4 Metal journeys

flows, stocks and demand for steel and aluminium

The materials we use start in the ground as ores/minerals and transforming them into finished goods is a long journey. If we can create a map of that journey, we can build up a picture of scale, anticipate the set of processes we need to explore, and by looking at the way the flow has evolved in the past, can start to predict what might be required in future.

Let's imagine that you're reading this at the end of a warm day in early summer, sitting outside in your favourite chair, and on the table next to you is a clean empty glass and a perfectly chilled unopened can of your favourite beer. The can glistens in the evening light, its dappled moisture announcing its cool readiness in the warm air...

... and it's going to sit there waiting for us throughout this chapter, but while looking forward to seeing it again, let's briefly look backwards in time at the journey the can has been on to get ready for this wonderful moment: back to being filled and sealed; to the heat of the lacquering line; the threefold stretch in can making; the blanking line; the coating line and the tension stretch-leveller; the tandem cold rolling mill; the annealing and solution heat treatment line; the water quench; the tandem hot mill; the reversing mill; the pre-heating furnace; the cooling air of the open warehouse; the direct chill caster; the crucible. At every stage, it has been processed with tremendous care so that now while it's waiting to be opened it is an object of unimaginable quality: purged of edge cracks, surface imperfections, split noses and fish tails, blanking skeletons, mis-feeds and deep drawing ears. Slimmed down by nearly 50% since casting, this can is a miracle of engineering development and control, one out of 280 billion drink cans in action this year[1] and drinks cans are just one of the products we found in our catalogue.

We'll leave our can where it is (but perfectly insulated so it's ready for later), and try to put some data around our brief odyssey. We found out in the last chapter where steel and aluminium are currently used. In this one, we want to put some numbers on those uses. In particular we want to find out how current global production of liquid metal flows into final uses: what's the journey, and what masses are involved each year? how has the required mass of metal built up in the past to the levels we use today? what stocks of steel and aluminium goods are on the planet today? what can we say about how demand is going to develop in the future?

How does steel and aluminium flow from ore to final uses today?

We saw in the last chapter that processing steel and aluminium requires a carefully controlled sequence of deformation and heating stages, to create the properties we want. Two other factors affect the physical journey from ore to finished product:

- The resources required to make metal—ores, coke, coal, gas and electricity—are not uniformly distributed across the earth's surface. For example, much of our bauxite and iron ore comes from Australia[2], but there is a large supply of relatively cheap hydro-electricity in Canada[3].

- Making liquid metal, casting it and deforming it into the stock products we've already mentioned, has significant economies of scale: the cost per unit of metal delivered generally decreases as the total volume made by the equipment increase.

As a result, the production of finished goods containing steel and aluminium involves many conversion steps, and many different businesses. Because of the two factors above, this conversion works via a clear intermediate stage. The steel and aluminium industry which make liquid metals, cast and form them into stock products with high economies of scale at relatively few locations. These products are not in the form required by the final consumer, but are of a sufficiently general shape that they can be formed, cut, drilled and joined into any required finished form.

We want an overview of the flow of material through a series of transformations, and because scale matters to us, we need an overview at a global scale. When we started our work in this area, only parts of this map of flows had been documented, and was largely hidden in tables of numbers, so we've worked hard to collate estimates of all the remaining numbers and the result is the two maps on the next double page.

We've constructed these maps as Sankey diagrams, with the same rules as for the Sankey diagram of global energy transformation we presented in chapter 2. In this case our units are in megatonnes (millions of tonnes, Mt). Looking at the maps from left to right you can see how ore is transformed firstly into liquid metal, then into stock products, and then into the components that are assembled into final goods. As our focus is on steel and aluminium, but almost no product is made solely of those two metals, we've chosen to end the diagram with components, rather than finished products, but you can see immediately that the final uses are precisely the ones we indentified in our detective work in the last chapter. The first half of each map is based on data from the World Steel Association and International Aluminum Institute, although we've had to perform various adjustments to make sure everything adds up. But for the second part, we found no existing data set on the final destinations of all stock products, so the tangled web of lines leading to final uses is the result of us solving a sort of Sudoku puzzle of data sources. For example, data from the Aluminium Association suggests that 62% of the steel in a car is sheet metal[4], and according to two wire rod companies, 10% of all the world's steel wire rod is used in cars[5]. So to create the maps we've worked our way through a large pile of data covering both the composition of final products, and the destinations of intermediate stock products, and then resolved conflicting estimates as required.

The grey lines on the two maps show flows of scrap metal leading to recycling processes. Interestingly, for both metals, we collect far more scrap from production processes than from products that have reached their end of life. This is very helpful because, remembering the last chapter, scrap with a uniform composition can be recycled back into material of equal value, but scrap of mixed composition will generally make metal of less value. Typically the composition of production scrap is known, and it is separated at source, while post-consumer scrap is mixed. For steel, it is possible to remove some unwanted impurities, but for aluminium it isn't, so most recycled aluminium is used in the casting family of aluminium alloys which have a less pure composition than the wrought family. The only major exception is for drinks cans which have been thrown out after use and the industry is, rightly, proud of this story. In future, as the supply of post-consumer scrap increases, we will want to use more of it to reduce demand for new metal made from ore, but unless we separate the different alloys effectively, recycled material will be useful only for less demanding applications.

