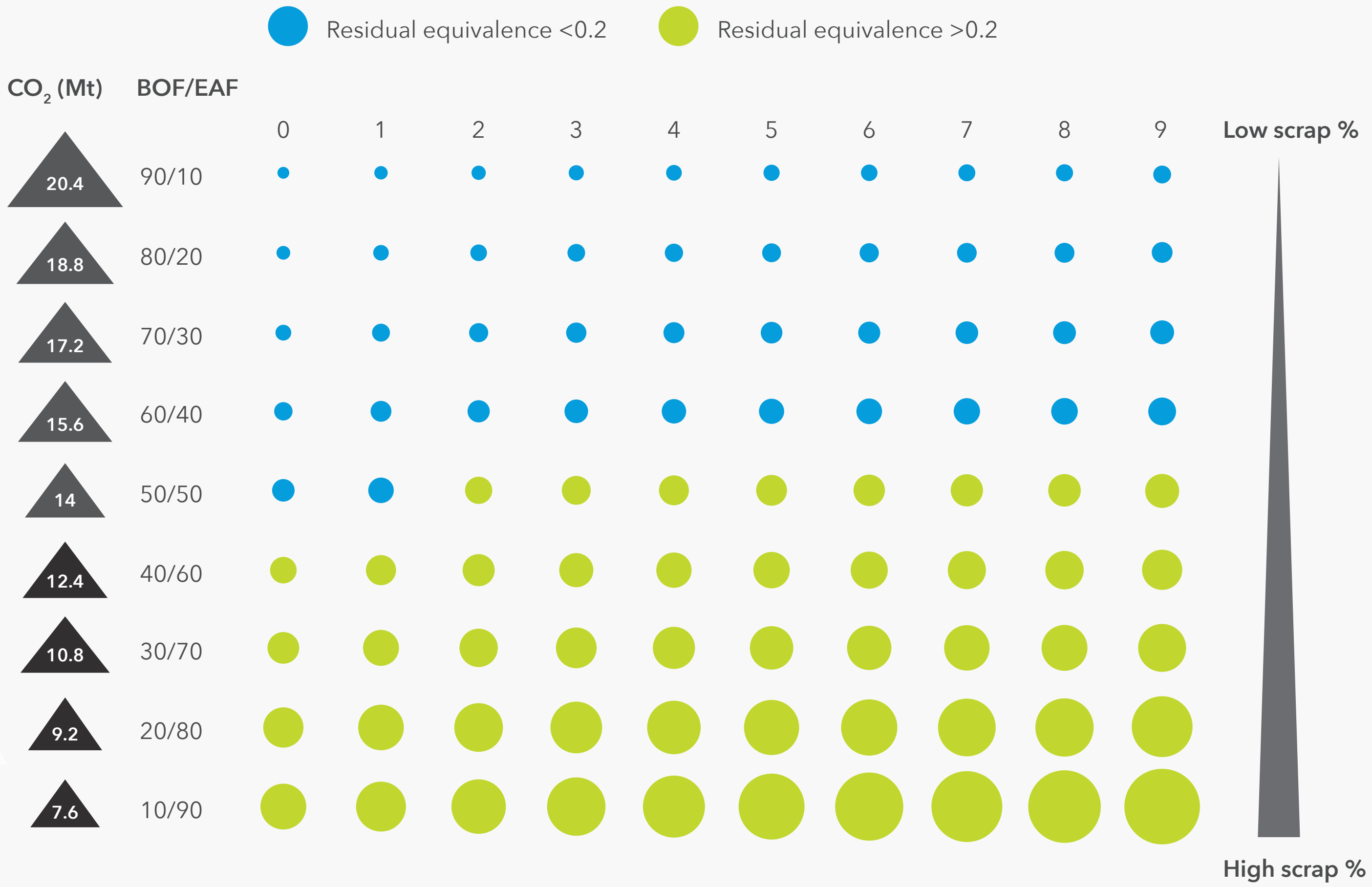


Figure 1. BOF & EAF technologies offer different competitive advantages

In the UK, the annual production of crude steel is 7.3Mt, circa 5.7Mt of which is from the BOF route as opposite to EAF (circa 1.6Mt). To support the shift towards 'net zero' by 2050, steelmakers have to rethink their production strategy by considering the ratio of BOF to EAF route in the steelmaking process. From now until 2050, the UK generated scraps are likely to go through multiple cycles based on the average life cycle length of steel in consumer products (e.g. Construction 10 years, Cars 12.5 years, Rail 25 years) [4]. A recent study [5] by the WMG Advanced Steel Research Centre (ASRC), University of Warwick, modelled the various combinations of BOF/EAF technologies to investigate the accumulation of residual elements through multiple cycles (Figure 2). The key findings indicate that:

- Increasing the % of BOF produces higher CO_2 emissions and consumes lower scrap content, in which residual elements accumulate gradually through multiple cycles.
- Increasing the % of EAF produces lower CO_2 emissions and consumes higher scrap content, in which residual elements accumulate quickly through multiple cycles.



*Note: 0.2 is the threshold used by steelmakers in the UK; BOF is charged with 20 wt.% scrap according to industry practice

Figure 2. Accumulative residual element builds up significantly as EAF becomes a dominant production technology [5]

To increase the scrap usage in steelmaking, it is critical that firms can access 'clean' (high grade) scrap. However, empirical evidence indicates that steelmakers face various SC issues to support the transformation to scrap-based steelmaking. For instance, 80% of UK scrap is being exported to the overseas market [6], where the demand for both 'clean' and 'dirty' scrap is higher than in the UK. To gain an overview of the current SCs, an assessment was conducted to identify areas for improvement.

Things to know about the supply chain…

What is a supply chain?

There is no single definition of what we mean by SC, but common understandings tend to align with three perspectives.

- A **network** that connects the upstream suppliers and downstream customers
- A series of **flows** within the business, including the material, information and cash flow
- A **process** that links the core functions – planning, procurement (source), manufacturing (make), logistics (deliver) and recycling (return)

Overall, SC can be defined as [7]:

'A set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer.'

What is supply chain management?

SCM is all about coordinating business activities with SC partners to deliver value to end customers, which is referred as [8]:
'A management of upstream and downstream relationships to deliver value at the lowest cost for all parties in the whole chain.'

Effective SCM increases the visibility, integration and sustainability, which are operationalised through five principles:

1. **Understand market demands** – segmenting the demands into different types based on product variability and volume
2. **Develop tailored practices to support different demand types** – developing and implementing tailored business practices to support each demand type
3. **Create supply chain flows** – adopting a process-oriented approach to establish alignments within and between firms to enable the flows (of material, cash and information)
4. **Just in time delivery** – optimising inventory and production (buffers) throughout the SC to deliver products at the right time
5. **Improve process efficiency** – continuously monitoring and improving the process to maintain highly efficient management

To support SCM, the SCOR (Supply Chain Operations Reference) model is implemented by firms to address and improve decisions in five general areas:

- Plan – demand forecasting, sales and operations planning
- Source – procuring raw materials
- Make – manufacturing
- Deliver – order management, warehousing and transportation
- Return – recycling

Assessing current scrap steel supply chains to identify issues

A typical scrap steel SC (Figure 3) in the UK involves multiple key players – scrap suppliers, steelmakers, original equipment manufacturers (OEMs) and end customers, in which the flow of scrap and steel is passing through each player inside and outside the UK to form the chain.
Three types of scrap are generated in the SC [9] (Figure 3).

- **Home (or internal arising) scraps** are generated during the steelmaking, casting, rolling and finishing processes within a steel plant
- **Industrial (or prompt) scraps** are generated during the downstream manufacturing of steel products by first tier customers
- **Post-consumer (or obsolete) scraps** are generated when the product containing steel reaches the end of its life cycle

Those scraps need to be processed via the following steps before they enter the steelmaking process, and this is usually carried out by scrap suppliers.

- **Collecting/Sorting** – collecting scraps from different sources and sorting them into different material categories (i.e. steel, aluminium, plastic)
- **Shearing/baling** – cutting metals into small pieces and compressing them into cubical blocks for ease of transportation and ready for use in steelmaking
- **Shredding** – fragmentizing materials into the required size to prepare for the next step (separation)
- **Separation** – using methods such as floatation, magnets, X-rays, density, and even hand picking to recover metals from other materials (plastics, foam, glass, aggregates, woods, rubber etc.)

The above are general steps for processing scraps before they are delivered to steel plants, and the process may vary depending on the type of scrap.

In terms of quality, home scraps are the most valuable type of scrap due to the known metallic components [1], but they only account for 20% of the global supply. The quality of industrial scrap is generally much better than post-consumer scrap due to a lower level of contamination. However, post-consumer scraps have the potential to be high quality (low residual and high iron content) if they are processed properly in the SCs.

In 2018, the UK generally…

- consumed 11.9 Mt of steels
- manufactured 7.3 Mt of steels
- generated 11.3 Mt of scrap steels (2.6 Mt of scrap was used in domestic steelmaking while 8.7 Mt of scrap was exported to overseas markets)

"industrial scrap is generally much better than post-consumer scrap due to a lower level of contamination."

