18 Options for change

for the major steel and aluminium using products

Now that we've identified a new set of options 'with both eyes open' we can return to the catalogue of products we identified in Part I to find out to what extent each strategy can be applied to each product.

With one eye open, in chapter 11, we found that we didn't have enough options to achieve our target 50% cut in emissions while demand grows to 2050. However, since chapter 11, we've re-examined the world of steel and aluminium with both eyes open, and found that we have a new and wider set of options, through material efficiency and demand reduction. So in the next chapter we'll return to adding up, to find out whether we can combine all the options we applied in chapter 11 with those in our new armoury to reach our target. But in preparation for that, we first need to look at how each of our new options apply to the major product groups we identified in our catalogues in chapter 3.

We'll continue to use our forecast of future demand from chapter 4, and in the absence of any other detail, will assume that the forecast of demand growth applies not just in total, but also to each product in turn: we can't predict 40 years ahead whether growth in car ownership will occur at a different rate from growth in the use of drinks cans. However, having seen that materials are used to provide a service and not as objects in their own right, we can re-interpret our demand forecast as a prediction of demand for material services. Therefore the option to use products more intensely, may allow us to reduce material inputs while growing service outputs. And if we treat our forecast as a prediction of service demand, this allows us to apply our option of last resort, from the last section of chapter 17: as an absolute reduction in demand for material services.

As we look at how our new options apply to different products, we also need to be aware of other forces for change. Anticipating changes in consumer fashion and specific technologies is beyond us, but returning to the pie charts of chapter 2, we saw that after the industry sector, the next two big sectors of the global emissions pie chart were the use of buildings and the use of vehicles. While we are aiming at a 50% cut in emissions in industry while demand grows, we must expect that the designers of future buildings and vehicles also will be aiming at similar reductions.

We're going to set up a 'mixing desk' for our options for change, with sliders to indicate the degree to which we'll pursue each option. We'll have one slider for each of chapters 12–17 of this book, and in this chapter we'll estimate for each product the two extremes of the slider. The lower value on each slider will show where we are today, and the upper value will show the limit of what we think could be achieved. For example, cars in the UK currently have an average life of 14 years, but could in future have a life of 30 years. So our life extension slider for cars will range between 14 years (the present) and 30 years (the maximum we can envisage in future). Similarly the fleet average mass of cars in the UK is 1.3 tonnes at present, but we know that Colin Chapman's Lotus Seven weighs 500 kg, and Volkswagen's current L1 concept car, which achieves 189 mpg in a diesel hybrid configuration, weighs 380 kg. So we could allow our slider for using less metal by design in cars to range from 1,300 kg now to 300 kg as the minimum we can imagine. Each slider will describe a representative product, such as an 'average car' so we retain a physical sense of what our forecasts require—but if your car has a different weight or expected life at present, you can scale the slider appropriately. If we find we have to apply all six sliders at their limits and still can't reach our target, we'll have two further 'catch-all' sliders: one for carbon capture and storage (CCS) and one for a global reduction in demand for services.

How should we deal with material substitution between the two metals, or between either of them and some other material? The question 'is steel better than aluminium is better than steel?' is not for us interesting, because it is too small a

A mixing desk for emissions forecasting!

question because we know demand for both metals is set to grow strongly. For the past 30 years, the aluminium industry has been promoting the use of aluminium in cars, and most engine blocks are now aluminium, but with a few exceptions, most car bodies are still made in steel. There will be further change in material composition in cars in future, but we don't know how it will develop. The much bigger driver of change in cars is that they must become significantly lighter in order to achieve better fuel economy, and this can be achieved with either metal: the two-seater 500 kg Lotus Seven is mainly made in aluminium; the four-seater 600 kg Tata Nano is mainly made in steel. So in our predictions about future product compositions, we'll stick with our global forecast from chapter 5—that steel demand will grow by 170% and aluminium by 250%—and assume that the relative proportions of the two materials in any particular product will always grow in this ratio.