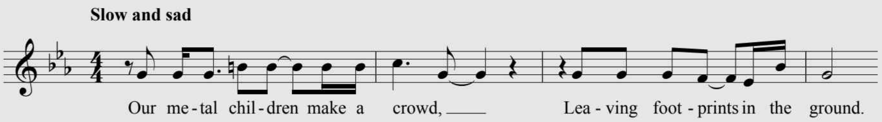
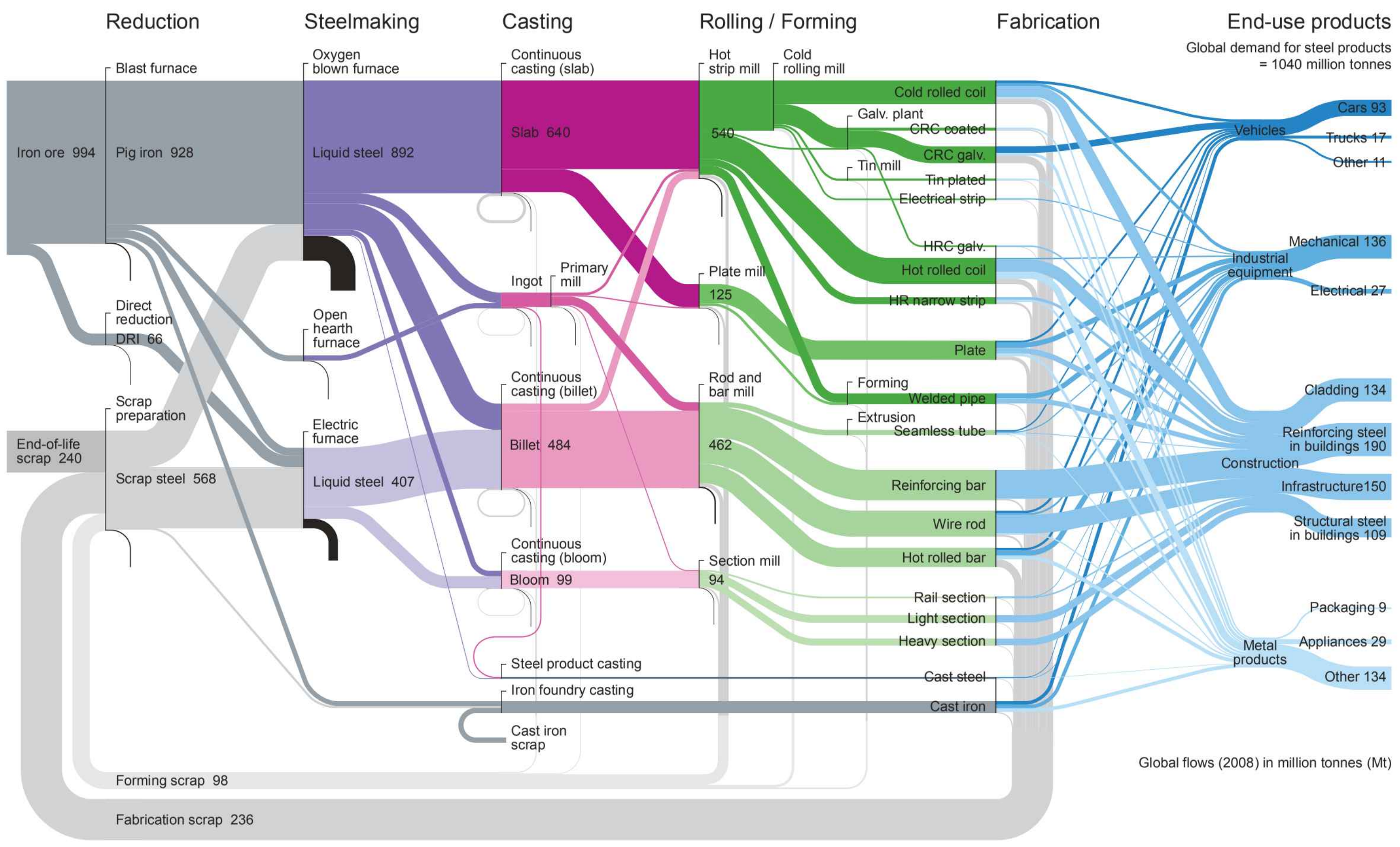
These maps of metal flow help us greatly in our quest to understand scale. We can quickly see what's big and what's small, and as we work through the book looking at every possible option for change, we can use the maps to work out how much the global flows of metal will change. Once we've worked through the next



Figure 4.1—**Sankey of steel flow**

The steel map shows that: two thirds of the world's steel is made from mined ore, and one third from recycled scrap; one-fifth of the scrap arises from within the steel industry itself, two-fifths from manufacturing and fabrication (making components) and two fifths from end-of-life products and buildings; the dominant production route for steel made from ore is the basic oxygen furnace, and from scrap is the electric arc furnace, although there is some interchange between the two; more than 99% of the world's steel is rolled after casting, and the resulting stock products are approximately one tenth plate (thick sheets), four tenths strip (thin sheets), four tenths rod and bar, and one tenth sections (constant cross-section profiles); half of the world's steel is used in construction, of which one third is reinforcing steel; most steel used in vehicle manufacture is from cold rolled coil, or from castings.

