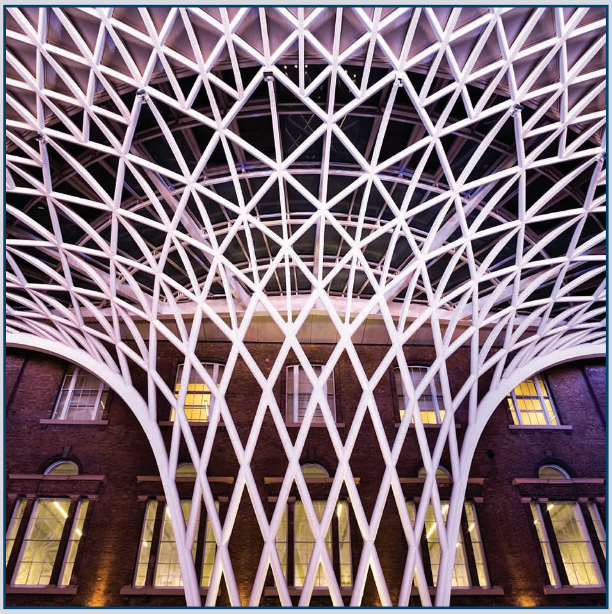
A bright future for UK steel



A strategy for innovation and leadership through up-cycling and integration

UNIVERSITY OF CAMBRIDGE

A bright future for UK steel

A strategy for innovation and leadership through up-cycling and integration

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First published April 2016

ISBN 978-0-903428-38-5

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The motivation for releasing this report in April 2016 at a time of profound crisis in the UK steel industry, is to attempt to bring increased focus on the need to rethink the way we produce and use steel – and to promote the opportunity for the UK to become globally leading in a transformed steel sector, fit for the 21st Century.

The background to this report was published in the 2012 book "Sustainable Materials: with both eyes open" (www.withbotheyesopen.com). The particular focus on up-cycling and integration as a strategy for the European Steel Industry was first presented in an article "The future of steel: time to wake up" in January 2016, in "Materials World".

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Executive Summary

Tata Steel is pulling out of the UK, for good reasons, and there are few if any willing buyers. It appears therefore that UK taxpayers must either subsidise a purchase or accept closure and job losses. This document presents a third option, to allow a transformation of the UK's steel industry, based on two innovations. Firstly, the global supply of steel for recycling will treble or more in the next thirty years, but the processes of recycling have lacked innovation. At present used steel is generally down-cycled to the lowest value steel application, reinforcing bar. Instead, UK strengths in materials innovation could be applied to up-cycle used steel to today's high-tech compositions. Secondly, the incumbent industry makes undifferentiated intermediate products such as plates, bars and coils of strip with low margins. Much more value is added to steel by downstream businesses that convert these stock products into the tailored components wanted by final customers. New integrated business models could connect liquid steel production to the UK's world-leading skills in architecture and construction, aerospace, automotive and other sectors, to find new value and innovation. This document uses evidence built up over six years of applied research by fifteen researchers funded by the UK's EPSRC and industrial partners spanning the global steel supply chain, to set out the case for this strategy, and propose an action plan.

The global steel industry today has more capacity for making steel from iron ore than it will ever need again. On average products made with steel last 35-40 years and, because it is magnetic, around 90% of all used steel is collected. The supply of steel collected from goods at the end of their life therefore lags the supply of new steel by about 40 years. It is likely that, despite the current downturn, global demand for steel will continue to grow, but all future growth can be met by recycling the existing stock of steel. We will never need more capacity for making steel from iron ore than we have today. The steel industry in Europe, with older assets and higher labour costs than in China, is therefore in a critically difficult position, regardless of local variations in energy and labour costs or the temporary protection of trade subsidies.

The focus of European steel makers in the past three decades has been to consolidate their operations, and to seek innovation in material composition and quality. This has led to impressive technical achievements in the properties of advanced steel which is sold at higher prices. However, this focus has drawn attention away from two areas which are now ripe for innovation:

- The quality of recycled steel is generally low, due to poor control of its composition, but there are many technical opportunities for innovation to address this and convert today's down-cycling to future up-cycling.

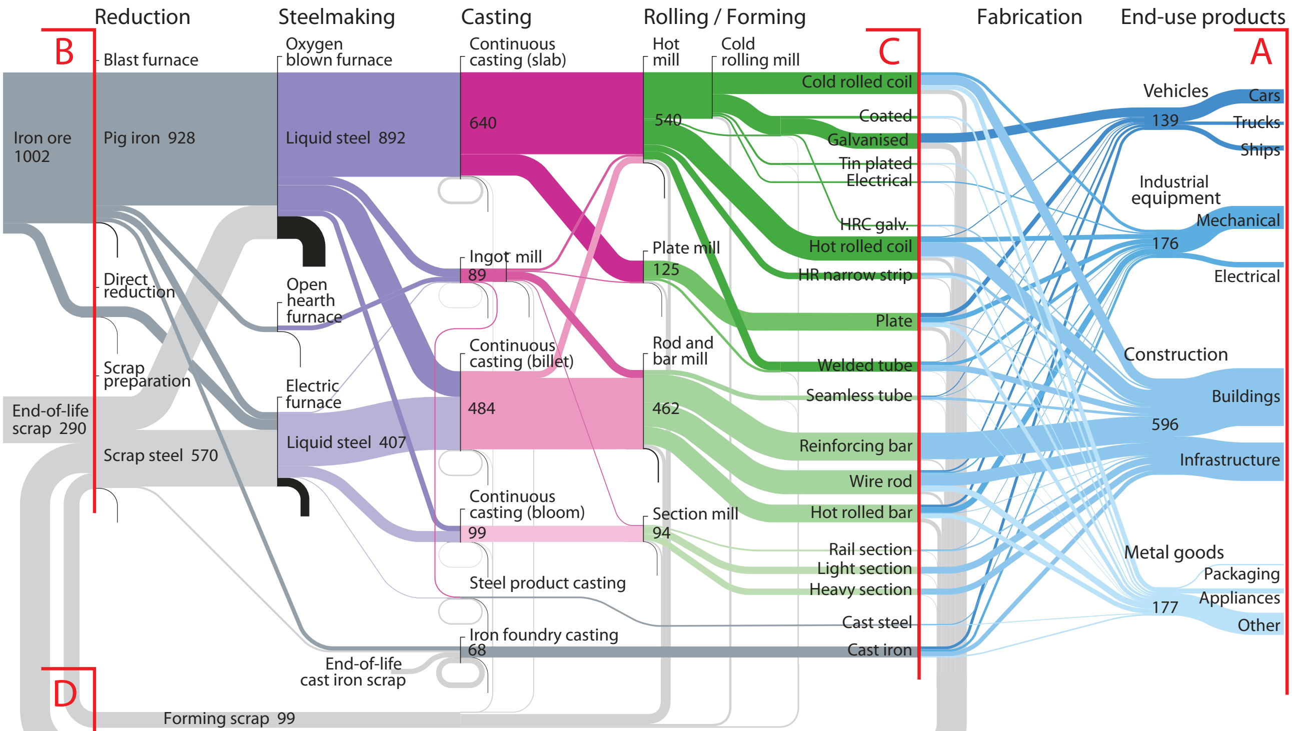
- The steel industry today makes largely undifferentiated intermediate goods, and fails to capture the value and innovation potential from making final components. As a result, more than a quarter of all steel is cut off during fabrication and never enters a product, and most products use at least a third more steel than actually required. The makers of liquid steel could instead connect directly to final customers.