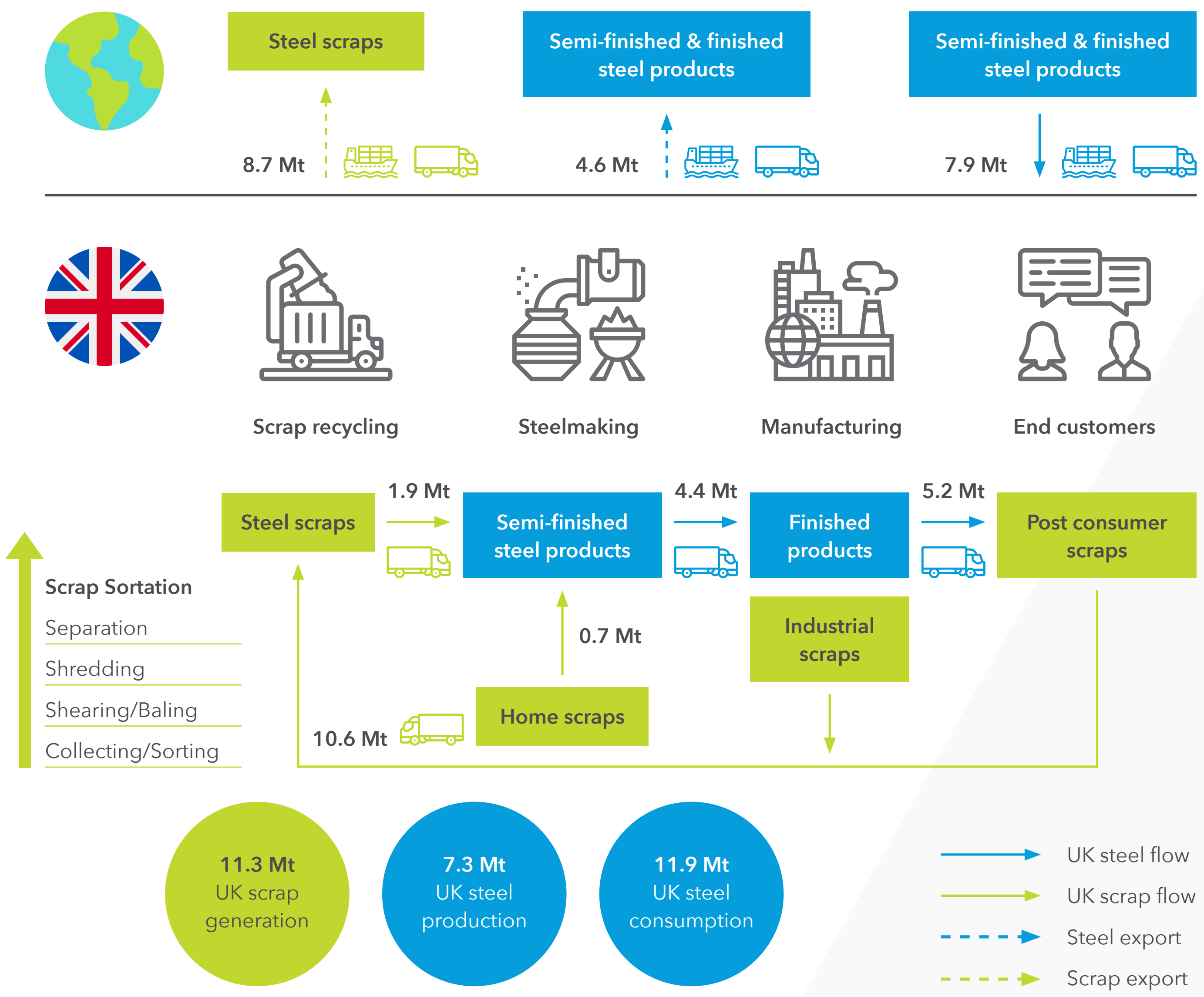


Figure 3. Overview of the UK scrap steel SC [3]

The SC map (Figure 3) indicates that the UK steel industry is in a weak position in the global value chain. The industry figures highlight that the domestic steel demand relies heavily on the import of high value finished products containing steels from the EU, while the UK exports low value steels in large quantities [1]. More importantly, the oversupply of low cost steel in the global market has kept the price very low since the economic crisis. This means that the UK fails to make profits from the most carbon intensive products of steel. To improve SC sustainability, the following assessment (Figure 4) identifies the vulnerabilities to and opportunities for creating more value.

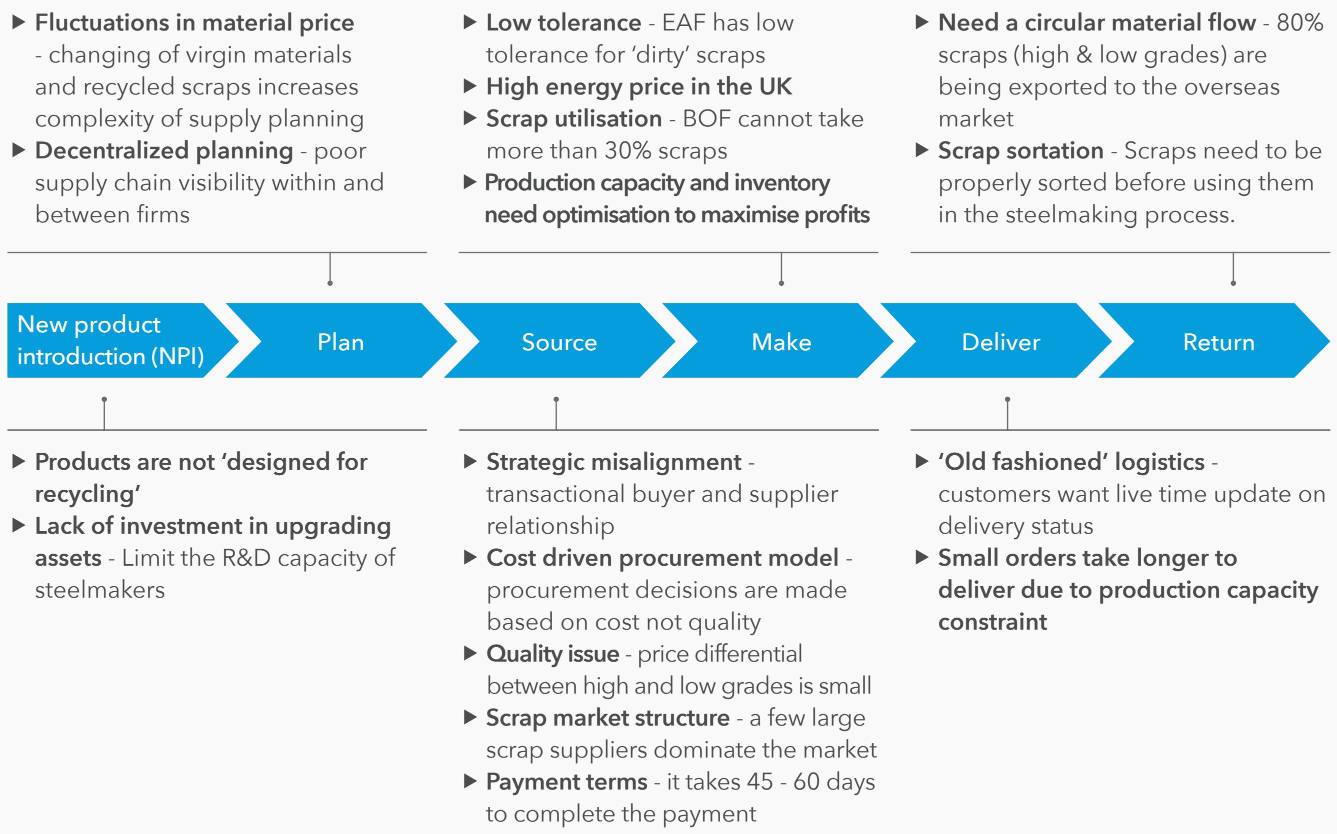


Figure 4. Assessing the current SCs to identify issues

New product introduction (NPI)

Steels are traditionally designed and manufactured in a linear model, where the focus is on turning raw materials into (semi-) finished products with little consideration of recycling. As sustainability becomes an important element of business strategy for steelmakers, recycling and utilising recovered materials needs to be considered in a circular business model. This transition requires steels to be designed and manufactured for recycling, which needs steelmakers and OEMs to align with each other to improve the product design. Challenges such as fierce global competition and high operating costs have meant the industry struggles to make profits, hence steelmakers have not had sufficient funds to upgrade production assets and strengthen R&D capabilities. This has significantly limited the technical and business model innovations that could potentially reduce our dependence on importing high value steels from overseas.

Plan

SC planning assists firms to fulfil customer demand with appropriate supply, in which the supply, demand and production plans are made based on historical sales data. Steelmakers regularly purchase primary materials, scrap steels or a mix of the two depending on the production route. The material price is determined by the international index, which often fluctuates as global demand moves up and down. The price fluctuation makes the SC planning more difficult for steelmakers especially when they are procuring on a monthly basis (i.e. scrap).

In terms of the planning strategy, some steelmakers have adopted decentralised planning, in which each business unit (clustered by steel products) is responsible for the production planning for the particular steel product. This means that the headquarters has limited visibility of sales data and inventory levels, which is a potential barrier for resource efficiency in the entire business. Similarly, the lack of visibility between the steelmakers, scrap suppliers and OEMs affects the planning of the E2E SC, which is commonly caused by misalignment among the players, limited access to real-time data and underdeveloped digital technologies.

Source

Source refers to the procurement of materials to fulfil planned or actual demand. The current procurement model in the steel industry is mainly cost-driven, in which steelmakers buy scrap on a monthly basis from one of the most cost-competitive suppliers. This allows them to avoid over-dependency on a particular supplier, to spread supply risks, and also prevents them from establishing a close tie with their supplier. This kind of transactional relationship indicates that there is a lack of SC integration in the steel industry, which therefore leads to some constant disagreements on scrap quality and payment terms. Empirical evidence highlights that there are several contributing factors. First, there is no standard measurement of quality in place to regulate the scrap's 'cleanness', hence it is challenging to judge if the delivered scrap meets or fails to meet the technical requirement of steelmakers. Second, poor cash flow in the SCs (it takes up to 45-60 days for scrap suppliers to receive the full payment), which puts the UK buyer in a less competitive position compared to the overseas buyer who can pay much faster.