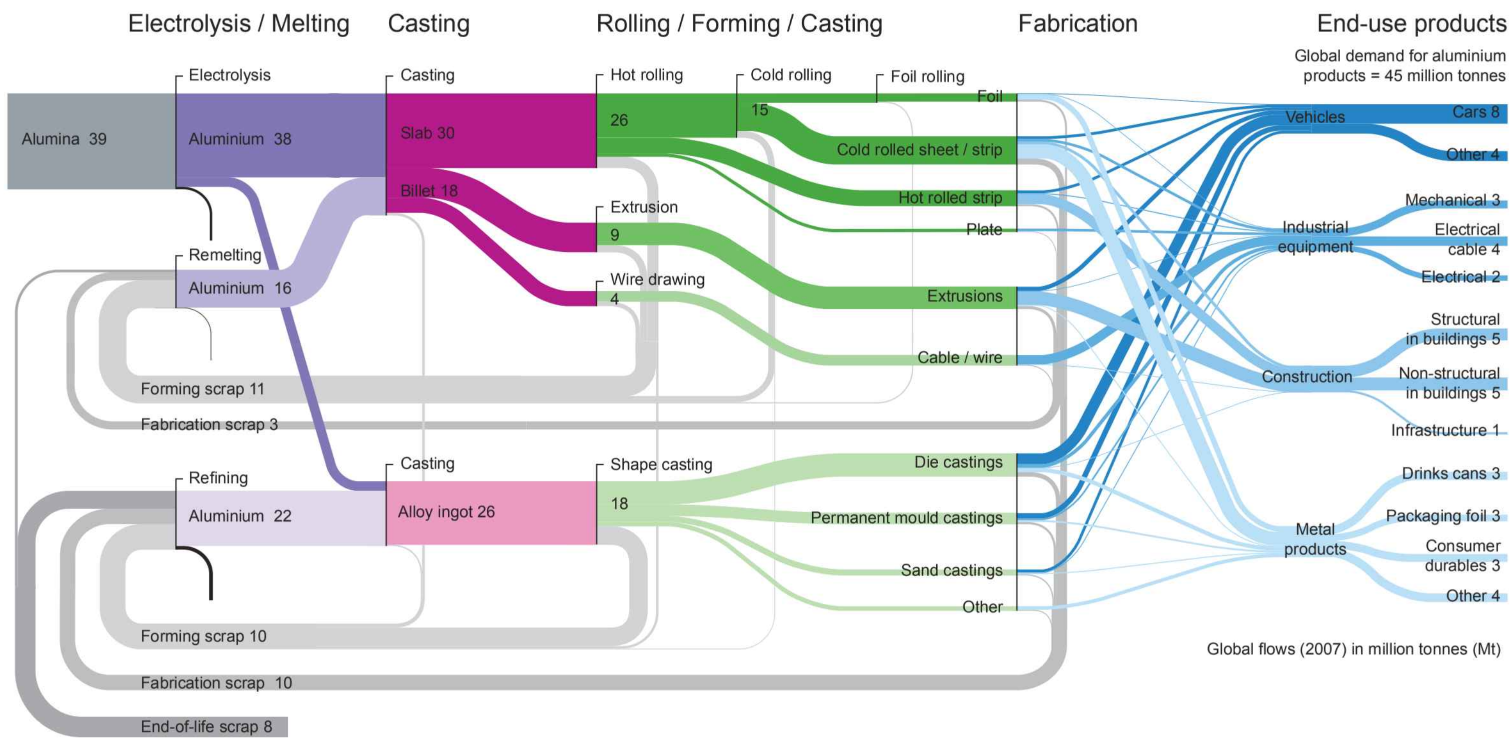


Figure 4.2—**Sankey diagram of aluminium flow**

Half of all aluminium is made from ore and half from scrap. Aluminium is produced from ore by electrolysis and aluminium scrap may be recycled via remelting or refining. Aluminium made from ore or remelted scrap generally has a low silicon content and is used in wrought products that are made via deformation processes. Aluminium from refining post-use scrap generally has a higher silicon content, so is used for casting products by pouring liquid metal into a mould. Two thirds of wrought aluminium is rolled into sheet or plate, a quarter is extruded and the remainder is used to make cable and wire. A third of liquid aluminium is directly cast into finished products, which is a much greater proportion than steel. Like steel, the majority of aluminium scrap arises during the production of stock and finished products: a quarter arises within the aluminium industry, half is from manufacturing and fabrication and the remainder comes from recycling discarded products. Manufacturing aluminium products generates a greater proportion of scrap than steel: over 40 % of liquid aluminium is scrapped in production compared to just over a quarter for steel. Aluminium is used in approximately equal volumes in vehicles, industrial equipment, construction and metal products. Although aeroplanes are a well-known application of aluminium, the total masses involved are small, and they do not even show up on our map.

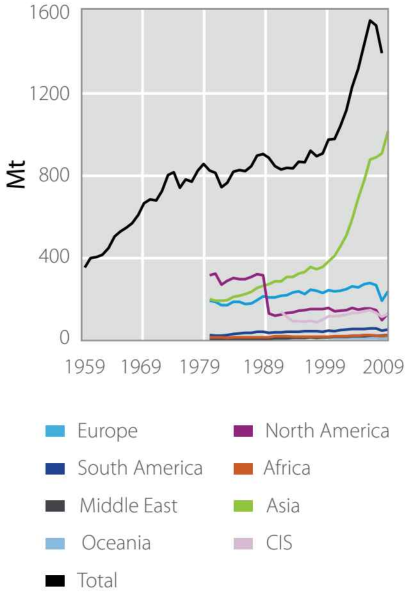


Figure 4.3—**Historic global steel output 1959–2009**[7]

chapter exploring the energy and emissions involved in each process, we'll be able to see how any strategy for change might affect the total emissions implied by the map.

Our maps show us the process chains we have to explore when thinking about energy requirements, give us an understanding of scale in metal production and teach us about scrap. When we predict future environmental impacts, particularly CO_2 emissions, from making steel and aluminium components, we need to anticipate how the maps will change: will they both simply expand as demand grows, or will the distribution of flows change? To start answering this question, we first need to explore how demand for the main applications in both sectors has evolved over time.

How has demand for steel and aluminium built up to present levels?

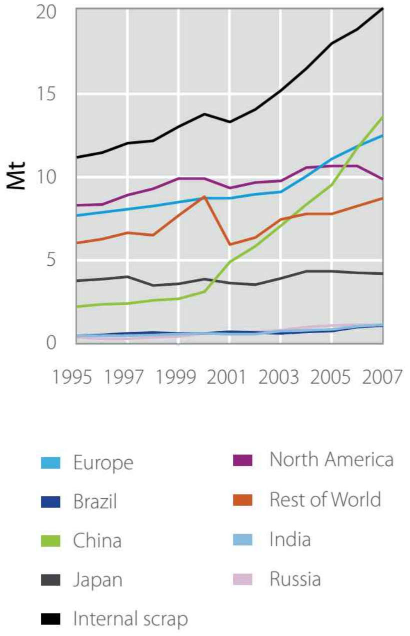


Figure 4.4—**Historic global aluminium output 1995–2007**[8]

In our prologue, we made an analogy about present levels of material use based on sculptures. Global production of liquid steel and aluminium is currently 1400 Mt, and 76 Mt respectively, so dividing that by a global population of around seven billion, we get to 200 kg of steel and 11 kg of aluminium produced for every person on the planet every year. This metal has the same volume as an 8 year old child and a new born baby respectively, and since we thought of it the image of those metal children, and the emissions of more than 400 $kgCO_2$ emitted in making them, has haunted us.

Our steel production per person is three times our average weight and yet because the materials industries operate at such vast scale, in out of the way locations, most of us are virtually unaware of our metal consumption. Interestingly this wasn't always the case: before the Second World War we had no agreed single measure of the economy, and instead used a range of production figures concerning pig iron production, railway freight tonnage and so forth[6]. If only we could go back: it would be much harder to have a financial crisis driven by a pyramid scheme of betting if the bankers had to prove their assets in pig iron rather than fairy tales.

Bessemer invented modern steel making in 1855, just 150 years ago, yet today we make three times our body weight of the stuff every year. Figures 4.3 and 4.4 show the recent history of global steel and aluminium output and we've shown estimates of where it was made. Some recent events show up clearly in the graphs, for example the recession in 2008 and rapidly expanding production of both metals in Asia in the past decade.

To understand how demand for the two metals might develop in future, we need to make two changes to these graphs. Firstly we need to change them to metal produced per person, to separate out the effects of population growth and to see if production per person keeps growing, or if there's a plateau. Secondly, because both metals are widely traded, both as stock products and in completed goods such as cars, we'd like to manipulate them to find out how much is consumed per person, by country, rather than how much is produced. We don't have perfect answers to either question but help is at hand from two of our colleagues.