Lightweight cars: Lotus Seven (top) and Tata Nano (bottom)[8]

We've looked at substitution of other materials in chapter 3, and found that there really aren't many options. We could potentially use more magnesium alloys in cars, with the advantage of a good ratio of strength to weight, and with low yield losses when the metal is injection moulded to final shape. However, casting magnesium currently requires intense use of the gas SF_6 (sulphur hexafluoride) in order to exclude all oxygen from the liquid metal (which would otherwise combust); SF_6 is the worst of all greenhouse gases with a global warming potential over 20,000 times worse than carbon dioxide. Studies of the substitution of magnesium into cars suggest that the emissions benefit of weight saving, and hence fuel economy, is currently eclipsed by the effect of this gas. We've seen that both Airbus and Boeing have made a significant shift from aluminium to composite materials in the past 10 years, and as we know, if you make aeroplanes you'll do anything to save weight. But producing composites is more energy and carbon intensive than manufacturing aluminium[1], and composites cannot in any meaningful way be recycled[2]. So although we are confident some material substitution will occur, there are no clear 'better' materials, and we could with some confidence join in the steel and aluminium industry's claims that they are (jointly!) key materials for our future. So we won't include any effects of material substitution in our exploration of future product options.

In the remainder of this chapter we'll look at the products from our catalogues in chapter 3, to anticipate how we could apply our options for the future, with both eyes open.

Construction

Steel in construction

In the UK, government legislation on energy consumption in commercial buildings requires that by 2019, every new building will be 'net zero carbon', i.e. designed with very efficient heating and cooling with energy supplied from carbon-free sources[3]. Governments in other countries are also aiming to reduce energy use in building, for instance Germany and Scandinavia promote ultra-low-energy 'passive houses', and in China low-carbon 'eco cities' are planned. However, the use of energy in a commercial building is largely unrelated to the structural frame that supports it. The key features of a building that determine its energy requirements in use include the ratio of window separation to ceiling height, the presence or not of atria or chimneys to boost natural ventilation, the location and design of windows to control radiant heating by the sun, and the exchange of heat between the interior and exterior via leaks, insulated surfaces, windows, and ventilation. Requirements for steel (and cement) are therefore not strongly influenced by evolving regulations on energy use in buildings.

Three main forms of steel are used in construction: structural sections, reinforcing bars and sheet steel used for cladding and 'purlins', the light, horizontal elements in 'shed' type buildings such as supermarkets and warehouses.

In our survey of options, we've seen that there is a significant opportunity to reduce requirements for structural steel in buildings through avoiding over-specification, avoiding excess rationalisation, and through applying 'using less by design' with new manufacturing techniques. Compounding these opportunities we've estimated that structural steel requirements could at best be reduced to around two fifths of current levels. We have seen that structural steel could be re-used extensively, and with a more standardised set of components we estimate up to 80% of structural sections in buildings could in future be re-used. However it is unlikely that much if any material from infrastructure projects could be re-used, as it is usually replaced only after problems with corrosion or fatigue damage.

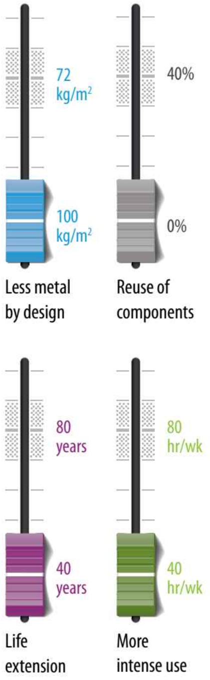
In parallel we should be able to reduce our demand for reinforcing bar per unit of service through better optimisation of layout, and through a shift to higher strength steels. The second option is particularly important in China at present. As yet reinforcing steel has never been reused: if it is used below the ground it is in effect lost, as the cost of extracting old piles is so great that contractors on 'brownfield' sites prefer to build around old sub-surface structures than to replace

Reinforcing steel in a demolished building

or re-use them; if it is used above the surface, then at the end of the life of the building, as part of demolition, reinforcing steel may be separated from concrete (by shaking or hammering) and recycled, but it is never re-used. However, if in future we assemble buildings from modular reinforced concrete elements, parts such as standard floor-slabs in multi-storey buildings could be re-used, so we'll allow for 20% reuse of reinforcement in this application. It is difficult to envisage any change to our strategy of abandoning sub-surface reinforcement bars at end of life, so we will continue to exclude this metal from future recycling streams.