Evidence suggests that the current market failure is because the price differential between high and low grades of scrap is too small, and the current cost-driven procurement model is biased towards low-cost scrap without carefully considering the cost implications of using better quality scrap in steelmaking. Studies also show that internal misalignment between the production and procurement teams can exist, where the former focuses on improving operational efficiency (buy good quality scrap) and the latter focuses on minimising overall operating costs (buy cheap scrap). Moreover, as already mentioned, the lack of an objective measurement for quality control makes it difficult to match supply with demand. Steelmakers are buying scrap based on the UK scrap catalogue (developed based on the scrap grading system), which only provides a general description of size and source but no specification of residual elements. This has caused disagreements over the quality of the scrap purchased, which is not measured in the trade.

The current supply base of scrap steels is formed by four tiers (Figure 5). Tier 1 suppliers are large scrap recycling companies who process and supply more than 1 million tons of scrap locally and internationally each year. Tier 2 suppliers are large city scrap recycling companies who process and trade less volume than 1 million tons per year. Tiers 3 and 4 suppliers are based in small cities and towns. They collect scraps from different sources and supplying them to Tiers 1 and 2 without appropriate sortation. The scrap quality and price are increased as suppliers move up the tier. Both local and overseas steelmakers are mainly buying from Tiers 1 and 2 suppliers, as they are capable of sorting scraps and delivering them in large volumes through various transportation channels. This hierarchical structure gives Tiers 1 and 2 suppliers a strong bargaining power in the SCs, which significantly increases their influence in the market trend.

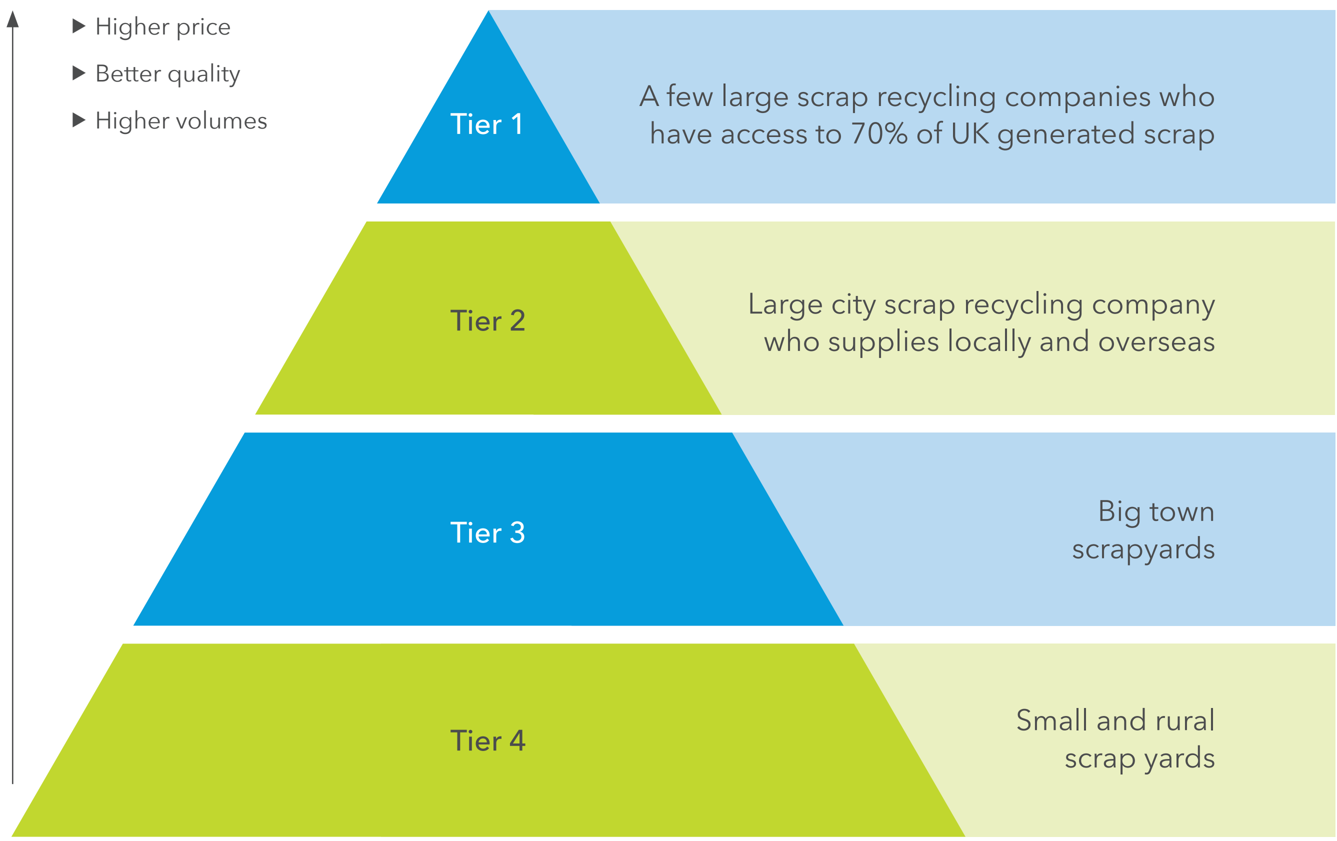


Figure 5. The hierarchical structure of the UK scrap market [6]

Make

Make refers to the steelmaking process that currently faces three challenges.

The energy price for UK steelmakers is higher than their main competitors in other countries (e.g. 62% higher than France and 86% higher than Germany in 2020/2021) [10]. This puts the UK steelmakers in a less competitive position due to such high production costs. Increasing scrap usage in steelmaking only aggravates the issue, particularly when scrap contains high residuals, as melting non-Fe content will use more energy.

EAF technology has relatively lower tolerance compared to BOF in taking 'dirty' scrap, in particular high residual elements have a negative impact on the high steel products. If the tolerance can be increased, steelmakers could save costs by procuring cheap scrap. Compared to EAF, BOF can take 'dirty' scrap up to 25% but the plant may struggle to achieve the 'net zero' target by 2050 with the current production assets due to high CO_2 emission.

The inventory and production capacity (known as 'buffers' in the SC) need to be optimised to increase profitability with fixed operating costs. Currently scraps are procured at a certain time of each month and inventoried in the scrapyards for nothing as the plant is waiting for more orders to come in to even out the production costs. This has the potential to cause some of the delivery issues.

Deliver

Small sized orders are likely to be delayed in delivery as it takes a longer time for steelmakers to match the size of the production batch. This is because manufacturing small orders is not cost-effective due to the high fixed operating cost.

Steel products are delivered by third-party logistics through road transport (mainly lorries) within the UK and by a mix of road and water (vessels) transportation to overseas markets. The delivery is quite old-fashioned and low tech, which does not allow customers to access the instant status of the order. This affects customer satisfaction, particularly when the order is not delivered on time. To reconfigure the delivery system, capital investment is needed but this is difficult to fulfil due to the lack of available capital investment.

Return

The return process refers to the recycling and reusing of scrap steels in steel production.

There are approximately 11 Mt of scrap (see Figure 3) generated in the UK each year, of which 80% is being exported overseas, primarily to Turkey, Pakistan, Egypt and Spain due to low local demands. The current scrap export volume may prevent the national transformation from BOF to EAF production, during which the demand for scrap quantity and quality will reach a peak in the next 30 years. In terms of scrap quality, steelmakers rely on scrap suppliers to sort the scrap before delivery to the steel plant. However, evidence shows that scrap quality is a major issue in the SC and needs to be improved through the advancement of proper sortation technologies.

Overall, the assessment provides a holistic view of SC issues, which informs the development of strategies and enablers for future growth.

> "Evidence suggests that the current market failure is because the price differential between high and low grades of scrap is too small"

Strategies and enablers to build sustainable scrap steel supply chains

To address the identified issues, this section presents a set of key strategies and enablers for optimising the current SCs (short-term) and supporting future transformation (long-term).

Optimising the current supply chains

We propose four strategies to help in improving the scrap steel SC operation.
It is important that the strategies should be adopted collectively and focusing on one of them will not be sufficient.

The four strategies are:

1. Adopting a 'process approach' to build an E2E SC integration
2. Establishing circular SCs to enable the material flow
3. Implementing an SC finance solution, such as reverse factoring, to facilitate the cash flow
4. Adopting digital technologies to support the information flow