Professor Daniel Mueller at the Norwegian University of Science and Technology (NTNU) leads a research group who explore all possible aspects of metal stocks and flows. Along with his colleague Tao Wang, they have produced Figure 4.5 to show the output of several steel producing countries divided by the population at the time. The great revelation of this graph is that steel output per person seems not to grow indefinitely but to reach a plateau. We're not sure why the plateau is different in different places, but Daniel Mueller and Tao Wang suggest that Japan's high plateau may be influenced by a prevalence of high-rise buildings, strict building requirements due to the risk of earthquakes and corrosion from the hot, humid and coastal climate. However, while production in developed countries appears to have reached a plateau, in developing countries, notably China and India at present, the graph demonstrates rapid growth.

Recalling the global figure of 200 kg per person for steel and 11 kg per person for aluminium, it appears that production per person in the UK has stabilised

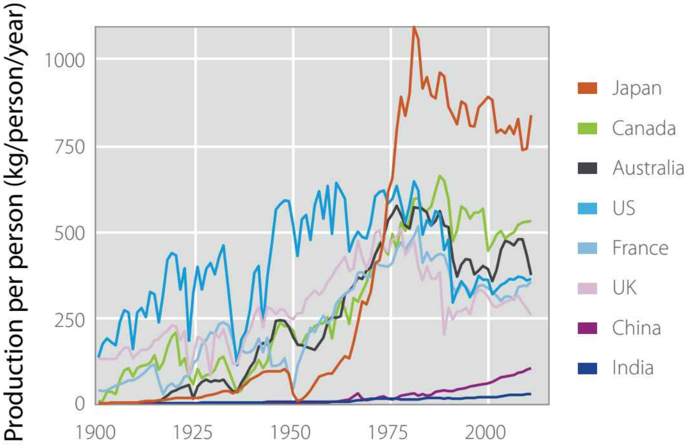


Figure 4.5—**Crude steel production per person for different countries**[9]

at the global average figure. At first sight that seems sensible, but on reflection, it isn't right. Figure 4.5 is based on national production figures but doesn't take account of trade because we don't have the numbers. So the fact that one country produces more than another may only mean that they have a large number of metal producing sites. What we really want to know is how much we consume per person.

We have found two estimates of consumption, both for the UK. In the UK at present we produce around 10 Mt of steel per year[10], of which we use around a half in the UK. But Figure 4.6 also shows that we import around 15 Mt of steel. As half of that is in products made from sheet steel, and we'll show in chapter 13 that we generate a lot of scrap when producing sheet components from liquid metal, we estimate that we cause about 23 Mt of steel to be made in other countries. So our total "steel footprint" is around 28 Mt—or 450 kg per person.

To check this number, we can turn to Professor John Barrett at the University of Leeds in the UK. His research group aims to show how the UK's emissions arise not from production but from consumption. This is very important: if we take responsibility for our emissions, we must do so regardless of where they occur. Despite national claims to a British sense of fair play, we are currently not doing this. Our national emissions figures take no account of what we import, and as we are net importers of goods, that suggests we're underplaying our real emissions impact. We also deny causing any emissions due to air travel, because the aircraft didn't burn the fuel when standing on the land of the UK. Good eh? Must have been dreamt up by bankers.

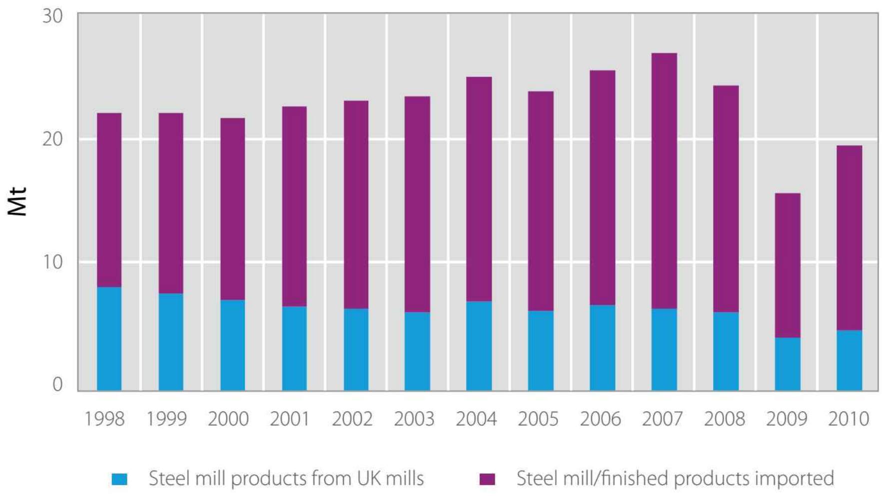


Figure 4.6—**UK steel requirements**[11]

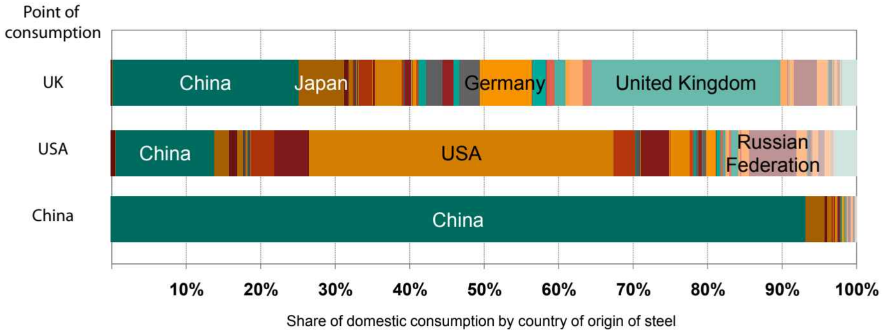


Figure 4.7—**Consumption of steel by country of origin**[12]

John Barrett has been working to come up with a fair figure of UK emissions based on what we buy not what we make. He does this by looking at the flows of money between sectors in the UK and elsewhere, so for example, when we buy a German car, he can estimate where our money ends up and what activities were involved. At the end of his arduous and data-intensive calculations, he comes up with a figure of 32 million tonnes as the UK's steel footprint and the share of domestic consumption by country of origin is shown in Figure 4.7. It's only an estimate, but now we have two different ways of coming to a similar number for UK consumption of steel, which appears to be around three times greater than UK production. We haven't found similar estimates for aluminium, but the UK's output of aluminium is now very small, so we have to assume that our real aluminium footprint would be an even greater multiple of what we produce. We would love to be able to produce new versions of Daniel Mueller's graph based on John Barrett's calculations of consumption but we only have one data point so will have to wait.