These two opportunities create the scope for a transformation of the steel industry in the UK. Existing strengths in materials technologies could be re-directed towards upgrading recycled steel. The construction industry that delivered the London Olympics, our leading aerospace industries, and resurgent automotive sector provide the network of partnerships required to re-connect the production of liquid steel to its final users.

In response to Tata Steel's decision, UK taxpayers will have to bear costs. If the existing operations are to be sold, taxpayers must subsidise the purchase without the guarantee of a long term national gain. If the plants are closed, the loss of jobs, income and livelihoods will reverberate throughout the UK steel supply chain. The costs of lost tax income and additional benefit payments alone are estimated at £300m-£800m per year and will ultimately be born by taxpayers. Instead, the strategy presented here enables taxpayers to invest in a long term structural transformation. This would allow UK innovation ahead of any other large player, with the potential of leadership in a global market for used steel that is certain to treble in size.

The government of Denmark's Wind Power Programme initiated in 1976 provided a range of subsidies and support to its nascent wind industry. This leadership allowed it to establish a world-leading position in a growing market. This document proposes that a similar initiative by the UK government could mirror this success and transform the steel industry. Rapid action now to initiate a task force to identify the materials technologies, business model innovations, financing and management of the proposed transformation could convert the vision presented here to a plan for action before the decision for plant closure or subsidised sale is finalised.

Steel in the world today



Global steel flows for 2008 in million tonnes

Steel is the world's most used metal, by far, and we make over 200 kg of liquid steel each year for every person alive. The figure above illustrates the 'flow' of steel through the world economy in 2008, with the width of each line proportional to the mass of steel produced. Since 2008, the volume of steel production has increased, but the proportions of the flows have remained similar.

Four key points are marked on the figure:

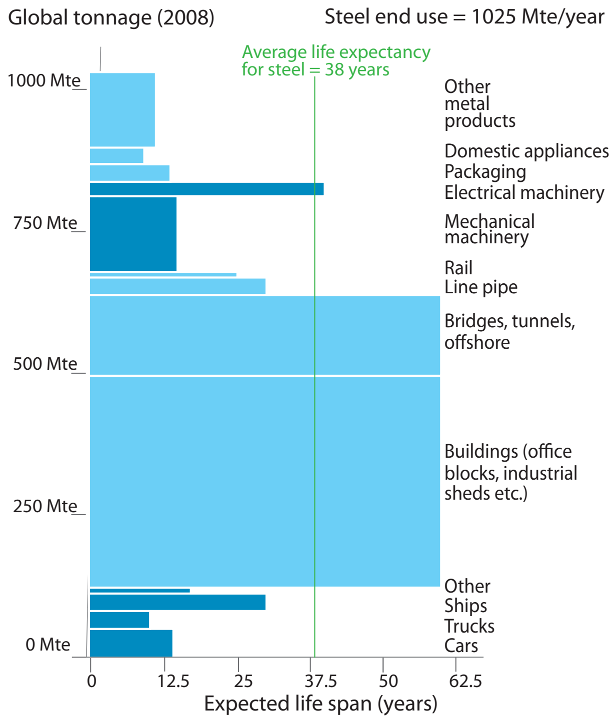
A. More than half of all steel is used in construction, with the other major uses being the manufacture of vehicles, industrial equipment and final goods.

B. Roughly two thirds of today's liquid steel is made from iron ore, with the rest made from scrap, but at present more than half of this scrap is from the manufacturing process itself, rather than from end-of-life goods.

C. The steel industry makes the intermediate products shown, and sells most of it through stockists to a downstream supply chain.

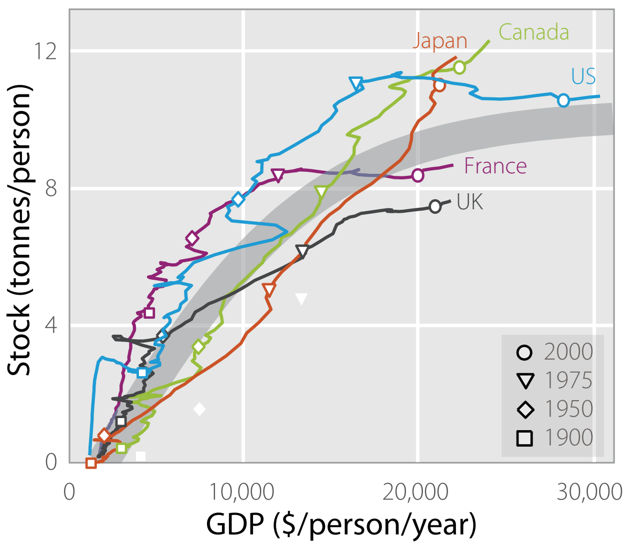
D. A quarter of the finished steel made each year (including a half of all sheet steel) never makes it into a product but is cut off in manufacturing because final users want components (such as car doors) that do not closely match the intermediate products (coils of strip steel).