The third form of steel used in construction derives from rolled sheet—and is used for purlins and cladding. Purlins are often damaged during deconstruction, so although they can be re-used, we have allowed only a maximum of 50% re-use. Cladding, often made from stainless steel, is subject to changing standards for thermal insulation, so reuse is currently restricted to agricultural sheds. However, the opportunity to reuse cladding is likely to increase as the new insulation standards become widespread, so we've also allowed for up to 50% future re-use.

Structural steel and reinforcing bars are cut to length accurately during fabrication, leaving only small off-cuts. Also, the sheets used for cladding tessellate and can be cut to regular, often rectangular, shapes. Therefore, in these applications there is little opportunity to reduce yield losses in construction or to divert scrap to other applications. All three types of steel would see the same benefit if the life of the building or infrastructure were extended, or used more intensely. At present, when buildings are demolished, this is because of changed user preferences rather than degradation, so we can safely assume that all building lives could be doubled. The owners of infrastructure are already highly motivated towards life extension, but we found evidence suggesting that the UK's motorway bridges from the 1960's are failing earlier than intended, so some life extension will be possible through better control of the construction process. Most buildings could be used more intensely. If an office block has no other purpose, and if everyone using it works for 40 hours per week, it is unused for over 75% of the time. So we assume that the intensity of building use could double. Potentially, infrastructure could be used more, but in several cases we found that it is already used beyond initial specifications, for instance when national laws on maximum truck weights change. Therefore there is limited scope for using infrastructure more intensively[4].



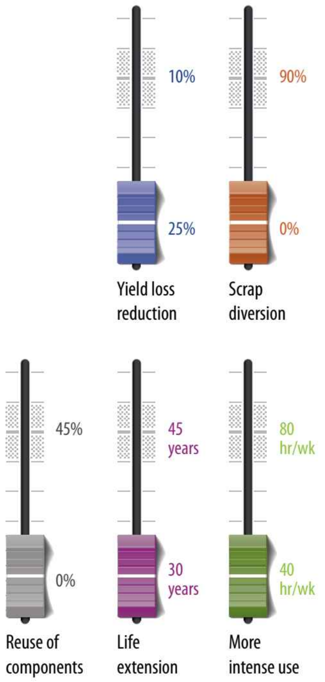
Steel in construction
(based on a 7-storey office block)

To set up our sliders, we've averaged the discussion in this section according to global average proportions of structural steel, rebar and sheet. So although we estimated that we could use two thirds less structural steel than at present by design, the overall limit to reduction in steel in construction is only one third—

because it is more difficult to save reinforcing bar and sheet. The numbers on the sliders are based on a typical office building, a 7-storey building with 100 kg/m^2 of steel and 10,000 m^2 of floor area. We assume proportionally similar savings for other building types.

Aluminium in buildings

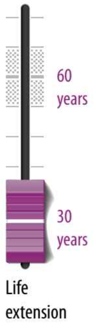
About half of the aluminium used in buildings is made by extrusion and of necessity must have a constant cross-section, so there are few opportunities for saving metal with efficient design: extrusion already allows excellent flexibility for designers wishing to optimise material use. There is some scope for yield improvements in extrusion[5] and solid bonding may allow efficient diversion of scrap from both production (the head and tail of each extrusion) and from cutting to length in fabrication. Re-use of aluminium window frames and other building components is not yet practised, and is inhibited by the difficulty of extracting used components without damage, by water staining of older frames, and by the fact that windows are generally removed when a higher specification is required. Reuse of aluminium building components is possible so we assume it will develop to some extent. The same issues apply to aluminium cladding as for steel, so we'll assume that up to 50 % of it could be reused in future. More intense use of buildings would give the same benefit for aluminium components as for steel in buildings.