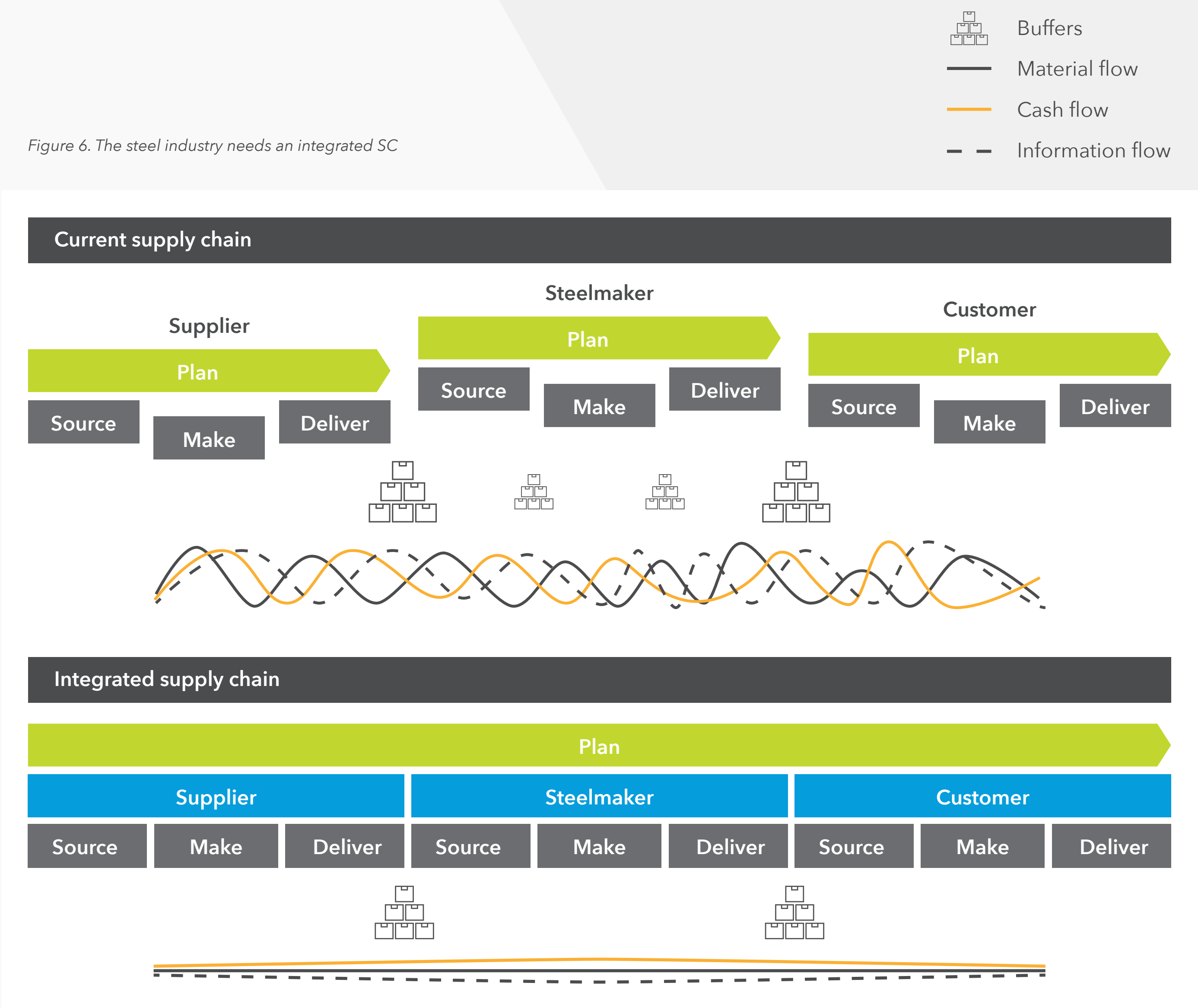
Strategy 1:
Adopting a 'process approach' to build an E2E SC integration

E2E SC integration enables firms to retain competitive advantage through strategic and operational integration across the business, in which all firms in the chain are taking a coordinative approach to planning, procuring, producing and delivering products and services [11]. Achieving the state of 'integration' requires firms to progress through two critical stages – internal and external integration. Internal integration allows business functions, particularly plan, source, make and deliver within the firm, to align and support the overall business strategy. External integration enables firms to build a strategic alignment with their suppliers and customers to deliver value to end customers at the lowest possible cost and achieve mutual benefits.

Empirical evidence indicates that the current state of the scrap steel SCs is lacking in integration (Figure 6), which leads to the following issues uncovered in the SC assessment.

- poor strategic alignment within and between firms in the scrap steel SCs
- 'lumpy' material, information and cash flows
- poorly managed buffers (inventory and production capacity)

Figure 6. The steel industry needs an integrated SC



To establish an integrated SC, there needs to be a 'paradigm shift' in the way that steelmakers manage their business and connect with scrap suppliers and OEMs. The majority of manufacturing firms have adopted a 'functional' approach in organising their business, which creates many silos that break down the SC flows [12]. This significantly inhibits the E2E thinking, as functional silos focus on their operational performance rather than considering the performance of the entire business/SC. Shifting from 'functional' to 'process' thinking is a critical step change to establish the SC integration, which generally brings four benefits (Figure 7) [13]:

- Reorganising business activities following SC flows to enable a seamless process
- Collaborating with SC partners to establish an integrated planning system
- Establishing E2E SC visibility through effective communication and information sharing
- Taking a coordinative approach with suppliers and customers to right-sized buffers (inventory and production capacity)

Benefits of 'process thinking'	Seamless process	Integrated planning	Better visibility	Effective buffer management
From	Business is organising around functions	Decentralised planning and functional segmentation	Unable to visualise real-time situation	Managed by individual functions - buffers either too big or too small
To	Build business linkages following SC flows	Integrated business planning and segmentation across SC	Able to visualise the real-time situation across E2E SC	Managed by coordinative approach across SC - right-sizing buffers
How to transform	Organise business around functional linkages and integrate all stakeholders	Collaborate with SC partners and integrated planning and segmentation	Integrate real-time situation visibility across E2E SC	Take coordinative approach across E2E SC to right-size buffers

Figure 7. Adopting a 'process' approach brings four benefits [13]

The adoption of the 'process approach' enables strategic alignment within and between firms in the scrap steel SC, which eventually leads to a close tie between buyer and supplier and improved E2E visibility. This would enable [3]:

- Increasing the understanding of technical requirements for scrap between scrap suppliers and steelmakers
- Development of the objective measurement of scrap quality to meet demand with appropriate supply
- Both sides to understand each other's challenges and associated costs (i.e. scrap procurement budgeting, investment in new scrap sorting technologies)
- Collaborative R&D on scrap quality improvement

Strategy 2: Establishing circular SCs to enable the material flow

To support the transition from BOF to scrap-based EAF steel production, the demand for clean scrap steel will be increased to produce high quality steel products. To support the increasing demand, establishing circular SCs is necessary for steelmakers, scrap suppliers and OEMs to co-create values by recycling and reusing secondary materials through the integration of forward and reverse SCs.

This would create four types of value (Figure 8) [14]:

- **Environmental value** is achieved by increasing sustainability through scrap utilisation in steelmaking. This allows firms in the chain to establish a 'green' corporate image and achieve a significant reduction of landfill waste and CO_2 emission. Moreover, retaining scrap for domestic usage reduces carbon footprints generated from shipping scrap to overseas markets.
- **Economic value** is achieved by reducing costs through operational efficiency. In a circular SC, scrap suppliers, steelmakers and OEMs would work together to collect industrial scrap from the OEM's production line, in which the residual elements are low and chemical composites are known. This saves costs by eliminating the risks of using dirty scrap in steelmaking.
- **Information value** is achieved by collecting data from the SC to support the overall operation. A circular SC requires steelmakers to work closely with scrap suppliers and OEMs to understand the performance of products through their life cycle, which generates data that can be fed back to the R&D to support innovation initiatives such as 'design for recycling'. Furthermore, improved SC visibility enables each entity in the chain to plan the inventory and production more effectively by capturing accurate supply and demand data.
- **Customer value** is achieved by fulfilling customer demands and increasing satisfaction through sustainable product and service offerings. Sustainability has become a critical factor when OEMs assess their suppliers, leading to potential opportunities to establish a tailored SC that includes scrap suppliers, steelmakers and OEMs to recycle scrap generated from supplied steel products. This allows steelmakers to access premium scrap, in which the chemical composites exactly match the demand and therefore reduce the quality variation of steel products.

To support the adoption of a circular SC, firms must understand the enabling and inhibiting factors, which include:

- **Financial factors** – Utilising 'clean' scrap in the steelmaking process significantly reduces operating costs by eliminating carbon emissions and product quality issues. However, increasing the circularity of material may require upfront investments, such as setting up a tailored SC to enable steelmakers to collect scrap from the OEMs that they supply. Although scrap suppliers have logistic capabilities that can be deployed to support this, the reconfiguration of the delivery system needs investment to make this happen.
- **Institutional factors** – The government and local authorities play a critical role in supporting the operation of circular SCs in the steel industry. Factors such as financial incentives and recycling policy need to be considered. The UK steelmakers face high operating costs, in which business rates and energy costs make up a huge amount of the cost. Therefore unstable financial performance makes improving the SC a low priority in the business. There are areas in the recycling policy that need improvement to ensure that scrap is collected and sorted following a standard procedure. In particular, the UK scrap standard should be further developed to specify the residual element within each type of scrap. Having a standard measurement for scrap quality will contribute to the establishment of alignment within (procurement and production function) and between (scrap suppliers and steelmakers) firms in the SC.
- **Operational factors** – The current logistics in the scrap market are well established to move materials around the country, which can be reconfigured to improve the circularity. Industry figures indicate that UK-generated scrap significantly exceeded the domestic consumption, implying that local supply can support the transformation from BOF to EAF. This puts the UK in a strong position to transform into scrap-based steelmaking. Empirical evidence indicates that the lack of information visibility, dependence and business model alignment, are critical inhibitors to forming a more circular SC. To address these issues, the industry needs to establish an integrated SC to build strategic alignment between key players, and then operational alignment will follow to enable material, information and cash flows.
- **Social factors** – From the customer perspective, offering 'green' products increases the firm's competitiveness in the market as the consumer demand for sustainable products has been increasing in recent years. From the firm perspective, retaining a balance between profitability and sustainability urges firms to rethink the way that they operate to achieve a balance in the long-term. For example, the cost-driven procurement and resource efficiency-driven production in the steel company need to be aligned to support the business objective.
- **Technological factors** – Empirical evidence indicates that advanced scrap sorting technologies are available in the market but not deployed due to the lack of financial incentives. This suggests that a clear price differential between high and low grade scrap would motivate scrap suppliers to improve the scrap sorting technologies. Having a stable supply of 'clean' scrap will surely support the national transformation to scrap-based steelmaking. The digitalisation of the SC has become generalised as it enables connectivity, visibility and traceability throughout the SC. However, the digital SC in the steel industry is in a nascent stage, and needs significant development to improve the information flow.

Environmental Value	Economic Value	Information Value	Customer Value
▶ Corporate image ▶ Green processes and products	▶ Cost reduction ▶ Risk mitigation	▶ Product and process information ▶ Product lifecycle	▶ Serving customers better ▶ Corporate image and brand protection

Financial	Institutional	Operational	Social	Technological
✓ Value of recycled materials		✓ Capability of reverse logistics ✓ Supply and demand balance	✓ Awareness ✓ Customer perception	✓ Technical feasibility of scrap sortation
× Upfront investment costs × Operating costs	× Financial government incentives × Recycling policy	× Information visibility × Dependency × Business model		× Digitalisation

Figure 8. Drivers and enablers of/inhibitors to forming circular SCs

The next step for improving the circularity of material flow is to explore ways of turning inhibitors into enablers, most of which can be addressed through the improvement of information and cash flows.