The figure below shows estimates of the predicted lifespan of the new products made from steel in the same year. On average, steel goods last for 35-40 years, but because steel is magnetic it is easily separated from other wastes and is our most recycled material. Apart from ~10% of steel used below the surface (for oil pipes or building foundations, for example) almost all end of life steel will be recycled.



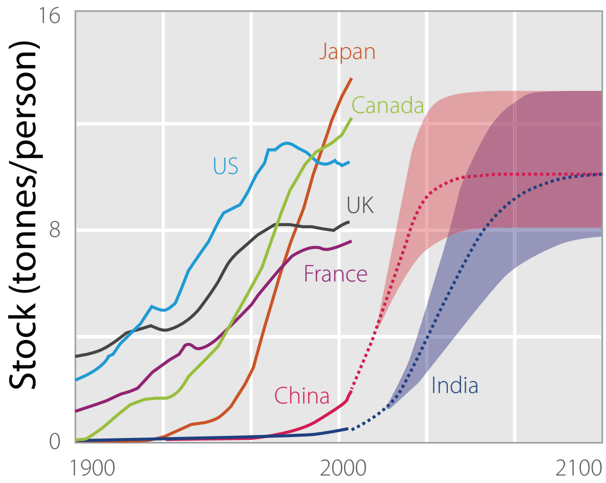
Future demand for steel

Steel is traded globally, so it is difficult to predict future demand from the history of production in any country. However, estimates of the accumulated stock of steel in different countries, show that as countries become richer, their requirement for steel becomes predictable: once we have a stock of around 12 tonnes of steel per person, we need no more.

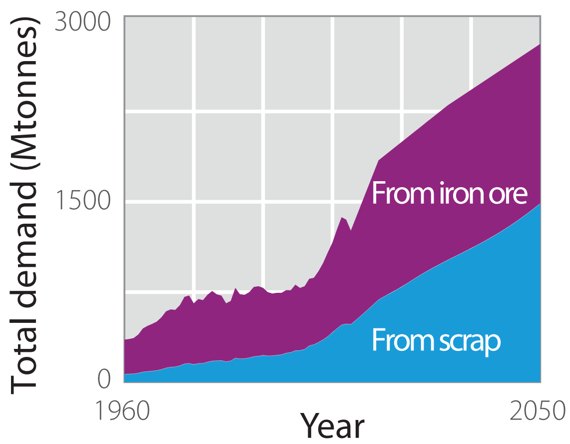


The figure above shows this tendency towards saturation for several developed economies: once we have enough vehicles, infrastructure and buildings we cannot use more, so our requirement for steel is then to replace these 12 tonnes every 35-40 years. This requires about 300 kg of steel per person in the UK per year – 50% greater than the global average.

We can estimate future global demand for steel by looking at how developing economies build up their stocks, and how developed economies maintain them. The next figure shows this pattern over time for the same countries as above, and also gives an illustrative forecast of the build-up of stocks in China and India. The steepest gradient of China's build up is about now, which is why China's steel capacity has expanded so much in the past two decades, and why, having passed its peak rate of construction, China now has surplus steel to export.



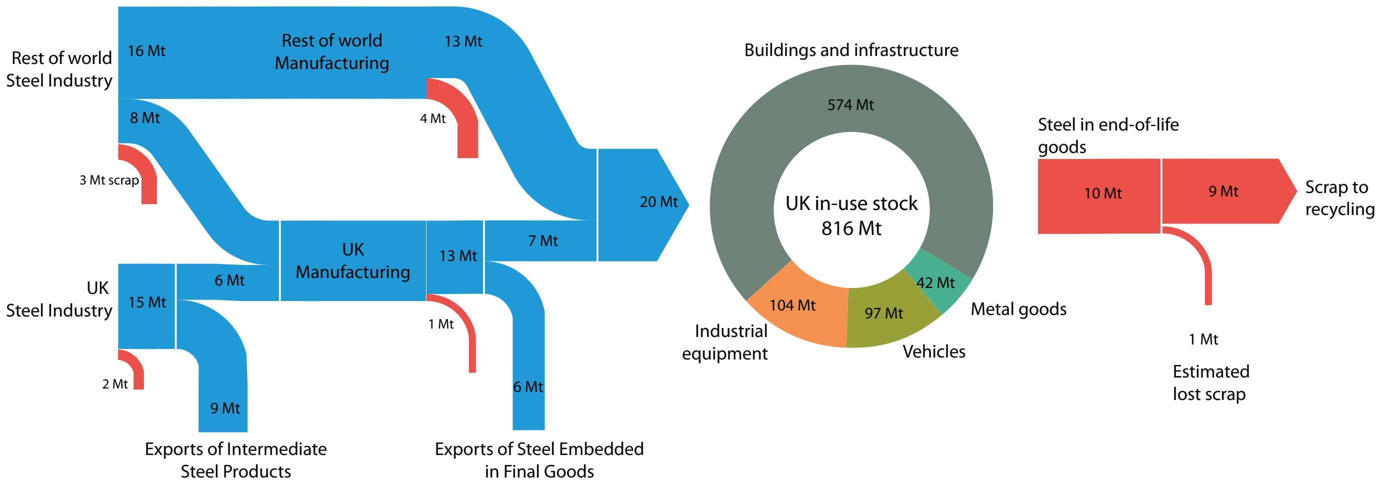
The forecast for future global steel demand shown below is consistent with these patterns of national behaviour.