Let's quickly replay what we've just found about UK steel consumption, through the eyes of Chinese negotiators on climate change. We showed that in the UK we are responsible for more production in other countries than in our own, particularly in China, and to us it is clear that we should negotiate future international agreements on climate policy based on consumption not production. Therefore we agree with Chinese negotiators that targets for emissions reduction in China should be modified to account for trade—apparently good news for China. However, if we now impose our UK targets on emissions reductions to our consumption, that means we must reduce production emissions wherever they occur. So unless the Chinese steel industry cuts its emissions by 80% per unit output sold to the UK, our targets clearly tell us that we should buy less steel from China. Take your pick!

We've learnt in this section that although per capita production figures appear to reach a plateau, these are not for the UK good indicators of our total consumption. This makes it rather difficult for us to look ahead and forecast future demand for the two metals, whether in the UK or elsewhere, so in the next section we'll move onto estimating stocks of the two metals in different countries. Perhaps we'll be able to spot a pattern there so we can make some forecasts.

What stocks of steel and aluminium goods exist today?

The fact that in the UK we're each 'consuming' around 450 kg of steel and let's say 35 kg of aluminium per year is quite surprising: what on earth do we do with it? Most of us have no idea that we're purchasing these two metals at this rate. Worse, given that metals last a long time, our stock of both metals must be many times our annual demand. So we must each be responsible for several tonnes of steel and about half a tonne of aluminium. What have we done with it?

We're into difficult territory here because no one has ever collected comprehensive data to answer the question. So we're back to estimates, and estimating current stocks of steel or aluminium within a country is remarkably difficult. Broadly we have two options: to make a 'bottom-up' approach based on what we find in a particular area, or a 'top-down' estimate based on production figures.

For the 'bottom-up' approach, we could draw a boundary round some representative geographical region and then count the total stock of steel or aluminium in that region. If the region is representative, this should allow scaling up to a national estimate. This would be extremely arduous, although remarkably we have found a few PhD theses from students who've been positioned at municipal waste dumps for a year or more recording exactly what gets deposited: we can't imagine anyone more deserving of the cold beer we left on ice at the beginning of the chapter. Respect! But this bottom-up approach is imperfect. It would be very difficult to cover a large enough area in sufficient detail to be representative: just think of the vastly different architectural styles and building materials used for houses in different countries, and you can see the challenge.

In contrast, the top-down approach requires adding up annual production and net imports of each metal and subtracting annual disposal through waste management, to calculate the 'net additions to stock' for each year. Adding up these net additions should give us a figure for total current stocks. That would be straightforward, if only all our governments had decided 100 years ago to keep all the appropriate records. However, of these three variables—production, net imports, and disposal—we only have data on production. The monetary value of net imports can be estimated from trade data, which has been collected for many years, but estimating the metal content in each type of traded product is difficult. Disposal figures have only been recorded recently.

In reality, we can't know precisely how much steel or aluminium is in current stocks, but Daniel Mueller, Tao Wang and Benjamin Duval have created an extensive top-down model based on six countries to see how steel stocks are built up over time as economies grow. In Figure 4.8 we can see the results of their model, with steel stocks per person (called iron after the chemical name) plotted against income per person. We see, not surprisingly, that as a person's income increases they build up their stock of steel. The graph also suggests that steel stocks might reach a plateau, above which more money no longer means more steel—but more on this later.

Based on Figure 4.8 (the grey band) Mueller, Wang and Duval then estimate stocks of steel per person for all countries, based on their current wealth (GDP per person) as shown in Table 4.1. Steel stocks range from 0.1 tonnes per person for the poorest nations to over 13 tonnes per person for Japan, with the world average around 2.7 tonnes per person. Despite the vast quantities of steel being produced at present in China, stocks still lag the global average, at around 2.2 tonnes per person. India, the other major growth economy in Asia, falls even further behind with only 0.4 tonnes per person.

Country	**Steel stocks (tonnes/person)**
Argentina	4.1
Australia	9.8
Bangladesh	0.1
Brazil	3.1
Canada	12.1
China	2.2
Congo, DRC	0.1
Egypt	1.1
Ethiopia	0.1
France	7.5
Germany	9.0
India	0.4
Indonesia	0.3
Japan	13.6
Mexico	4.8
Nigeria	0.1
Pakistan	0.1
Philippines	0.1
Russia	4.6
South Africa	3.0
South Korea	7.9
Spain	8.7
Thailand	2.2
Turkey	4.2
United Kingdom	8.5
United States	10.5
Vietnam	0.1
World	**2.7**

Table 4.1—**Steel stocks in-use for selected countries**[23]