> "Effectively implemented finance solutions will provide competitive advantage and financial certainty to the involved SC members."

Strategy 3:

Implementing an SC finance solution, such as reverse factoring, to facilitate the cash flow

Insufficient cash flow is one of the key issues in the current scrap steel SCs that prevents steelmakers from accessing high-quality scrap. To address this, SC finance solutions can be adopted [15]. SC finance is emerging as a core initiative to unlock the trapped financial resources in the SCs and mitigate the concentration of financial risks. Effectively implemented, it will provide competitive advantage and financial certainty to the involved SC members. The innovative financial instruments offered under the SCF (supply chain finance) umbrella such as reverse factoring (confirming) can manage and steer the financial flows while keeping them aligned with the material and information flows in the scrap steel SCs. Reverse factoring results in a win-win situation for the involved members by improving their net working capital and liquidity, strengthening their relationships with the SC members and reducing the probability of their bankruptcy [16].

The key actors in reverse factoring comprise both primary and supporting members. In the scrap steel SC, primary members include steelmakers and scrap suppliers while supporting members commonly refer to banks or non-bank financial institutions (NBFIs). The process of reverse factoring starts with an agreement between the Bank/NBFI and steelmaker. Once agreement is agreed upon, it involves the following six steps (Figure 9):

1. Scrap supplier sends an invoice to the steelmaker.
2. Steelmaker approves the invoice and sends confirmation to the Bank/NBFI.
3. Bank/NBFI sends invoice approval notification to the scrap supplier and makes it available for early payment.
4. Scrap supplier requests an early payment.
5. Scrap supplier receives the early payment from Bank/NBFI (less interest and fees).
6. Steelmaker makes payment to Bank/NBFI on the maturity date or extends the payment terms.

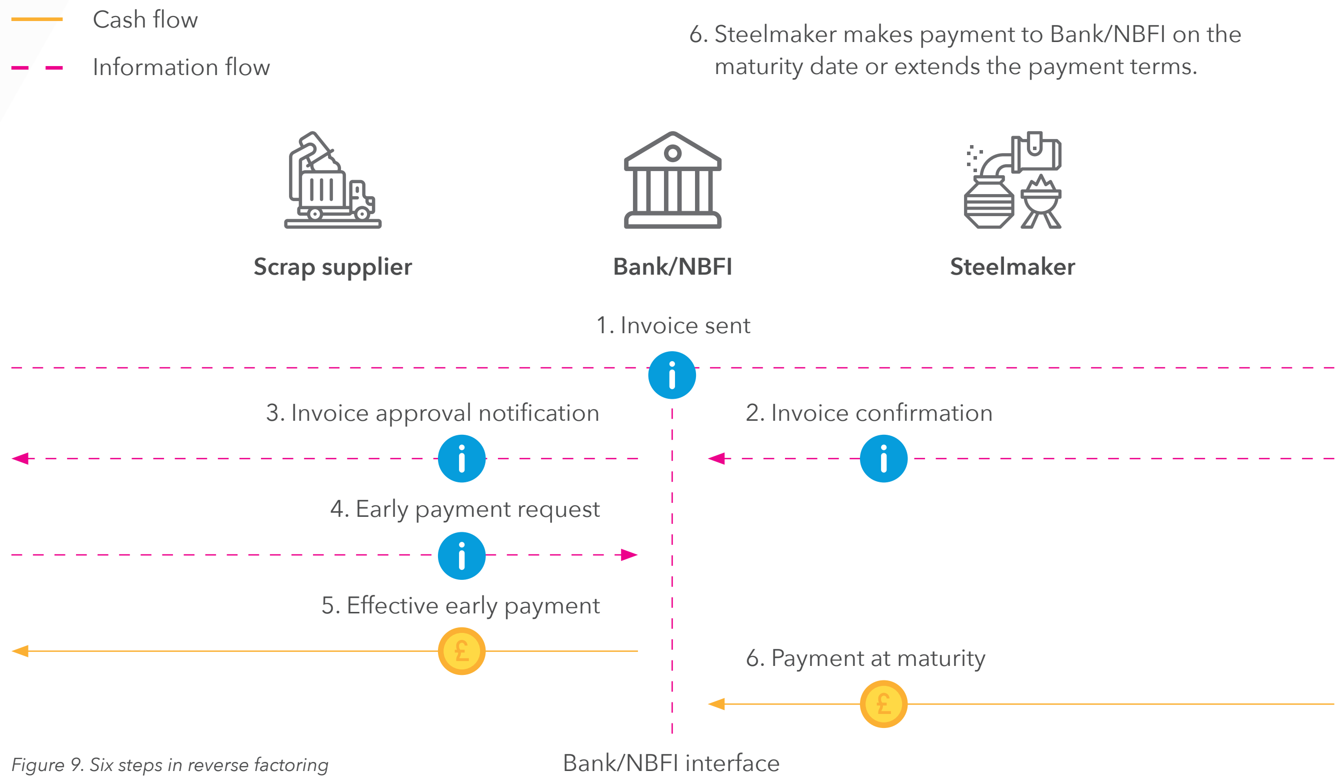


Figure 9. Six steps in reverse factoring

Successful adoption of reverse factoring brings benefits to both supplier and buyer in SCs. The immediate advantages for steelmakers are longer supplier payment terms, optimised cash flow and a stable SC, while key advantages for scrap suppliers include reduction of trade receivables, better pricing, no impact on their credit lines, better cash flow, and strong relationship with steelmakers. This would help the steelmakers and scrap suppliers to rebuild their relationship and put UK steelmakers in an equal position to that of overseas buyers in the scrap market. Also, improved cash flow provides steelmakers with opportunities to enter long-term contracts with scrap suppliers, which will make the supply of high quality scrap more stable.

The previous study referred to [16] has identified some general factors that inhibit or enable the implementation of reverse factoring, in which the following factors apply to the steel industry.

- SC integration – a collaboration between scrap suppliers, steelmakers and OEMs is essential to make it happen
- Financial risks – entering the reverse factoring scheme significantly reduces the concentration of financial risks by distributing them through the SC
- Information visibility – SC visibility needs to be improved through the establishment of business alignment
- Digital technologies – proper adoption of digital technologies can remove the manual process and ease the information sharing (e.g. scrap quality)
- Low transaction costs – costs related to information exchange, monitoring costs, finance searches and fees for renegotiating credit contracts can be avoided in the reverse factoring

What to avoid in SC finance: Case of Greensill

Lately SC finance has been in the news due to the Greensill Capital. It was founded just ten years ago, and once considered to have a market value of $7bn; the firm filed for insolvency in the UK in March 2021.

It all started with how working capital was financed by the Greensill Capital. Under the SC finance umbrella there are many solutions such as reverse factoring, factoring, invoice discounting, payable financing and inventory financing [17]. However, it is the unpaid invoices that are generally the basis for the majority of the SC finance solutions. Typically, once the service/product is delivered and an invoice is generated, suppliers can opt for the SC finance to get paid earlier for these invoices. Greensill Capital took this idea to the next level. It took into account long-term purchase contracts and advanced financial support based on the predicted future receivables for the upcoming years.

This, however, raised questions about the long-term performance of the suppliers and creditworthiness of the buyers. To answer these questions, Greensill Capital on-boarded the insurance companies to mitigate the associated risks. Although this option is perfectly valid, Greensill become reliant only on these predicted future receivables financings for only a few buyers. In addition, Greensill Capital ended up with some clients who struggled, became less credit worthy and owed estimated billions to Greensill.

The key takeaway from this situation is to avoid SC finance based on structured long-term predicted cash flow till we have new data-driven techniques, measures and regulations in place for structured long-term SC financing.

The adoption of SC finance can optimise the cash flow in the current SCs, which cannot be successful without an efficient information flow. The next section provides an overview of how digital technologies can be adapted to facilitate the information flow.

Strategy 4:

Adopting digital technologies to support the information flow

The whole world has entered the era of 'Industry 4.0', where many digital technologies have been developed to enable better SC connectivity among firms through improved information flow. A recent industry report [18] indicates that the steel industry is at the middle stage of digital maturity, and firms must explore opportunities that can take them to the next level.

Based on the SC assessment, we have identified technologies that can be applied in the scrap steel SCs to facilitate the areas of plan, source, make, deliver and return [19] (Figure 10).

