Prolonging Our Metal Life

Making the most of our metal services
Prolonging our metal life

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WellMet2050

WellMet2050 is a £1m, 5-year 8-person research programme at the University of Cambridge, funded by the Engineering and Physical Science Research Council (EPSRC) of the UK government to look at all options to reduce global carbon dioxide emissions associated with steel and aluminium. The project is supported by a consortium of over 20 global companies, with whom we are developing case studies, demonstrators and analysis to reveal the emissions benefits, business opportunities and technical challenges of a raft of emissions reduction strategies.

Our story in one page

A third of the world’s energy is used in industry, to make buildings, vehicles, equipment and products. Demand for these goods comprises both new demand in growing economies, and replacement demand in developed countries. If we’re concerned about future global energy use—whether because of prices, availability, or due to climate change—would keeping goods for longer reduce our need for energy? This report examines this question for goods made with steel and aluminium, accounting for around 10% of global carbon emissions from energy and processes.

Is it always a good idea to keep goods for longer? If the goods not only require energy in production, but also in use—as happens with cars and offices for example—then might it be better to replace them sooner rather than later if efficiency in use is improving? We’ve examined this question and found, of course, that the answer depends both on the ratio of energy required in production to that in use, and the rate at which the requirement for energy in use is improving. If car fuel consumption reduces at 3.5% per year—which is the rate required to meet EU regulations for future vehicle efficiency, then for a current typical car, there is a small benefit to be had from extending vehicle life from 10 years to 15 years. However, if in addition we could upgrade the engine every 5 years, to take advantage of new fuel economies, the total saving would be greater than the energy required to make a new car. So, in exploring life-extension, we need to be aware of opportunities to upgrade the performance of goods, through more frequent replacement of key components.

There is then a potential benefit to keeping goods for longer, but as we know, for many goods we’re doing just the opposite—and discarding them more frequently. Why is that? We find that products are discarded for four different reasons: because their performance diminishes over time (“degraded”); because other products out-perform them (“inferior”); because the demands of their user changes (“unsuitable”); and because of more systemic changes in preferences (“unwanted”). Using these categories, we’ve made an assessment of the reasons that users discard goods. Our evidence suggests that the majority of products are not broken when they are discarded, and therefore we must either use our products more intensively to fully realise the physical properties of the metals we make, or extend the lives of our products by replacing the obsolete functions with upgrades. This latter strategy also allows replacement of the broken functions when physical failure has occurred. We’ve examined four case studies in detail to explore this—a steel plate mill, an office block, a car and a fridge—and described each design using an “onionskin” model based on the life expectancy, metal share and cost share of different key components. We find that upgrade is more likely for products which metal substructures make up a significant share of total costs.

In fact we have the technology to design almost any steel or aluminium product to stand the test of time: several museums have examples of steel swords more than 2,000 years old; the famous Iron Bridge at Ironbridge Gorge near Coalbrookdale, built by Abraham Darby III and opened in 1781, still stands and is now a UNESCO World Heritage Site; just over a decade later the Ditherington Flax Mill in the outskirt of Shrewsbury is thought to have been the first building to use iron for its columns and cross beams and still survives today; Oriel Chambers, an iron-framed office building in Liverpool designed by Peter Ellis in 1864, is still in daily use. So clearly the constraints to long life are not primarily about durability—we already have good solutions to most problems with corrosion or wear for instance, and modern condition monitoring and maintenance practices can make these cost effective. Instead, the challenge is to find ways to maintain the value of older goods through pursuit of technical strategies that realise the physical separation of the product functions (modular design), allow products to adapt to changing needs (adaptable design), and extend product life beyond first use (through restoration, upgrades and cascading reuse).

So given that we have the technology to use our metal products for longer, why don’t we? When taking a closer look at commercial and industrial replacement decisions we find biases that act against consumers choosing more durable products. We also find that producers like replacement demand as it increases sales. Does this mean that nothing can be done? We think not. Greater durability may not be a desirable tack-on strategy to business as usual, but as part of a rethink in business strategy can become viable and even lucrative: modular designs may allow cheaper model changes, take-back may inhibit a competitive ‘grey-market’, regular servicing and upgrades may provide more predictable cash-flow than replacement sales as well as better customer lock-in. Government policy could support the appropriate development of life-extension opportunities through high quality information and certification, through a rebalancing of tax incentives towards extension rather than replacement, and through promotion of whole life costing.

Longer life and more intense use of metal assets.
Prolonging our metal life

The environmental case for product life extension is subtle—we get more service out of our products and so save embodied energy, but we have fewer opportunities to exploit advances that save use phase emissions. This section explores how we might increase the services we get from our products and explains how to evaluate the trade-offs associated with life extension.

Let’s just use our products more

A third of our global energy is used to make the buildings, vehicles, equipment and products we use. This energy is expanded to make products that provide a service over a period of time. If we could get better at exploiting the services our products offer we could reduce these production emissions. The graph below shows, in grey, the total service that is offered by a product. The blue use profile shows that the product is under-utilised—it is not used to capacity and is discarded before the end of its physical life.