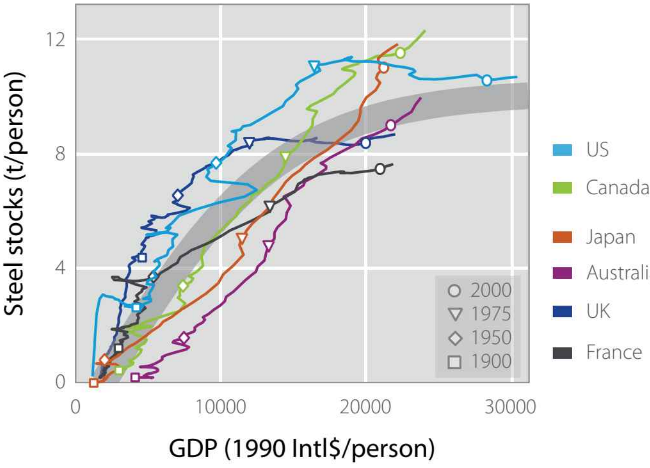


Figure 4.8—**Steel stocks in-use against GDP for different countries**

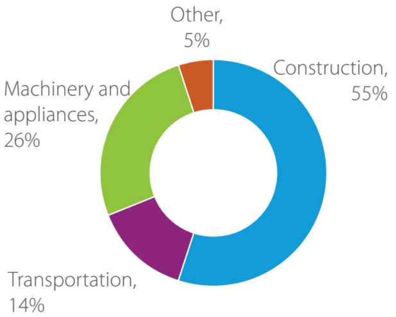


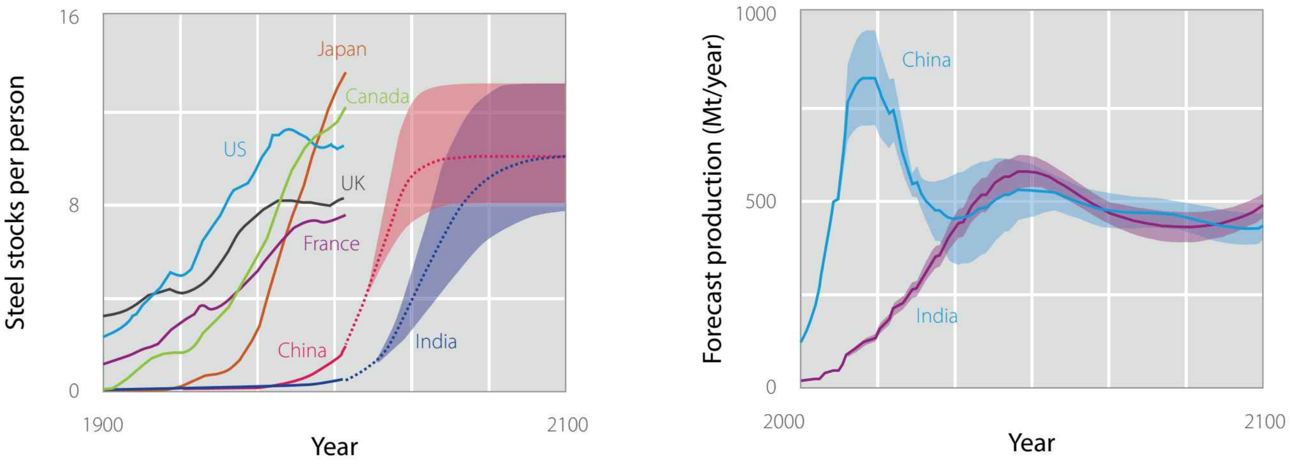
Figure 4.9—**Composition of UK steel stocks**[13]

The numbers in the table give total stocks, but for the UK we also have enough data to show roughly what stocks each person 'owns', and this is illustrated in the pie chart of Figure 4.9. We each use between one and two tonnes of steel in vehicles. This is roughly the weight of a car, although in reality, each person has less than a whole car and the rest is made up of other vehicles. Two to three tonnes of our individual stocks are in machinery and appliances. This includes household appliances like fridges, lawnmowers, computers, televisions and furniture as well as a proportion of the steel used in industrial machinery, such as farming and manufacturing equipment. Most of the rest of our individual steel stock is in buildings.

Steel stocks in construction vary by country, from under three tonnes per person in France to nine in Japan, and in the UK we have about four tonnes each. Typically about two thirds of this is in buildings and the rest in infrastructure, mainly bridges and pipelines. The difference between countries reflects local preferences in building towers and skyscrapers, as well as commercial and industrial buildings: the French have a strong preference for reinforced concrete framed buildings, while the Japanese (and the British) make much more use of steel frames.

Having found out more about our personal steel stocks, we can see why stocks tend to saturate as countries become wealthier. In the UK, most of us who want a car already have one and we have little land for new buildings or infrastructure, so although we upgrade what we already have, we are unlikely to increase the total stock significantly. This stabilisation of stocks is typical of developed countries, as illustrated in Figure 4.10. The graph on the left shows historical levels of steel stocks in six nations all following similar S-shaped curves, and levelling

Figure 4.10—**Forecast of stocks and production in China and India**



out at between 8 to 12 tonnes per person. If China and India follow a similar development path then, as shown in the graph on the right, annual demand for steel in these countries will rise rapidly before eventually stabilising.

Graphs like these have not yet been produced for aluminium stocks, however, Professor Tom Graedel and his student Michael Gerst at Yale University have collected some aggregated estimates. They found that in certain developing countries stocks are around 35 kg of aluminium per person, while in developed economies they have reached between 350 and 500 kg per person, leading to a global average of 80 kg per person[14]. However, unlike steel, it seems that aluminium stocks are not reaching a plateau even in developed economies, probably because our use of aluminium in applications such as construction and cars is still growing. We anticipate that aluminium stocks may eventually saturate between 500 kg and 1000 kg, but for now will use the lower value.

Understanding stock levels gives us a basis for predicting future demand. We buy steel and aluminium for two reasons: to replace the goods we throw out and because we want new goods. Trading in an old car for a brand new car is replacing stock, but buying a second car grows our stock. For a developing country, this means that the driver of demand changes as stocks build up. In the UK we have a stable stock of nearly 10 tonnes per person, which we replace at a rate of around 400 kg per person per year. In contrast, in China, stocks are much lower at around 2 tonnes per person[15]. Maintaining this stock, at similar replacement rates to those in the UK, would require production of no more than 100 kg per person, but Chinese demand is much higher than this due to stock expansion, leading to demand for around 400 kg per person[16]. So China and the UK appear to have similar rates of consumption per person, but for different reasons: UK demand is to maintain an existing higher but stable stock; Chinese demand is to maintain and grow a much smaller stock.

We're nearly ready to attempt a forecast, but first, let's check two other features of metal stocks and their saturation.

Firstly, our friends in economics might be tempted to tell us that demand for materials grows with GDP, as we get richer we consume more. Yet our graphs in this section have told a different story: while a country grows richer, metal production increases to drive up stocks, but then we stabilises at some threshold, required to maintain stocks at some plateau.

Secondly, if stocks really do stabilise, can we achieve the nirvana of a ‘closed loop’ economy? This is a great banner phrase and for example Chinese policy is currently directed towards the idea of a future “Circular Economy”[17] but the reality has proved elusive. Achieving a closed loop would require that stocks stabilised at a plateau for longer than the average product life time, and that our collection and recycling of old material occured with no losses. This is as yet far from the case: despite clear incentives, and well managed collection schemes, we only recycle around two thirds of our used drinks cans; most aluminium foil is not recycled, because it isn’t collected or is recycled in mixed streams with high losses[18]; steel reinforcement bars in sub-surface concrete (for example foundations and tunnels) are not extracted at end-of-life; deep-sea line pipes are not removed at the end of their life. So we’re still a long way from collecting all of our discarded metals for recycling, although our box-story overleaf on aluminium lithograph plates used for printing tells a positive story about a closed-loop in action.