Despite the current reduction, the figure anticipates future growth in total demand for steel. However, the figure also anticipates the split between steel made from iron ore and steel made from scrap based on the anticipated lifespan of steel products and their recycling rates. This shows that all future growth in demand for steel can be met by recycling: the world will never need more capacity for making steel from iron ore than it has today, but the volume of steel available for recycling will treble in the next 30-40 years.

The current crisis for steel making in the UK is not temporary, and is faced by other European steel makers also. Older assets for making steel from iron ore in countries with higher labour costs have little chance of long term competitive success. Furthermore, if serious action is taken to reduce total global emissions, then without carbon capture and storage – which is still unproven except for enhanced oil recovery – the world's total production of steel from iron ore must be reduced and more value captured from the existing stock of steel.

Steel in the UK



Steel is not demanded for its own sake. It's embedded in finished products. Demand for finished goods bought or made in the UK in 2007 necessitated the production of 44 million tonnes of steel. 10 million tonnes of this was scrapped during product manufacturing processes. 14 million tonnes were exported in finished goods and 20 million tonnes stayed in the UK, embedded in the stock of buildings, infrastructure, machinery, cars and equipment. Steel used in buildings and infrastructure has a longer lifespan than in cars or equipment. So although the UK stock has nearly stabilised, only 10 million tonnes of steel were discarded. 90% of this was collected for recycling, of which around two thirds was exported.

If the stock of steel stabilises, we can anticipate that over the next two decades, around 20 million tonnes will be discarded annually. In particular, the rapid growth in demand for steel in construction which occurred in the UK during the 1970's will turn into a boom in demolition and steel recycling.

UK steel industry assets, mainly owned by Tata Steel, were largely constructed in the 1960's and are configured to produce steel from (imported) iron ore. Continuous efforts to optimise and upgrade these assets have achieved remarkable performance, but inevitably, they now lag behind the latest plant installed in China in the past decade.

However, if the UK steel industry were transformed to process used steel rather than iron ore, scrap which is exported at minimum value today, could be upgraded either for higher value export as intermediate goods, or converted into final goods for domestic use or export.

Steel recycling

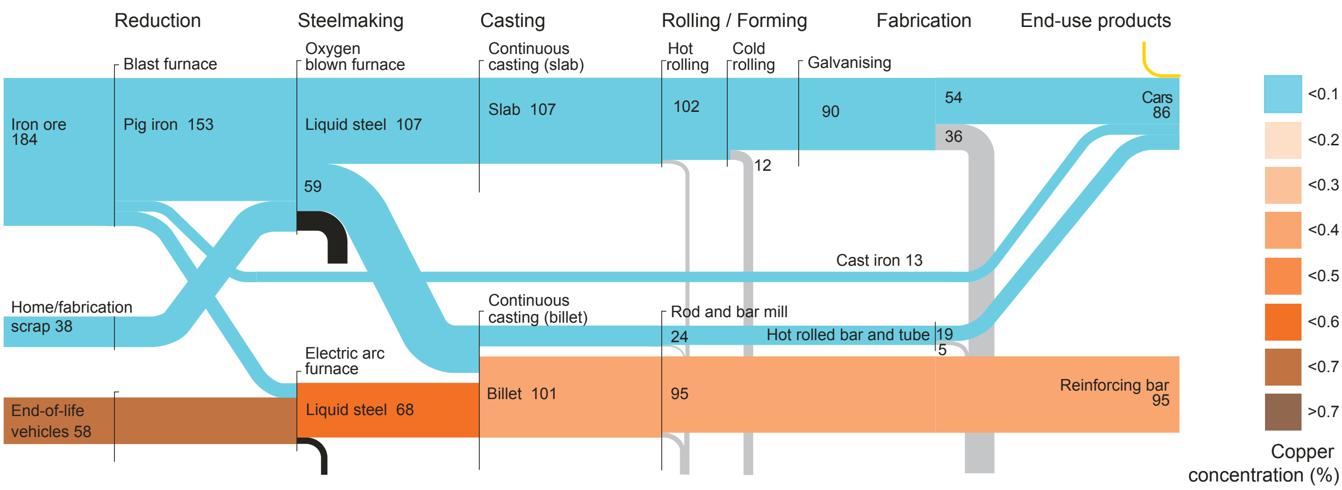
Until the innovations of the Darby family, Bessemer, Siemens and other 19th Century pioneers, the challenge of steel making was to remove carbon from the liquid iron to avoid unwanted brittleness. Subsequently, materials scientists have explored the addition of increasingly exotic elements from the periodic table to increase steel's strength and tailor its performance for applications such as high strength bridges, lightweight bicycles or high temperature engines. The key innovation in the first phase of this story was to blow oxygen through the liquid iron: carbon in the steel is attracted to the oxygen, leaving behind a purer liquid.

Current steel recycling technology creates a liquid metal by melting a mix of steel scrap in an electric arc furnace, and attempts the same means of purification. However, although oxygen is effective in removing carbon, it does not remove all other impurities, and tin and copper are a particular problem. Tin used to coat steel cans for packaging, and copper used in motors and wiring in cars and appliances, prefer iron to oxygen, so remain in the molten steel, and degrade the performance of the recycled material.

This is illustrated in the figure which is a subset of that on page 2 and illustrates the current use of steel in cars. The highest quality of steel is used to make the latest car models, which include around 750kg of steel and 25kg of copper in electric motors and wiring. Old cars are partially dismantled then crushed and shredded, which mixes the steel with the remaining copper, about 0.7%. The copper cannot be removed from the liquid steel by oxygen blowing, so recycled car steel must be diluted by new metal made from iron ore, and even then can be used only to make one of the lowest value products – reinforcing bar. Because reinforcing bars are surrounded in service by concrete, they can tolerate up to 0.4% copper, but the flat steel needed to make cars can accept only 0.1%. This un-separated copper would have been worth around £20 per car if collected, and flat automotive steel has a higher value than reinforcing bars.