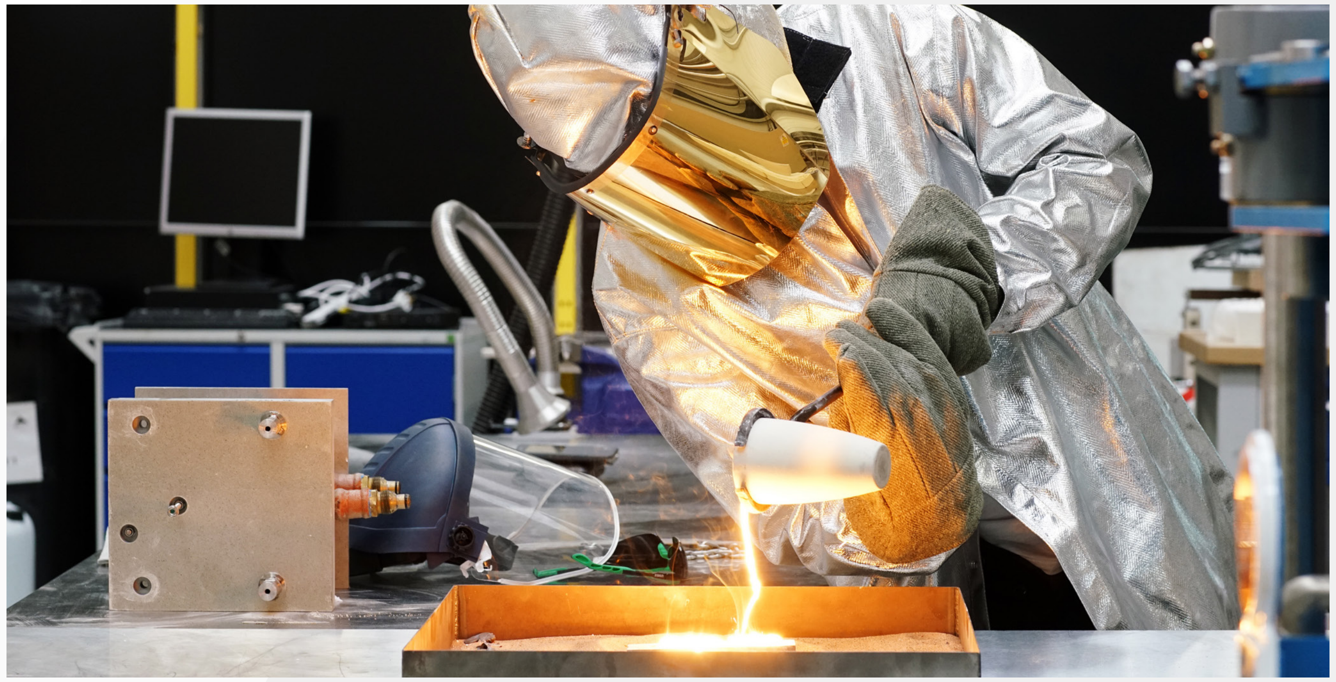
Plan – Adopting big data analytics in SC planning enables firms to make decisions based on accurate and timely data (e.g. supply and demand data). Establishing a digital platform throughout the SC allows better connectivity and information sharing between scrap suppliers, steelmakers and OEMs.

Source – Moving to digital procurement improves SC visibility and integration within and between firms. It allows all parties to access real time data (e.g. purchasing order, supply availability and demand forecasting) and track the progress to improve overall efficiency. The scrap sorting process can be fully automated to reduce human errors and keep quality consistency. Scrap delivery can be facilitated by installing smart sensors in the containers to reduce health and safety issues.

Make – The Internet of Things (IoT) can be adopted to monitor the performance of production assets based on the analysis of onsite generated data, from which machine failures can be reported immediately.

Deliver – The product collection process can be fully automated in the warehouse to reduce human jobs. The instant delivery status can be generated and sent to customers through the application of IoT. Inventory can be monitored through the application of radio-frequency identification (RFID) and IoT, which provide greater visibility of the stock level.

Return – Being able to trace and track scrap would be beneficial to scrap recycling, especially when steelmakers work with scrap suppliers and OEMs to recycle the premium scrap. This can be achieved through the application of RFID and blockchain, which documents the identifiable information of recovered scrap, such as provenance and chemical components of scrap steels. Also, having access to scrap availability (e.g. grade, source and volumes), helps businesses in the SCs to plan their operation effectively.



Use cases across the SC	Plan	Source	Make	Deliver	Return
	▸ Big data analytics to assist SC planning ▸ Digital S&OP (sales and operations planning) platform to enable better connectivity	▸ Digital procurement to allow data access for everyone ▸ Hands free scrap sorting process ▸ Smart sensors in containers to monitor the condition of scrap	▸ Automated production line intervention ▸ IoT to monitor performance of production assets	▸ Hands free picking process in warehouse ▸ Instant update of delivery status ▸ Inventory monitoring	▸ Supply chain analytics enable better visibility of scrap availability (e.g. type, volume, and source)

Existing Technologies		Plan	Source	Make	Deliver	Return
Better visibility	Cyber Security	✓	✓	✓	✓	✓
	Data Analytics	✓	✓	✓	✓	✓
	Internet of Things	✓		✓	✓	
	RFID		✓		✓	✓
	Serialisation	✓		✓	✓	✓
Seamless process	Additive manufacturing			✓		
	Block chain		✓	✓	✓	✓
	Automation	✓	✓	✓	✓	
	Mobility	✓	✓	✓	✓	✓
	Robotics		✓		✓	

Figure 10. Use cases and available digital technologies in the scrap steel SC

The adoption of digital technology can be enabled through three levers [20].

SC integration – Digital technology cannot work without data, which relies on effective collaboration between SC partners to share data in a standard format. This requires a mutual understanding of how data should be shared and used internally and externally to manage the information flow in the SC.

Technology – Firms need to upgrade or rebuild their IT infrastructure to create an operating environment that is suitable for digital technologies to unleash their power in the SC. For example, there is no such digital platform currently existing in the steel industry to support the connection and coordination of SC activities between different entities.

Talent and culture – Digital technologies require special skillsets to operate, such as big data analytics, machine learning and artificial intelligence. Firms need to ensure that they can recruit and maintain a skilled workforce. Moreover, the top management should create a business culture that supports the digital transition and identify strategies to help employees in adapting to changes. This section summarises the strategies and enablers to improve the current scrap steel SCs from the aspect of SC integration, material flow, information flow and cash flow in the immediate future.

Supporting future transformation

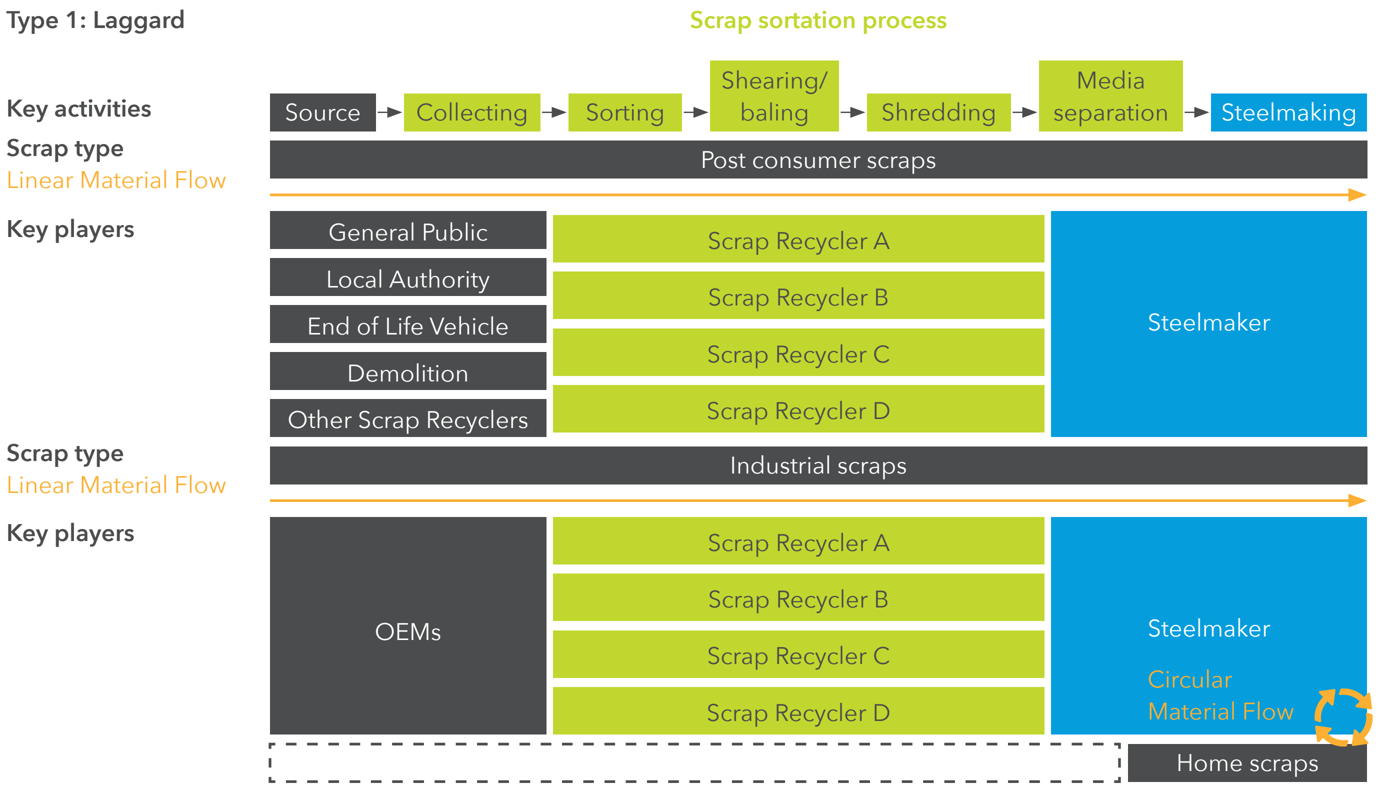
To support the UK steel industry achieving the sustainability goal – producing steels using recycled scrap in the long term, this section presents two practical considerations for the steel industry to gain a competitive advantage through SC innovation.