What can be done to address this under utilisation? There are three options: the use profile can be extended by using the product at full design capacity or ensuring the product is only discarded when broken; the service space can be shrunk to more accurately reflect the product’s use and to avoid over specification; finally, the service space could be extended by making longer lasting higher capacity products. Which option is best depends on the relationship between the use profile and the service space: increasing capacity or product life only makes sense if it results in an increase in use; using a product more intensively can shorten its physical life but still be beneficial if it increases overall service output. So what’s the relationship between intensity of use and product life?

Using them more may shorten their life?

Perhaps what we win in greater intensity of use we lose in shorter life? Firstly there are different ways that we can increase intensity (we have to distinguish between using products more frequently and using them to capacity) and secondly because different products are more or less sensitive to use (depending, for example, on whether they have wear dependent moving parts). We explore this in the box story below and see that it is possible to increase the service we get from our products through greater intensity of use. This is particularly the case for products such as buildings where there is little trade-off between product life and how often we use them. For wear-constrained products, such as cars, we find that product life is more sensitive to changes in frequency of use than to changes in load. As a result increasing load (for example by increasing the number of passengers in a vehicle) increases the service we get. Increasing frequency of use has a neutral impact on physical life, but can still be beneficial if it prevents products being discarded for non-physical reasons.

Making the environmental case

We can see that increasing average passenger loading from 1.6 to 4 (the orange line) makes little difference to the physical life of the car (because the car weighs more than the passengers) but more than doubles service output. Doubling the annual mileage (the pink line) halves the physical life of the car but does not change the service output. This reduces the chance that a car is discarded before the end of its physical life. If it results in an increase in use; using a product more intensively can shorten its physical life but still be beneficial if it increases overall service output. So what’s the relationship between intensity of use and product life?

Using vehicles more intensively

Similarly, increased loading on trucks, trains, ships and washing machines causes a disproportionately small loss in product life, though the ratio will vary widely by product type. Offices are currently used less than a quarter of the time and could be used more frequently with no effect on building life.

What about use phase emissions?

So far we’ve only explored part of the story. Product life extension saves emissions embodied in production but it also means that we have fewer opportunities to exploit advances that save use phase emissions. The trade off between use phase and embodied emissions is similar to that faced by Formula 1 racing teams: a car may be losing 2 seconds each lap due to worn tyres, but changing to new tyres will take 20 seconds, so it is only worth pitting for a tyre change if there are more than 10 laps left in the race.

In order to take into account use phase emissions we need to look at a string of successive purchases and make assumptions about improvements in the best available technology. For each string of purchases we can plot cumulative emissions (that’s the embodied emissions from making the product including repairs and upgrades, and the sum of the annual use phase emissions) over time. We can then compare different product life and upgrade strategies as we’ve done for the case in the car in the box story below. A key variable that determines the saving of emissions is the relative size of use phase and embodied emissions.

Is product life extension becoming more important?

We expect product life extension to become more important over time as the embodied energy share of key metal intensive products is increasing over time. What is causing this trend?

Well, use phase emissions currently dominate (see bar chart below) for buildings (76-83% per square metre), passenger vehicles (85–94% per passenger-kilometre) and freight vehicles (86–95% per tonne-kilometre) and so have been targeted by environmental legislation. For example the EU’s tailpipe emissions targets demand that average fleet emissions are reduced from 160gCO2/ km in 2008, to 120gCO2/km in 2012 and 95gCO2/km by 2020, with a further reduction required to reach the UK’s 80% reduction target by 2050 (see graph car on following page), and the Part L building regulations and the UK’s Zero Carbon targets for new building projects aim to increase use phase emissions to net-zero by 2019. Meanwhile embodied emissions are predicted to remain constant. This doesn’t mean that there’s a lack of innovation in this area.

Upgrade as a strategy for vehicle life extension

In the graph shown, the base-case (blue) is a typical mid-size car (125gCO2/km tailpipe emissions) with a design life of 200,000km over 10 years. At years 0, 10 and 20, new cars are purchased creating 6.3tCO2 of embodied carbon emissions per car (no technology improvement rate is applied to this). The use-phase emissions are assumed to improve by 3.5% every year (in line with the car-maker’s targets and EU regulation), giving 128 gCO2/ km for the first period, and 90 gCO2/km and 64 gCO2/km for the following two periods. Total emissions of the 30 year period come to 75 tCO2. The life-extension strategy (orange) extends the product life to 15 years, with only two new cars. This saves only 15tCO2 (20% of emissions, much less than the 6.3tCO2 embodied emissions saved, because the strategy delays upgrading to the latest engine technology. The upgrade strategy (green), each car is again held for 15 years but is upgraded every 5 years with a new engine at a cost 19% of embodied emissions in a new car (9.9tCO2). This takes advantage of the improved engine technology to reduce use-phase emissions with a minimal penalty in embodied emissions (additional changes to the vehicle may be required to achieve these use phase changes but are not taken into account here). The strategy results in a 7tCO2 (9%) emissions saving, which is more than a new car, and could offer an acceptable life extension model for car manufacturers. This is relatively small compared to the cumulative emissions over the period. Greater savings will be achieved for products for which embodied energy is more important.
In fact, constructors and manufacturers will need to work hard to hold embodied emissions at current rates, as many use-phase improvements require more complicated solutions with energy intensive materials, for example: using aluminium in cars provides use-phase benefits from light-weighting but increases embodied emissions considerably; efficient buildings require extra insulation, triple glazed windows and mechanical ventilation systems, which also increase the embodied emissions.