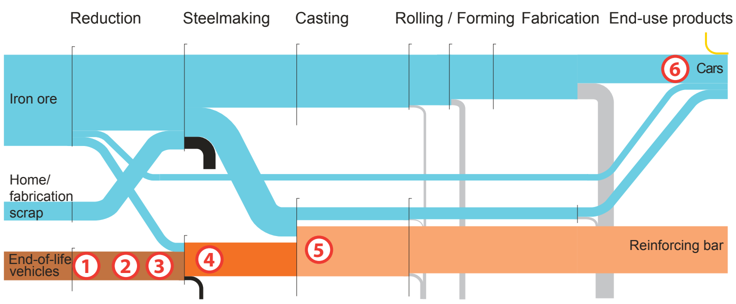
Steel recycling from old cars today is therefore largely down-cycling because of copper contamination. A further consequence of current practice is that many of the valuable alloying elements used in modern steels are lost in the process. Economically and geopolitically important metals such as chromium, nickel and molybdenum used in significant proportions in car steels are not managed at end-of-life, so also end up in reinforcing bars, where their unique properties are not used. Managing the valuable elements embedded in steel stocks could therefore contribute to addressing concerns about the future security of supply of critical metals.

The supply of used steel for recycling is going to treble and current practice is largely down-cycling. This signals an opportunity for innovation, but recycling also has the critical advantage of being much less energy intensive than steel making from iron ore. Steel is made from iron ore using coal, and from scrap using electricity. With today's mix of electricity supply in the UK, the total greenhouse gas emissions from making a steel component from recycled metal are around half those when making the steel from ore. If in future, the supply of low-carbon electricity expands, the emissions associated with recycled steel could drop further, and in the limit, could approach zero.



Innovation: up-cycling

In the past fifty years innovation in steel processing has been incremental, and the trophies of innovation in the world of steel have been awarded for new compositions. The strength of steel has risen by a factor of nearly ten, while other properties related to manufacturing, electrical performance, corrosion resistance and many more, have been significantly improved. Not surprisingly, steel recycling has attracted less interest – while recycling is predominantly from internal scrap, there has been less motivation to improve it – and therefore it is a rich field for innovation. Despite the fact that copper and tin are not attracted to oxygen, there are no fundamental physical or chemical barriers to up-cycling by controlling the composition of molten used steel and the figure demonstrates many other areas for new developments:

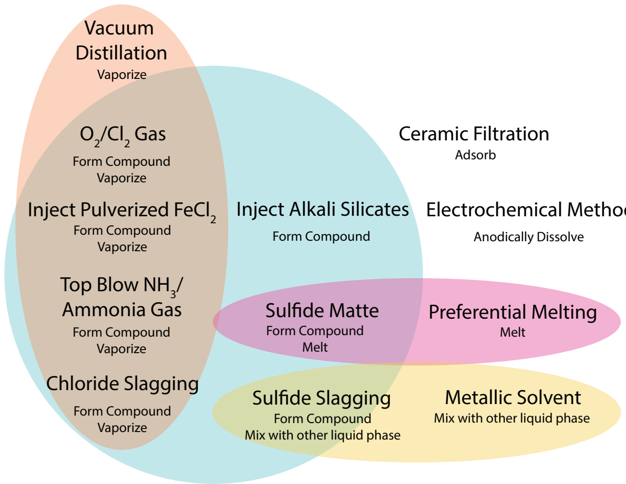


1. Steel-bearing products at end-of-life could be disassembled with more care, to maintain larger components and avoid alloy mixing. In some construction projects, I-beams could be re-used directly creating the same business opportunity exploited by authorised own-brand used car dealers.

2. Cars and appliances are currently shredded to allow rapid separation of non-metallic components. However this creates mechanical bonds between steel and copper fragments, and other impurities. New approaches to improve this process, for example with robotic cutting and handling, could greatly increase the control and hence value of the separate material streams.

3. Novel sorting technologies, such as laser induced breakdown spectroscopy, are emerging to allow automated sifting of mixed waste streams but have to date had little application in steel recycling.

4. There are many options to purify molten scrap steel other than oxygen blowing. The diagram below presents a survey of many approaches that have been tried briefly in research laboratories in the past 40 years, but abandoned at the time because of a lack of commercial interest. Technologies being developed to handle metals in waste electronics could be transferred to steel.



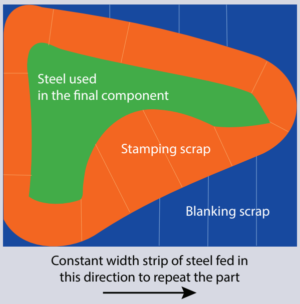
5. New processes, such as belt casting can be developed to allow processing of less pure steels into higher value products.

6. Product designs can be modified to simplify the challenge of steel recycling, by reducing the use of unwanted elements such as copper, or by enabling more rapid separation at end of life.

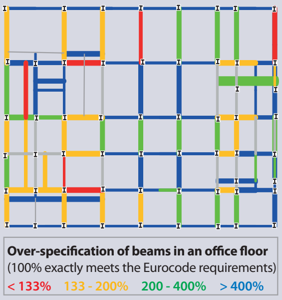
At present, with global over capacity throughout the steel sector, scrap prices are at an all time low, so scrap could be stockpiled. This scrap pile – the UK's annual steel scrap would cover Hyde Park to a depth of six metres – will become the feedstock of future up-cycling, and can be organised by ease of composition control to allow phasing in of new technologies as they become available.

The UK has always been a leader in materials innovation – the 2010 Nobel Prize in Physics celebrated the first experiments with Graphene in Manchester, the most advanced bainitic steels were developed in Cambridge, and across the UK research and development of electronic, bio, nano and other novel materials is spinning out from research into entrepreneurial business. These strengths could be focused rapidly on the key challenges of up-cycling steel.

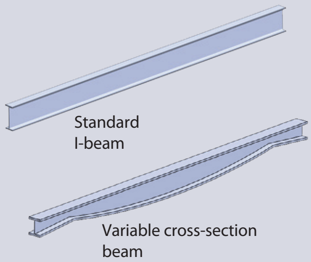
Innovation: integration



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



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



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

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

Henry Ford famously owned everything from the mine to the showroom, but more recently the steel industry has consolidated to focus on the production of intermediate products: the coils, plates, tubes, bars and sections shown on page 2. These standard forms are globally traded, largely undifferentiated and mainly sold through stockists. As a result, the steel industry operates at a distance from many final users of steel, and the four case studies above illustrate the resulting inefficiencies.