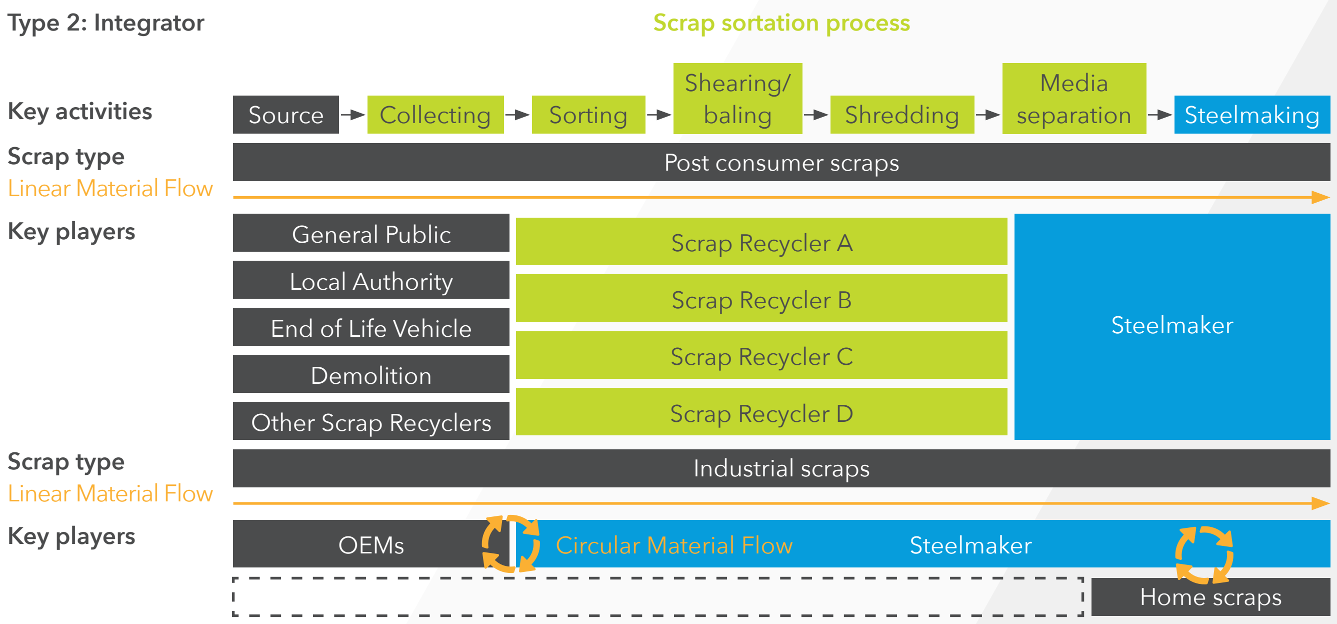
1. Three scrap sorting archetypes – Moving from 'Laggard' to 'Pathfinder'
2. Future business model – 'Selling steel as a service'

Three scrap sorting archetypes – Moving from 'Laggard' to 'Pathfinder'

A recent study [21] highlights that the adoption of a circular economy in SC design enables greater sustainability, which requires a greater level of digital technology adoption and SC integration. Based on empirical findings, three scrap sorting archetypes (Figure 11) are developed to lay out the possible options. The implication (Figure 12) of each archetype is discussed around the following questions:

- Is additional financial investment necessary?
- Can domestic scrap supply (quantity and quality) fulfil the increasing demand by 2050 when UK steels will be produced via the EAF route (100% scrap) only?
- What level of SC integration is needed to support the adoption of archetypes?
- What level of digital technology adoption is required?





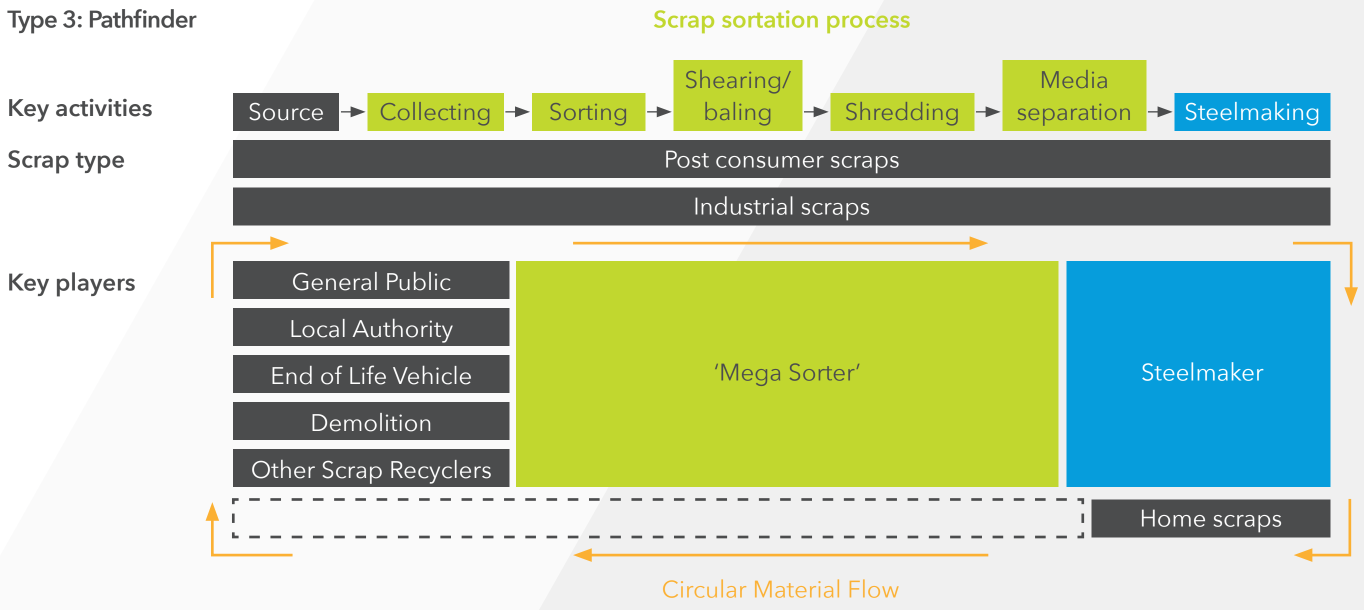


Figure 11. Three scrap sorting archetypes

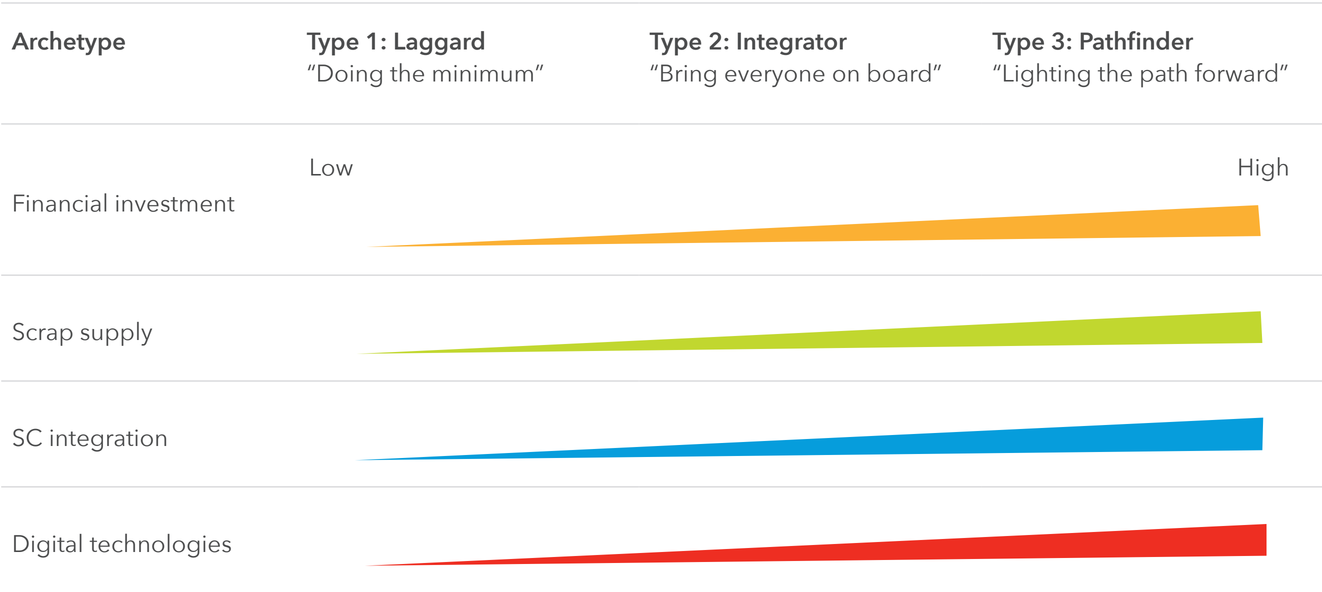


Figure 12. Three archetypes have different strategic focuses

Type 1: Laggard

Laggard is a representation of the conventional scrap sortation model, in which scrap suppliers play a dominant role in recycling and processing scrap. In this model, most scrap sorting activities are being carried out by scrap suppliers, but EAF operators tend to 'clean' scrap further via an additional step – media separation (separating ferrous scrap from other wastes using magnets). Both post-consumer and industrial scrap are going through a linear flow as they are available to both local and overseas buyers. Home scraps are normally generated and reused in the steelmaking process internally, hence they are rarely traded in the scrap market.

Laggard is the current operating model in the scrap steel SC, which does not require any additional investment to maintain it. However, the domestic scrap supply may not be sufficient to meet increased domestic demands by 2050 if 80% of scrap is being exported to overseas countries. The level of SC integration is low in the current state, in which firms are keeping each other at arm's length rather than working together to deliver value to end customers. The adoption of digital technologies in the steel industry is relatively low compared with other industries, which needs to be improved if the industry wants to move to Type 2: Integrator.

Type 2: Integrator

Integrator focuses on building an integration between SC entities to form a circular material flow. There is an opportunity for steelmakers to directly collect industrial scrap (i.e. manufacturing offcuts) from the OEMs that they supply, providing the chemical composites of the scrap meet the technical requirement of steelmakers. Although OEMs regularly sell scrap in the marketplace, some steelmakers have managed to secure long-term contracts with OEMs to retain stable access to scrap.

Additional investments are required as steelmakers need to either establish their logistics or hire a third-party company to take scrap back to the steel plant. The proportion of industrial scrap is only 10.4% of the overall UK generated scrap per annum, meaning such a low volume may not be sufficient to meet the scrap demand by 2050. Hence it is suggested that steelmakers should consider other ways to 'mine' scrap from the current SC network. This archetype indicates a critical step towards SC integration as the steelmakers and OEMs are collaborating to enable efficient recycling of scrap. More importantly, knowing the chemical characteristics of recycled scrap reduces the potential technical issues during the steelmaking process, therefore reduces the operating costs and product defect rate. The adoption of digital technologies (Figure 10) is a critical enabler to support the transition from Laggard to Integrator as information generated from OEM's plant could be beneficial for the overall SC planning.