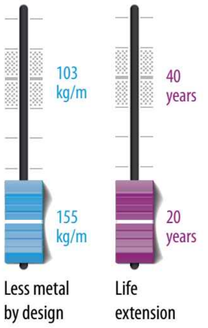
Aluminium in buildings

Rail track and line pipe in infrastructure

We've chosen rail track and line pipe as representative of non-structural applications of steel in infrastructure. We've seen several opportunities for extending the life of rail track, by cascading, by design with new higher strength steels, and by restorative processes. ReRail, capping worn rail with new high strength steel, is as yet unproven, but would allow significant life extension for the bulk of steel in the rest of the rail. As track wear is proportional to train weight, future design of lighter rolling stock would also support life extension. With intense development we estimate that we might double the life of future rail track. We identified two credible options to use less metal by design for deep sea line pipe: if we could find a different laying process, pipes could be assembled on the sea bed, saving around one third of current metal requirements. This might be achieved through remote welding, or by mechanical joining as used for pipes in shallow seas[6]; improved condition monitoring, for example by robotic 'pigs' that clean and monitor the inside of the pipe, would help ensure pipe safety over its life, and allow a reduction in over-design. Inevitable corrosion and fatigue restrict opportunities for reusing pipe at the end if its life.



Rail track

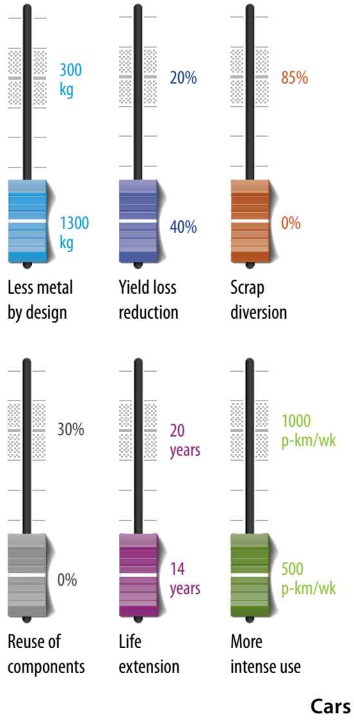


Linepipe
(600mm diameter pipe)

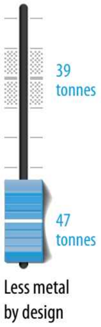
Vehicles

Cars and trucks

The average car in the UK weighs 1.3 tonnes, is used for 4% of the year, and when in use has an average of 1.6 occupants. So most of the time, most cars have significant excess capacity, and the car is significantly heavier than its cargo. Cars require much more fuel when accelerating than when driving at constant speed, and fuel consumption rises significantly beyond about 65 miles per hour. So a car designed to minimise environmental impacts would be light, be full of people, and travel more smoothly with a lower top speed. (All of this applies regardless of the power source used to drive the car, which is why we've argued that developing plug-in electric cars now is the wrong priority: vehicle weight should be addressed before switching to electric power.) As a result, we are confident in predicting that future cars will be lighter than today. How can this occur? Cars could be smaller. We know we could live without many of the gizmos (electric windows, seat angle adjusters) that attract us to shiny new cars, which as they are operated by heavy electric motors, add significant weight. Future control systems may help to reduce the danger of crashing, or we might accept lower speed limits, or lanes segregated by vehicle mass to ensure the safety of lighter cars.



The same benefits of different driving behaviour apply for trucks, but the vehicle mass is less important because trucks are designed to carry loads heavier than themselves. 'Road trains' with multiple trailers pulled by one vehicle offer fuel savings if fully loaded, and reduce requirements for metal per tonne of cargo carried. However, there are fewer opportunities to save vehicle weight for trucks than for cars. Car manufacture has high yield losses, and there are many technical options for developing more efficient production chains to reduce them. We learnt from Abbey Steel that car blanking skeletons can be cut into blanks for other users, so scrap diversion could be applied more aggressively in future. We already re-use car and truck components through salvage yards and second-hand dealers, and some component remanufacture occurs. However, as the design of engines and gearboxes changes rapidly, component reuse will remain limited. In future, as we saw demonstrated by Professor Tekkaya in Chapter 15, we may be able to re-shape sheet metal parts, but this still needs extensive development. Although the lifetime of cars could be doubled to 30 years, only the body structure, panels and closures are likely to last that long. The drive train, suspension and other moving parts of the car are likely to require earlier replacement or upgrade. We have averaged these opportunities according to component masses to predict a reduced upper limit of 20-years on our "Life extension" slider.