High growth businesses like Apple or Google have intimate connections to their customers to seek every possible opportunity for adding value to their offerings. The steel industry's disconnection from its customers illustrated in these case studies, creates inefficiencies which could be addressed by new integrated business models:

- 50% of all sheet steel is scrapped in manufacturing, the scrap is often returned in mixed form, and may be coated with paint, tin or zinc, creating a challenging recycling problem. Yet the clothing and textiles industry faces a similar problem and returns just 20% of its material as scrap. New cutting and forming processes, and new business models with many customers served from each steel coil, could be developed and implemented by a connected steel industry.

- steel is made so efficiently that it is cheap relative to UK labour, so excess steel is often used to make small reductions in labour costs. A connected innovating steel industry could add more value to less steel by producing exactly the components required by designers, integrating the liquid metal processes with downstream forming and fabrication, finding new efficiencies in joints and modular designs, and supplying kits of final parts ready for use rather than stock intermediate goods.

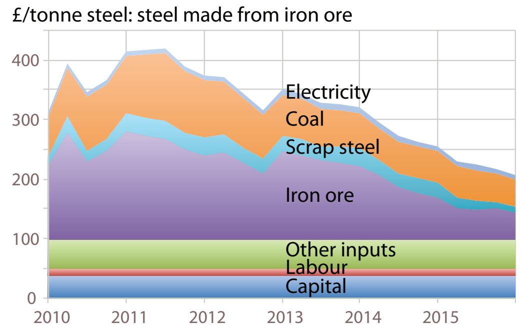
- the disconnect between steel makers and users created by steel stockists creates artificial economies of scale aiming at reducing costs to the stockists, not to the final customer. The current disconnected steel industry is in many cases unable to tailor its production to end user needs, because steel makers don't know what's actually required.

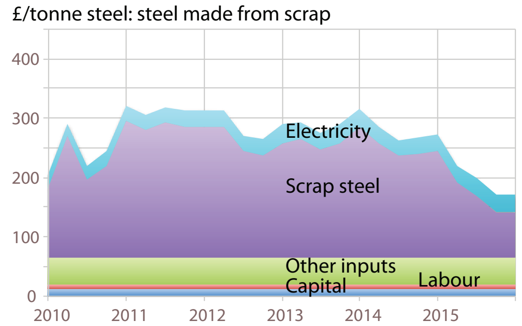
- large components, particularly in construction, are often undamaged in service, and could be re-used rather than melted. However the supply-chain for re-use doesn't exist, so re-use imposes very high search costs on interested clients. In contrast, the automobile sector has sought to internalise the value of second hand sales, through authorised re-sellers, providing certification and service guarantees, and holding sufficient stock to match supply with demand. A connected customer-oriented steel industry could do the same.

The UK is globally leading in architecture, construction, aerospace, automotive and other sectors downstream of the steel industry, and has the networks and skills required to seek new forms of business models by finding new and rich connections between steel suppliers and their final users.

Steelmaking costs

The major components of cost in making steel are the purchase of iron ore, scrap and other physical inputs, the purchase of coking coal or electricity, labour and capital costs. The true costs vary by the age, location, design and utilisation of each site and are commercially sensitive, so invisible. However, using a cost model provided by a UK consultant, with data from publically available sources, the figures below give an estimate of the costs of producing one tonne of liquid steel, from iron ore or scrap in the UK over the past five years. In both cases, the cost of producing the intermediate goods that will be sold will be greater than this – due to the casting, rolling or other processes that occur after the liquid steel is prepared, but these costs will be similar for either route.





The figures show that

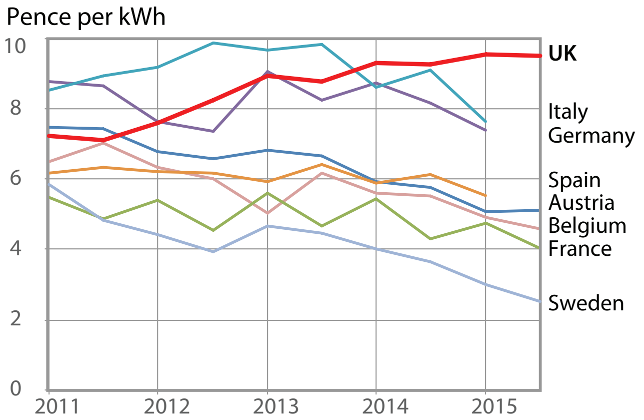
- the largest component of cost in both cases is the acquisition of the raw material – iron ore, coke or scrap. Both have declined significantly during this period, and so has the cost of steel making, driven by global over-capacity.

- energy drives around one third of the cost of making steel from iron ore, and one sixth of the cost from scrap, but both routes are sensitive to variations in electricity prices.

- labour is a relatively small component of cost. Capital costs are more important, and these are the most uncertain elements of these estimates

If the steel made from scrap is down-cycled to lower value applications such as reinforcing bar, these estimates show that the iron ore route remains attractive – the costs of both routes are similar. However, if used steel is up-cycled, it can be competitive against steel made from iron ore. Further, as the global supply of scrap for recycling is certain to expand, the cost of scrap relative to iron ore is likely to fall.

Both process routes are influenced by the price of electricity – even though coal is the dominant energy cost for steel from ore. This is a major challenge in the UK. The figure below, using data from the UK's Department for Energy and Climate Change, compares electricity prices for the largest industrial users in the UK with selected other larger European countries.



UK electricity is significantly more expensive than all other countries shown, and is the most expensive in the EU28. Relative to the median price across the EU28, UK electricity prices are nearly 80% higher.