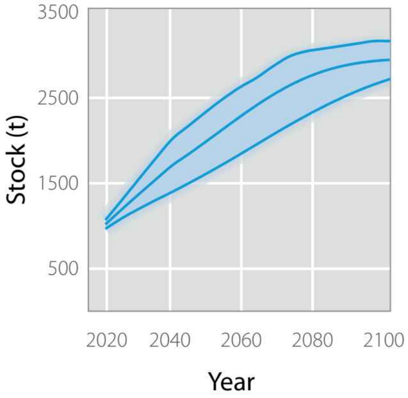


Figure 4.11—**Forecast of global steel stocks**

How will demand for steel and aluminium develop in future?

Our exploration of patterns of steel and aluminium stocks has given us a basis for forecasting future demand. If you tell us (a) how the population will grow in each country over the next 50 years (b) how economic development will occur in each country over the same time (c) whether there will be any new products invented during that period so that saturated demand in developed economies gets unsaturated as everyone races to purchase a new iSkyscraper—then we’ll be able to tell you exactly what demand will be…

…but of course, no one can possibly answer those questions, so instead we’ll use a simplified approach and apply it for steel. We’ll start with the United Nations’ forecasts of population over the next century as shown in Figure 4.13 and the US Energy Information Administration’s forecasts of global GDP growth. Dividing the second by the first gives us an estimate of future global wealth, which we can then apply to the graph of Figure 4.8, to predict future evolution in global steel stocks. And from annual changes in stocks, we can now forecast global steel production up until 2050.

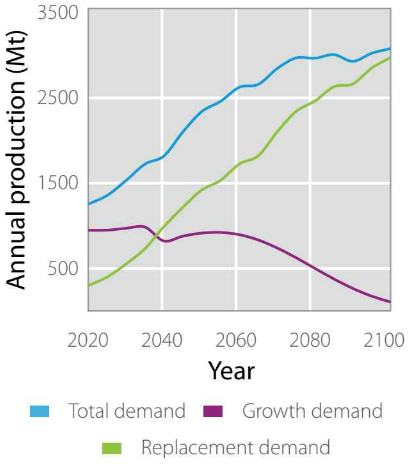


Figure 4.12—**Forecast production to replace steel stocks**

The resulting steel forecasts are presented in Figures 4.11 and 4.12. The first graph shows our simple forecast of global steel stocks and the second shows the resulting steel production required to grow and replace these stocks. Based on our simple

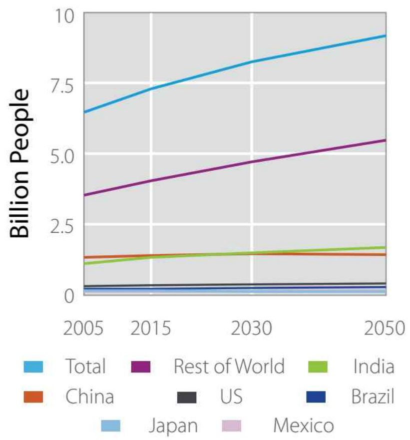


Figure 4.13—**Forecasts of future population**[20]

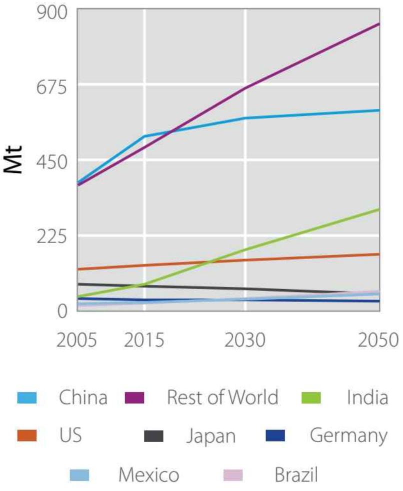


Figure 4.14—**Past and forecast steel consumption**[21]

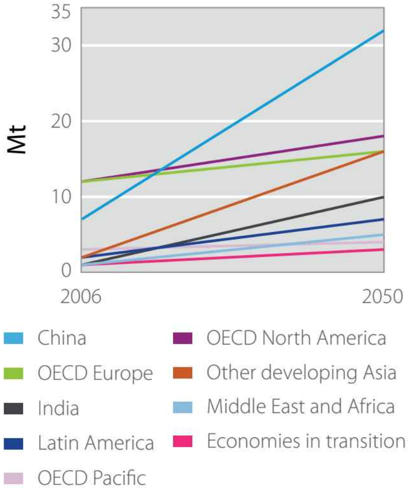


Figure 4.15—**Past and forecast aluminium consumption**[22]

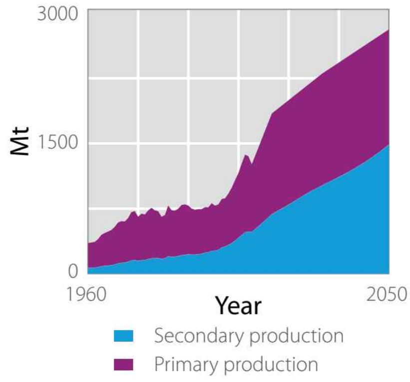


Figure 4.16—**Forecast of primary and secondary steel production**

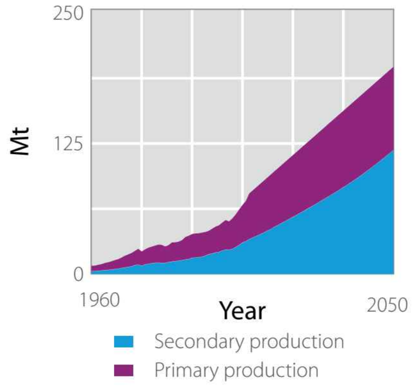


Figure 4.17—**Forecast of primary and secondary aluminium production**

model we predict that steel production in 2050 will be 1.7 times today's levels. We could produce similar graphs for aluminium demand if we had the required equivalent of Figure 4.8.

The approach we've described is also used by the International Energy Agency for their forecasts of future steel and aluminium consumption which are shown in Figures 4.14 and 4.15, although with different assumptions about steel stocks reaching a plateau. Because we are unable to create our own forecast for aluminium, we've chosen to use the IEA's forecasts of demand for the rest of our book.

Finally, as we want to anticipate energy and emissions associated with both metals, we need also to predict how future production will be split between primary (from ore) and secondary (from scrap) routes. We've shown this split on the IEA forecasts in Figures 4.16 and 4.17, which we've predicted by dividing the total demand into product categories, and used estimated product lifetimes to work out the flows of metal products into and out of use. Following our discussion about our failure to collect cans, foil and sub-surface rebar for recycling, we've used an estimate from Professor Robert Ayres at INSEAD in France that a practical maximum for recycling rates might be around 90%[19]. The graphs show that the fraction of secondary aluminium production might rise to around 60% by 2050, while for steel, with longer product life times, this fraction may be around a half. The circular economy is obviously a long way ahead of us yet.