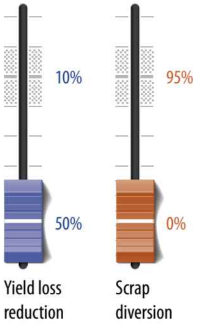


Train

Ships and trains

In recent years ships have been scrapped at a high rate due to a decision by the International Maritime Organisation to force a shift from single to double hulled tankers. Currently 60% of shipping containers returning from the UK to China are empty, but that reflects the direction of world trade in goods, so we have few opportunities to increase the intensity with which we use our ships. At end of life, ship plate salvaged from ship-breaking in Gujarat is currently re-rolled, and with the Indian sub-continent dominating the global ship breaking industry it may be difficult to expand this activity further[7].

Meanwhile trains, which are a key part of any future lower energy transport system, have in the UK, become significantly heavier in the past 20 years: the average train (a combination of intercity, diesel and multiple electric systems) has grown from 39 to 47 tonnes. This has been driven by use of larger crash structures and by demands for the improved reliability provided by multiple powered vehicles. In contrast, high-speed trains in Japan have become lighter. The Shinkansen rail system has reduced train mass by 40% since the 1960s. As anticipated for future cars, improved safety control has reduced the chance of crashes, allowing weight savings in the crash structure. So we can safely promote the design of lighter weight trains to save metal in production and to extend the life of rail track. At a minimum, we can predict train weights will return to those of 20 years past.

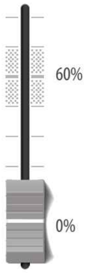


Plane

Aeroplanes

Aeroplane manufacturers primarily manufacture swarf, so there is great potential to improve their famously poor 'buy-to-fly' ratio. The ideas we've discussed include rolling plates with a wedge profile, better forging processes to achieve nearer to net shape stock products, and diverting swarf back into use via solid bonding. Aeroplanes require a relatively small fraction of total aluminium use, albeit a high profile one, so despite their inefficient use of material, they are not our highest priority. However, given the very high and growing contribution of air travel to energy and emissions in transport, the difficulty of making significant step changes in future fuel consumption, and the problem of land area requirements for growing biofuel to replace kerosene, an important strategy in reducing future emissions must be for us all to fly less. We've aggregated all reductions in demand for final services into one slider in the next chapter but would like to prioritise demand reduction in flying, as it is such a significant and growing fraction of transport emissions in developed economies.

Transmission cables

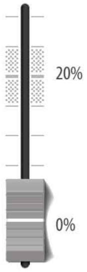


Transformers

Industrial equipment

Electrical equipment

Steel is used both to provide the structural infrastructure for electrical grids, and as an active electrical component in distribution and use. Galvanised steel towers (pylons) create electrical corridors that criss-cross nations as they distribute electricity from centralised power stations. The failure of one of these pylons would cause power-cuts and widespread disruption, so pylons are typically well maintained and only replaced when corrosion has undermined the integrity of the tower. Therefore there is limited opportunity to extend the life of the towers, and because their components are small and corroded in use, reuse at end of life is also unlikely. Electrical steels, with high silicon content, are used in large transformers throughout the electrical network, for example to step down the voltage from power stations to household voltage. The intensity at which the transformers are used determines their expected life, so there is little scope for intensity improvements in an already well-managed grid. However, at end of life, the steel tank surrounding the transformer could be reused, along with up to 60% of the transformer itself. The cost of transportation and disassembly currently inhibits this option.