Electricity prices are strongly influenced by government policy – on capacity planning, generation mix, taxes and other regulation. There are many options to modify these prices, and one example relevant to the proposal in this document, is that the electric arc furnaces used in making steel from scrap are intermittent batch processes. As the UK moves towards a stronger mix of renewable supplies, the challenge of balancing the total demand for electricity from the grid with supply (which is constant for nuclear power stations, but varies with the weather for wind or solar sources) will become more difficult. The electricity requirements for up-cycling steel could be timed to help balance total supply and demand.

Investment

Tata Steel's Port Talbot site, the UK's largest steel plant, has capacity to produce around 4 million tonnes per year of liquid steel from iron ore and roll it into coils of thin strip. Two thirds of the site is used for making liquid steel, with sinter and coking plants to prepare input materials, two blast furnaces and a basic oxygen steel making plant. The remaining third of the Port Talbot site includes continuous casting, hot and cold rolling mills and some other processes for conditioning the strip product, which could be adapted for use with liquid steel made from scrap. In the longer term, there are opportunities for example developed by Nucor in the USA, to create strip steel with very short production routes, directly connecting thin strip casting to rolling mills, to reduce the number of process steps and reheating cycles.

The strategy in this document recommends that, in the light of a certain three-fold growth in global supply of used steel, the current crisis should be a trigger to initiate a future steel industry based on up-cycling. Phasing out the blast furnaces at Port Talbot will create space for three new activities: scrap collection, sorting, separation and storage; electric arc furnaces; downstream processing and intelligence to connect the conventional products of steel making to the final users of steel.

The cost of site clearance is unknown, but there is space available on the site to store significant volumes of used steel. At current low prices, and with most UK scrap being exported, this is an immediate low risk opportunity: the scrap could be sold later if unused.

The capital costs of installing new electric arc furnaces are estimated to be around one quarter of the equivalent costs for new plant for iron ore, and appear to be of the order of £150-£200 per tonne. These could potentially be reduced as some of the UK's recent capacity in electric arc furnaces has been "moth-balled" so may be acquired more cheaply. Appropriate government procurement strategies may also be able to stimulate early demand.

The costs of creating an innovation park to exploit the integration opportunities identified in this strategy are more about infrastructure than capital: the downstream supply chain that uses steel exists and is strong within the UK. The Catapult centre model of innovation has seen rapid success in the UK, and a new Steel Catapult could be launched rapidly on the Port Talbot site, with incentives provided to draw in the key downstream sectors.

To give an estimate of scale only – true investment costs could only be found with focused and confidential work – assume that the cost of site clearance and re-organisation for scrap management is £100-200m, 4 million tonnes of new electric arc furnace capacity cost around £600-800m, and the establishment of a new Steel Catapult centre required £100-200m. These figures are extremely uncertain, but suggest that the cost of the strategy presented in this document may be of the order of magnitude £1-2bn. If this was provided as a low interest Government loan, the cost to the UK taxpayer of transforming the UK steel industry looks attractive, relative to the cost of redundancies or subsidising a sale. The strategy presented here proposes that this is an investment not a cost: a renewed steel industry in the UK will enable innovation that could not occur in its absence and there is the opportunity for world leadership in up-cycling and integrating steel production with final customers.

The case for government action

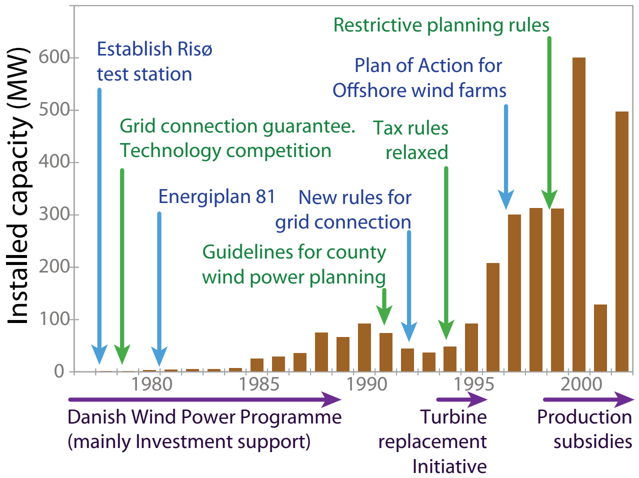
This strategy is not a simple call to install electric arc furnaces at Port Talbot. It is a call for renewal to enable and exploit innovation in areas of UK strength. Installing electric arc furnaces with no other action will allow production of low grade steel products, and the cost comparison between making steel from iron ore or steel scrap shows that this change may continue to need long term government support. In contrast, investing and innovating in steel up-cycling and in integrating steel producers with downstream users, offers much greater opportunity for adding value, while creating the conditions for innovation which can then be exported.

The fact that Tata Steel are selling their UK operations shows that this transformation cannot be achieved by the private sector alone: the investment required to deliver the strategy in this document cannot guarantee the rate of return required by private sector capital markets. Government support is therefore required, and should be justified by recognition of the potential for innovation: the focus of the steel industry on innovating in the composition of new steels made by iron ore has drawn attention away from the potential for innovation in up-cycling; the consolidation of the industry as a supplier of intermediate stock products has prevented the search for innovation in delivering value to the final users of steel components.

UK taxpayers will bear costs whatever happens to the future of Tata Steel in the UK. If the company is closed, 15-40,000 job losses are likely, depending on knock-on effects, and estimating that this leads to a loss of £10,000 of tax revenue per employee and a cost of £10,000 in benefits for each redundancy, the cost of closure will be around £300-800m per year. The cost of subsidising a purchase, with no long term strategy for innovation, is unknown but is likely to depend on some on-going form of subsidy, through reduced tax rates, energy price subsidies or the like. The proposal to provide a low interest loan to allow a transformation of the UK's steel industry at the level estimated on the previous page looks to be comparable or lower than these costs to UK taxpayers, and promises a greater return in the long term.