Type 3: Pathfinder

Pathfinder focuses on building a new SC network that enables cross-sector collaboration, the advancement of digital technologies and increased circularity of recycled materials [21]. To support this vision, a scrap sortation centre – 'Mega Sorter' – could be established in the UK to collect all domestic scrap from different sources, process them following the best industry practice and redistribute them to steelmakers according to the demand (scrap grade and quantity). This can be further extended to other firms in the chain by recycling and reusing both ferrous and non-ferrous (i.e. aluminium and plastics) to eliminate landfill waste and create value with fewer materials.

Pathfinder has the potential to bring several benefits to the steel industry. First and foremost, the quality of the scrap can be controlled through the adoption of objective measurement. Second, all parties in the SC can benefit from improved information flow if data, such as scrap availability (type, quality and quantity), source of origin and market demand, can be shared in the SC network. If the 'Mega Sorter' has visibility of the demands of each steelmaker, then 'demand profiling'[1] can be adapted to coordinate the SC planning in responding to different demand patterns [13]. This ensures that steelmakers have stable access to scrap, which enables them to direct more efforts towards steelmaking rather than scrap procurement. Finally, if UK scrap remains in use domestically, this significantly reduces the carbon footprint of shipping scrap overseas, and therefore supports the national transition towards 'net zero' goal.

Shifting from Integrator to Pathfinder requires significant financial investments in building the SC infrastructure and network. However, Pathfinder has the potential to fulfil the steel demand by 2050 through efficient scrap recycling and reuse. This archetype requires a high degree of SC integration (both vertical and horizontal) that has sustainability as its core. Moreover, digital technologies need to be in place to improve the information flow through the creation of an integrative data backbone, which enables everyone to share and access information to achieve mutual benefits.

[1] Demand profiling is a critical SC planning approach that helps manufacturing firms to identify different demand patterns based on product volume and variability, and co-ordinate the SC to respond to each demand type. For more details, please read reference 12.

Future business model – 'Selling steel as a service'

The UK steel industry will inevitably enter a future that relies on recycled scrap, hence it is critical that firms have an innovative business model to be both profitable and sustainable. Oversupply of steels in the global market has kept the steel price very low, which allows us to use steels wastefully today. An investigation of the steel SCs indicates that only a quarter of steels are used in final products, and the value of a finished product is mostly created in downstream manufacturing [1]. This means if steelmakers keep selling steel as products to stockholders or manufacturers at high volume and low price, they will struggle to make profits until the global steel price increases (Figure 13). Therefore, the steelmakers are urged to take a more proactive approach in seeking new ways of adding value to the entire SC.

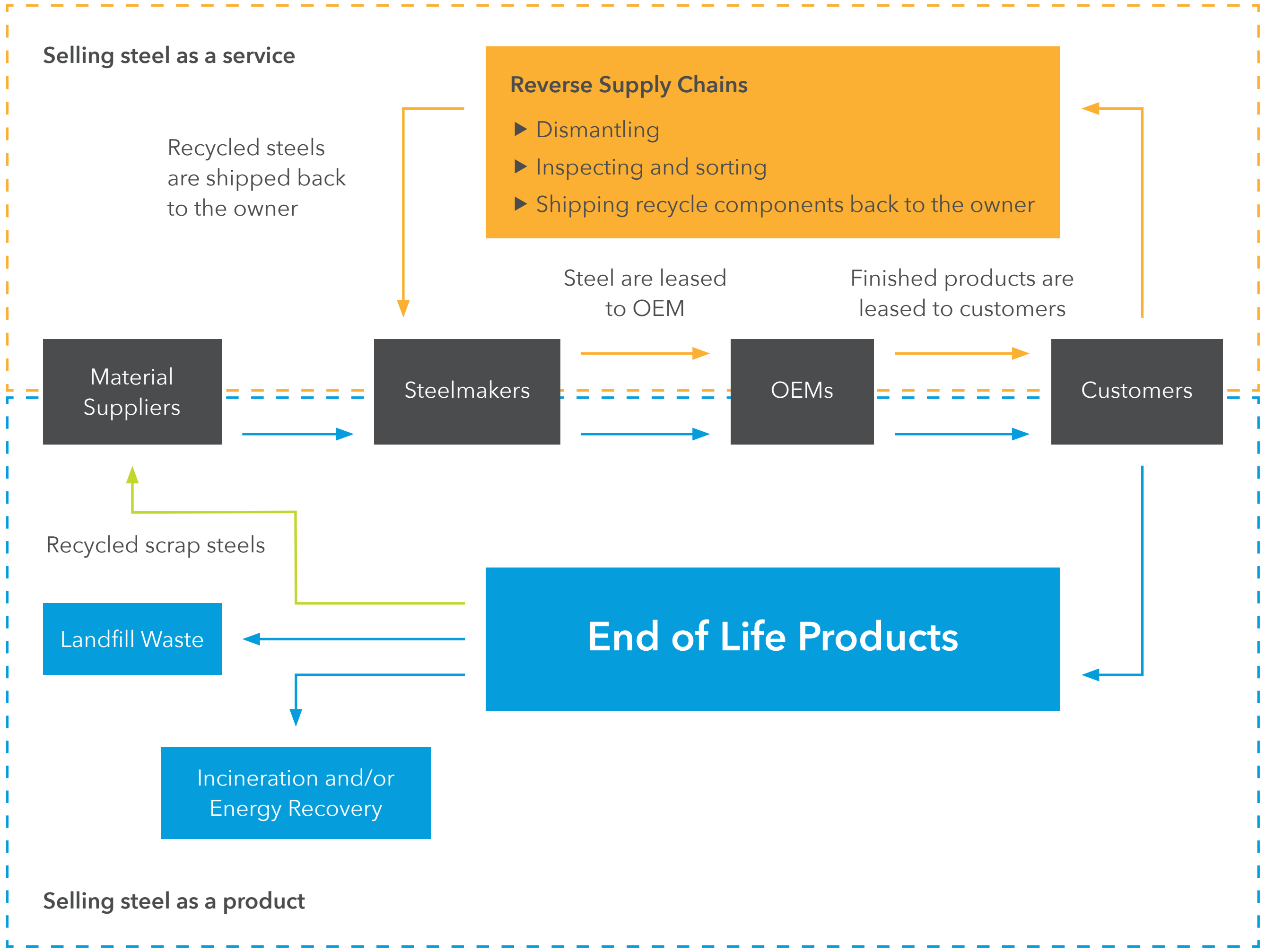


Figure 13. Future business model – 'Selling steel as a service'

Selling steel as a service becomes a strategic option as consumer buying behaviours are in a transition from buying the product ownership to the outcome delivered by products [22]. This is a great opportunity for steelmakers to enter this type of customer responsive SC and capture more values by leasing steels to downstream customers. Apart from construction that lasts approximately 60 years, the average lifespan of other products containing steels varies between 9 and 39 years. If steelmakers lease steels to OEMs in different sectors (i.e. automotive, machinery, aerospace, etc.), they will be able to secure long-term recurring revenues and more importantly, set barriers to lock out other competitors. From the sustainability perspective, steels will be traced throughout their life cycle and returned to the owner through the reverse SCs. In this way, the chemical components of scrap are known and the scrap supply will be more stable as the lifespan of steels within products is recorded. This is where the 'Mega Sorter' (Type 3: Pathfinder in Figure 11.) can play a role in the reverse SC, during which end of life products are dismantled, sorted and shipped back to the owner. In summary, this service-oriented business model is beneficial to the UK steel industry in the following ways:

- Retaining profitability by adding value for end users through a highly integrated customer-responsive SC
- Achieving sustainability goals through efficient material recycling and reuse
- Gaining competitive advantage by moving away from undifferentiated over-supplied commodity markets
- Creating opportunities for innovation that allows the UK steel industry to fulfil the national demand and reduce reliance on importing high value steels

Shifting from product to service economy creates the opportunity for both technical and business model innovations, which is the core strength of the UK steel industry considering its strong R&D capability and world leading research and infrastructure. As the 'net zero' deadline is approaching, the steel industry is at a turning point to rethink the business model for a sustainable future. This requires incremental changes in terms of material recycling, steelmaking and SCM, which if done effectively will lead the industry to a bright future.

> "If steelmakers lease steels to OEMs in different sectors (i.e. automotive, machinery, aerospace, etc.), they will be able to secure long-term recurring revenues and more importantly, set barriers to lock out other competitors."

Concluding Remarks

To survive in the global competition, there is little doubt that competing through SC sustainability is critical for future growth. It is not a single solution to all issues, but it is an aid to improving the commercial and environmental sustainability of the UK steel industry in general. Through a holistic assessment of the current scrap steel SCs, the operating challenges are revealed and a set of strategies and enablers are proposed for the immediate future. To summarise:

- Adopting a 'process approach' to build an E2E SC integration that enables scrap suppliers, steelmakers and OEMs to take a coordinative approach to manage SCs and create 'flow' (of material, information and cash).
- Establishing circular SCs to enable the material flow that secures a stable supply of high quality scrap and reduces carbon emissions from exporting scrap at low value.
- Implementing SC finance such as reverse factoring to facilitate the cash flow that eases the relationship tensions and creates better business alignment between businesses in the SCs.
- Adopting digital technologies to support the information flow that improves the overall visibility serving as a foundation for the SC innovation.

Effective adoption of the above strategies will improve the scrap steel SCs, but not be adequate to retain a competitive advantage in the undifferentiated global commodity market. Therefore, we urge steelmakers to reconsider the operating model – scrap sorting archetypes and explore pathways for adding more values through differentiated offerings – selling steel as service, which will eventually lead to increased productivity, sustainability and prosperity.

> "We urge steelmakers to reconsider the operating model – scrap sorting archetypes and explore pathways for adding more values through differentiated offerings"

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