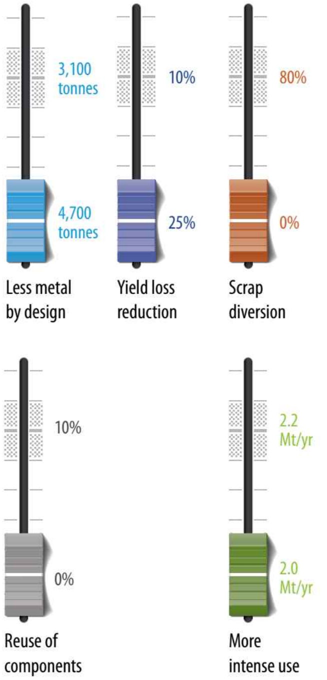
Bus bars and conduits

Both steel and aluminium are used in electrical cables. The aluminium conducts the electricity while the steel provides the strength to span the long distances between pylons. The main cause of end of life for overhead transmission cables is that over time they are required to transmit more power than initially intended. This excess power causes the cable to heat up causing annealing and thus a permanent reduction in tensile strength. This, in combination with the tension in the cable, causes structural sag, prompting replacement before (we hope) or after contact with an obstacle such as a tree. This issue will become more complex if we move towards a more electrical future, and there is considerable debate at present about the development of a "smart grid" that would allow connection of widely distributed, intermittent low power supplies (typically renewable sources) of electricity to be switched in and out of different grid segments. Such a grid would be materially intensive, and also vulnerable to changes in future specification. It should therefore be designed in a modular manner to facilitate upgrades. Proactive overhead cable replacement in the future may allow reuse of cables on lower power routes, so we have assumed potential for up to 50% reuse.

When underground cables fail, they are usually repaired rather than replaced, unless additional capacity is required or the insulation has failed. Underground cables are not reused at present because they cannot be certificated, and the insulation could be degraded. This is unlikely to change in the future.

Aluminium strips (known as bus bars) are also used to connect elements in switchboards, and aluminium conduits protect wires and cables. Such conduits are small and dispersed, so reuse might be expensive, but there is no technical obstacle so we have assumed up to 20% could be reused.

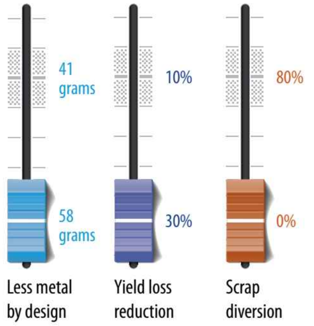
Mechanical equipment



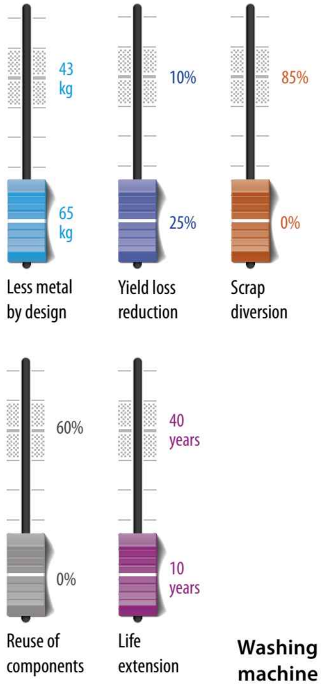
Mechanical equipment (based on a 4,700 tonne plate rolling mill, with a production capacity of 2 million tonnes year)

In our analysis of mechanical equipment, we focused largely on rolling mills, and found them to be an exemplar of our onion-skin model of design: most of the rolling mills ever made are still in regular operation, as the core metal providing the structural frame has survived undamaged and can still cope with expected loading. The outer layers of the onion skin, including rolls, bearings, drives and actuators, have been upgraded at appropriate intervals. We therefore have few suggestions about extending the life of current mechanical equipment. Given the complex geometries of many of their component parts, it may be possible to improve the yield in equipment manufacture, and we also identified an opportunity to develop replaceable wear surfaces, such as sleeved work rolls, to allow restoration of degraded components. We found that metal products in general could typically be made a third lighter by optimal design and manufacture so have assumed the same here. Fabrication of products from plate (a large proportion of steel in mechanical equipment) typically has a low yield, which could be improved by greater tessellation.

Mechanical equipment could be used more intensely, through better scheduling and co-ordination, both within and between factories. Increased flexibility in future equipment design may allow more continuous use of equipment while coping with the wide variety of products demanded by final consumers. Standardisation of reusable and modular products would reduce the variety demanded of mechanical production equipment which could further support more intense use.