Innovation in production depends on involvement: for hundreds of years the key steps forwards in product design and manufacture have been made by those who are actively involved, who are most aware of the limits to current practice and the opportunities to do things better. Recent UK strategy has led to the closure of many manufacturing sectors, so the UK can no longer innovate in sectors in which it is not active. The contrast with German leadership in manufacturing is painful, and reflected in the balance of payments of the two countries. While the UK's "High Value Manufacturing Strategy" proclaims the opportunity to create new knowledge-led innovations, the reality is that innovation depends on participation. Few if any UK politicians would fail to describe 3D printing as one if not the only key technology for future production, but in reality it will only ever produce a very small number of components: die-less fusing of powder can make very few useful parts. In contrast, steel provides the backbone to the whole economy. We are purchasing 300 kg of new steel goods for every person in the UK every year, and our buildings, infrastructure, vehicles, equipment and other goods depend on it. There are no substitutes for steel. Being active in seeking value with steel, the UK could lead innovation in this massive product range. Without steel production, the opportunity to innovate in these vast markets is lost.

The Danish Government through its Wind Power Programme from 1976-1989 stimulated the growth of a world leading wind industry that remains dominant today. Over time, Government support changed from provision of test facilities and investment support, through joint company financing, to production subsidies and turbine replacement incentives. Similar evolving pro-action by the UK government today could create a future leadership position in steel up-cycling and customer focused integration.



From vision to action

This document presents a vision based on evidence in the public domain. Action is needed to convert the vision into a basis for decision making – to ratify the main conclusions and to provide confidence in the likely future of a transformed steel industry.

The steel industry itself has lacked leadership. The fact that Tata Steel is selling its UK operations, and that other European steel makers face similar pressures, reflects the failure of incumbent leaders to develop strategies robust to the changing global market for steel. In parallel, the current structure of the UK government has inhibited a focus on steel: many Whitehall departments influence and are influenced by the domestic and international steel market, but none has clear ownership.

Converting this vision into an action plan therefore requires a newly configured task force, able to act rapidly. The components of such a task force might include:

- A steering group with Ministerial leadership, to co-ordinate strategy development to the point that a proposal for investment and support can be prepared for public scrutiny.
- A sub-group on up-cycling. This should include: representatives of the UK's metal scrap industry; the spectrum of UK materials innovation from academia to entrepreneurial success; incumbent users of electric arc furnaces including representatives from Tata Steel in Rotherham, Sheffield Foremasters, Celsa, Liberty House; equipment suppliers including Nucor from the USA, and developers of new technologies for steel sorting and characterisation. The aim of the group would be to develop a time-line for the achievement of different levels of up-cycling from different forms of steel scrap.
- A sub-group on downstream integration including leaders of successful UK Catapult centres, and representatives from leading UK practices in architecture, construction, design, automotive, equipment and aerospace sectors. The aim of this group would be to scope the potential for innovation through re-examining the entire steel supply chain, and identify a small number of near to market opportunities for demonstration and deployment.
- A sub-group to rethink the business model of the steel industry, including its partnerships, labour and incentive practices, and customer offerings. The priority of this group should be customer-focus, so could draw on leading players such as John Lewis, Google, Apple, Virgin Group, as well as the breadth of UK entrepreneurial success.
- A sub-group on finance and investment including representatives from the Treasury, Investment Banks, entrepreneurs, aiming to develop a credible financial model for the transformation of the sector.

It took nine months to finalise the decision to sell Tata Steel's Scunthorpe Plant to Greybull Capital, in a move which maintains the existing plant but does not address the structural shift that motivates this document. The crisis for the rest of Tata Steel in the UK is urgent, but there is still time to develop an action plan based on this document, in parallel with the exploration of other options, to allow a thorough evaluation of the potential for UK innovation and leadership in a next generation steel industry.

Notes

Page 2: The map of global steel flow was published as Cullen, J.M., Allwood, J.M. and Bambach, M. (2012). Mapping the global flow of steel: from steelmaking to end- use goods, Environmental Science and Technology 46(24), 13048-13055. A detailed supplementary information file provides links to all data sources and explains the use of estimation where it was required.

The histogram of steel intensive product life-spans was similarly published as Cooper, D.R., Skelton, A.C.H., Moynihan, M.C. and Allwood, J.M. (2014), Component level strategies for exploiting the lifespan of steel in products, Resources Conservation and Recycling, 84 24-32, also with data sources in a supplementary file

Page 3: The estimates of stocks of steel in use were estimated by comparing national statistics on production, trade and waste, by Müller, D. B., Wang, T. and Duval, B., 2011. Patterns of iron use in societal evolution, Environmental Science and Technology, 45(1) pp. 182- 188.

The forecast of future steel demand is taken from the International Energy Agency, IEA (2009) Energy Technology Transitions for Industry. IEA (International Energy Agency): Paris. p59 fig2.2. We created the forecast of scrap availability based on an estimate of the mix of products in service, using the lifespan data on page 2.

Page 4: The analysis of UK stocks and flows of steel has been accepted for publication as Serrehno, A.,C., Sobral Mourao, Z., Norman, J., Cullen, J.M. and Allwood J.M. (2016) Options to supply UK steel demand and meet CO2 targets, Resources Conservation and Recycling, to appear

Pages 5, 6: This is new analysis that we assembled in order to give the opening plenary lecture at the International Automobile Recycling Congress in Berlin, 16 March 2016, entitled "Purity in car recycling: Supply, demand, the environment, strategy and policy." We are currently writing this up.

Page 7: These case studies are described in our book, "Sustainable Materials: with both eyes open", by J.M. Allwood and J.M. Cullen, published by UIT press in 2012, and available online at www.withbotheyesopen.com

Page 8: The analysis of costs is based on a model made available online by UK steel consultants www.steelonthenet.com. The price data for iron ore, and scrap steel was assembled from a variety of indices, and cross referenced. The data on coal and electricity prices is from online data provided by the Department of Energy and Climate Change.

The comparison of EU electricity prices is from online data provided by the Department of Energy and Climate Change.

Page 10: The figure on Danish wind policy is adapted from one in Buen, J. (2006) Danish and Norwegian wind industry: The relationship between policy instruments, innovation and diffusion, Energy Policy, 34, 3887-3897.