Outlook

Our story in this chapter has been that we have a pretty good idea of how metals flow from ore into current uses, and a broad idea of what's being produced where, although we wish we knew more about consumption rather than production. We have shown a simple method for predicting future stocks and shown that we can use this to estimate how demand for metals will grow in future. Broadly we anticipate that demand for steel will grow by 1.7 times by 2050, while aluminium demand will grow by 2.5 times. As we set out in this book looking for options to deliver more sustainable materials, the precision of this forecast is much less important to us than its order of magnitude. Climate scientists are clear that we should aim to cut CO_2 emissions in 2050 to no more than half present levels, but over that period we've seen here that demand for steel and aluminium is likely at least to double. Halving emissions while demand doubles requires that we reduce the emissions associated with each product to one quarter, which is an extraordinarily demanding target.

Before we start adding up our options for change, we need to explore where energy is used and emissions arise in present day production, and to anticipate the challenge of implementing change, we need to find out how money flows in parallel with the metal. That's coming up in the next two chapters, but having now realised just how severe the challenge is, you might want to take a seat outside in your favourite chair, and look on the table next to you—where there's a clean

Lithographic plate

Lithographic plate is used to print the images and text that form our books, newspapers and magazines. We currently produce around half a million tonnes of aluminium litho-plate every year. Commercial print shops can use more than 100 hundred of these plates each day. An important characteristic is a high quality flat and degreased surface. 1xxx series alloys are often used (such as AA1050 and AA1100), or alternatively more durable 3xxx series alloys (such as AA3103 and AA3003) for mass printing.

Production may be from primary or recycled material. The business-to-business transaction, high specification and cost of the aluminium (accounting for 50% of the cost of lithographic coil), encourages nearly 100% closed loop recycling. Often, a recycling agreement will be part of the initial contract between the supplier and printer.

empty glass and a perfectly chilled unopened can of your favourite beer. The can glistens in the evening light, its dappled moisture announcing its cool readiness in the warm air, the three different alloys required to make body, cap and opener balanced in perfect harmony, ready to be recycled in a closed loop…

… but you can't recycle them until the can's empty. Cheers!

Notes

1. The aluminium producer Novelis (2011) reports that "Each year, more than 280 billion drinks cans are manufactured worldwide, and more than 85 percent of them are made from aluminium".

How does steel and aluminium flow from ore to final uses today?

2. The US Geological Survey produces annual mineral commodity summaries reporting national and global industry data, including where bauxite and iron ore is mined. The information on bauxite and iron ore mining is taken from the Bauxite and Alumina and the 2011 Iron Ore Mineral Commodity Summaries (USGS, 2011a, USGS, 2011b).
3. The US Energy Information Administration collects information on international electricity generation for different technologies, including hydroelectric power. Excel tables of all of their data can be found on their website (USEIA, n.d.).
4. The Aluminum Association produced a report on the manufacturing and lifecycle costs of different vehicles (Bull et al., 2008), and this included an estimate of the steel sheet contained within a conventional vehicle .
5. This data was collated from conversations with steel companies.

How has demand for steel and aluminium built up to present levels?

6. In their book, Macroeconomics: Understanding the wealth of nations, David Miles and Andrew Scot say until GDP was defined as a measure of growth "there existed a collection of disparate production numbers concerning pig iron production, railway freight tonnage, and so forth" (Miles & Stott, 2005). Victoria Bateman, economics lecturer at Cambridge University also pointed us towards a US resolution from 1849, which states "That the manufacture of iron is not a mere local or individual interest, but is of national importance, as affording a supply of a chief element of progress in time of peace, and an important engine of defence in time of war" (French, 1858).
7. This graph is produced from regional and global production data from the World Steel Association's steel statistical archives. Both this graph and the one for aluminium show regional net production (having accounted for the effects of trade) as well as the scrap recycled internally within the industry, which could not be separated by region. (World Steel Association, n.d.).
8. This graph is produced from regional and global production data from the International Aluminium Institute's mass flow model avaiable for the period 1997-2007. This data is not publically available but results of the mass flow analysis are reported in the IAI's global recycling report (IAI, 2009).
9. This graph is taken from analysis of patterns of iron use in society over time by Mueller et al. (2011).
10. The trade assocation for the UK steel industry, UK Steelreports on the state of the UK's steel industry in their annual Key Statistics report (UK Steel, 2011).
11. The UK steel demand includes steel mill products from UK mills used in UK products, steel mill products imported and steel contained in imported manufactured goods. (UK Steel, 2011)
12. This figure comes out of research on consumption by Barrett et al. (2011).

What stocks of steel and aluminium goods exist today?

13. Mueller et al. (2011) provide the data for this figure in their paper on iron stocks in use in their figure 4.
14. Michael Gerst and Tom Graedel wrote a paper summarising surveys of regional and global stocks of in-use metals from 124 different estimates (Gerst & Graedel, 2008).
15. This figure comes from Mueller and Wang's paper on iron stocks, Mueller et al. (2011).
16. Of course, part of the reason why China's per capita production figures are so high is because they are producing so many metals products for other countries. Part of their production will go towards production for other countries, a small part will go towards replacing their existing stocks (but not very much as the stocks are small and quite young) and part will go towards new demand, building up new stocks of metal products.
17. In 2008, China adopted a circular economy law, which aims to encourage increased recycling and further innovation in recycling technologies. A translated copy of the law can be found at China Environmental Law (2008). A summary of circular economy legislation around the world was put together by Davis & Hall (2006).
18. Boin and Bertram (2005) estimate that more than 30 % of scrap foil is lost when remelting.

How will demand for steel and aluminium develop in future?

19. From Ayres (2006) on why growth will not continue to be exponential.

Box stories, figures and tables

20. The population forecasts are taken from the IEA's book, Energy Technology Perspectives, (IEA, 2008a), which are based on UN predictions.
21. The future demand for steel is calculated by multiplying per capita demand from the IEA's projections in IEA (2009) by population projections.
22. The future demand for aluminium is calculated by assuming a linear relationship between current consumption and projections of total regional consumption for 2050 from the IEA (2009).
23. Mueller et al. (2011) provide the data for this table in their paper on iron stocks.