Food can



Washing machine

Metal products

Packaging

Returnable or reusable packaging is easy to design, and normal in Germany, but would require a change in user behaviour, and possibly legislation, to be adopted in the UK. Steel food cans and aluminium drinks cans could be re-used, if the cans were stronger to avoid damage in use, and could be cleaned and recoated in a way that met food safety standards. Steel aerosol cans could equally be refilled and re-used.

Foil, used for the cooking and preparation of food generally, is a poor use of aluminium as the waste stream of this valuable material is highly dispersed. Foil is discarded in small pieces and mixed in other waste, so is hard to separate and therefore mainly lost to landfill or incineration after first use. With collection rates around 50–60%, nearly half the material in drinks cans is also lost after first use. So, it would be sensible to replace aluminium food and drink packaging with a material with lower embodied energy, and ideally with packaging that could be reused many times. It's unlikely that foil can be made much lighter, and drink can weights are also approaching a limit, but we saw earlier that there may be opportunities to reduce yield losses in can making. Food cans, as discussed in Chapter 12, could be a third lighter if they were cooked in a different way.

Goods and appliances

Use of our two metals in appliances is dominated by fridges and washing machines which, as we discussed before, are discarded after lives of around 10 years, due to the failure of small low cost components that are expensive to replace. Design for substantial life extension is therefore a big opportunity for these applications, so that rather than having a new fridge every decade, we buy one for life but with a service model for repairs and upgrades. Electric motors and fridge compressors can be remanufactured or reused, and the sheet metal panels in white goods could be reformed into alternative shapes. We'll also assume that yield losses from fabricating these appliances could be reduced, and that they could also be much lighter.

Notes

1. According to Granta Design (2010), the manufacture of primary aluminium requires approximately 200MJ/kg, whereas a typical composite, such as carbon fibre reinforced plastic, requires 270MJ/kg. In reality, manufacture of aluminium is a mix of primary and recycled, further reducing the energy requirement for aluminium. In contrast, there is no viable method for recycling composites.
2. Recycling of composite fibres has been investigated by Seok-Ho (2011). However, over 1.5 litres of nitric acid are required per 100 grams of composite, and therefore the environmental implications are awful. The recovered carbon fibres only have a slight reduction in tensile strength. As the process extracts only the fibres, not the energy-intensive resin, there is only a limited benefit in this approach to recycling composites.

Vehicles

3. The UK Government has undertaken consultations to formulate this strategy, following on from its requirements that homes be carbon neutral by 2016. Though the exact rules and details have yet to be finalised, further information is available at DCLG (2007).
4. Roads and bridges are designed for a certain maximum weight of vehicle, which is limited by law. These limits have been increased three times in the past twenty years in the UK, so we have had to re-examine existing bridges to see if they can take a higher loading than originally intended, or if they must be strengthened. Statistics collected by McKinnon (2005) to examine the use of trucks, estimate that they carry their maximum load 36% of the time.
5. Yield losses in making commodity extrusion products, such as window frames are about 20–25%. This is due to scrap generated at the start of each extrusion, and from the butt welds that form between billets as they are extruded one after another. With better modelling and control of this weld, we may be able to reduce these yield losses in future.
6. Merlin mechanical connections have been used to join oil pipe by remotely operated vehicles in the North Sea. They use a clamp and pressure seal connection. Using mechanical connections avoids the need for welding, so pipes can have a plastic lining, which increases corrosion resistance so prolongs their life. These connections are reusable and reversible.

Vehicles

7. India, Pakistan and Bangladesh dominate the ship breaking industry, with roughly half the world's ships dismantled in India alone. Tilwankar et al (2008) state that over the life-span of the ship, approximately 10% of the steel is lost by corrosion. 95% of the remainder is in the form of re-rollable sheet, allowing approximately 85% of the ship's original steel mass to be reused. The predominant revenue stream of the ship breakers is from re-rolling the steel and so they are naturally motivated to maximize re-use.

Images

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