Together, the anticipated reduction in use phase emissions and steady embodied emissions mean that the share of embodied emissions increases (see graph above). See Making the Environmental Case™ for more details. This increase in embodied energy share strengthens the case for product life extension.

How do we attribute emissions?

Design life vs. physical life

Structures are built to a ‘design life’ but this does not necessarily mean they are physically degraded or unfit for purpose after this time has elapsed. Eurocode 0 defines the design life for buildings as the period for which the structure can be ‘used for its intended purpose with anticipated maintenance without major repair being necessary’. Buildings are built to withstand the worst-case scenarios (e.g. wind loads, concrete degradation and seismic activity) expected within this time frame. If a likely event does not happen, the building will stand beyond its design life. Equally extreme unforeseen events can bring about physical failure, e.g. outbreak of war, terrorist attacks.

Trade-offs with product weight

How much over-specification would we be willing to tolerate in order to increase product life? Well, the extra metal for the over-specification calls on primary production, but life extension saves secondary production by reducing the amount of remelting required. We can say that for over specification to be environmentally justified, the ratio of the proportionate increase in life to the proportionate increase in mass must be greater than the ratio of primary to secondary emissions—approximately 3 for steel, 20 for aluminium. That is to say it is worth over specifying a new building up to a third of its mass in order to double its life. These numbers assume a scope constrained supply and are applicable for only one life cycle. See Life Expectancy Trade-Offs with Product Weight™ for more details.
Steel and aluminium product life

To understand how to use our steel and aluminium products to capacity and for longer, we must first determine what the significant steel and aluminium end use products are, and then examine their use and failure modes. The chart below gives our estimate of the volumes of new products being made annually, with the colours indicating causes of failure.

The end-use of steel is dominated by construction (56%), whereas a more even distribution is found across the 4 sectors for aluminium. The average life expectancy for a steel product is 34 years, and for aluminium is 21 years, predominantly due to the use of steel in longer lasting construction and the use of aluminium in short-lived one-way packaging.

The table below shows the relative importance of each failure mode to the metals. ‘Unsuitable’ and ‘unwanted’ reasons for end of life dominate steel product obsolescence, accounting for 54% of products by steel mass. The largest contributors to this value obsolescence are buildings and their components. The structural integrity of a building is typically unchanged throughout life. However, if the building cannot be adapted economically to suit a new use, it must be replaced and its constituent components (e.g. structural sections), disposed of despite the fact that they have neither deteriorated nor been technically superseded. This is also found for aluminium used in buildings, with product end of life often due to building rather than component failure.

Creating the chart

The chart presents a breakdown of metal intensive end use steel and aluminium products produced in 2008. The most metal intense end use products were identified through a combination of top-down and bottom-up analyses from a range of data sources. The most significant top-down data sources are the “World Steel Association 2008 Sustainability report of the World Steel Industry”, “EUROFER” and “International Aluminium Institute Material Flow Data for 2008”. Bottom-up calculations were derived from data received from relevant companies, predominantly within the WallMark2050 consortium. Studies on volumes of semi-finished products were used to further calibrate the end use tonnages.

To establish failure modes, we have compiled a catalogue of representative product descriptions containing pertinent use and end of life information at a component level. The product descriptions have been verified in industry, and are being used in structured interviews with relevant experts. The causes of disposal are determined from the product descriptions and interviews, and abstracted to the reasons for end of life presented in the end of life framework. It is difficult to discriminate between the various failure modes to attribute a specific failure to a product, therefore the chart is an estimate, but can be used to make general statements about the scale of product failure modes. ‘Unsuitable’ and ‘unwanted’ types of failure have been combined to form ‘Unsuitable/unwanted obsolescence’ as discrimination is too subjective for many products. Product specific details on failure modes can be found in the working paper Steel and aluminium product lifeWP.

Do our products live life to the full?

On average, a steel product can expect to last for 34 years before being scrapped, and an aluminium product 21 years, but how much service do they provide in that time? The chart below shows how intensively we are using our products, with contours showing the equivalent time the products spend being used at full capacity. The radius of the data points is proportional to the annual end use breakdown.

Industrial equipment stands out as providing the highest equivalent years of service for both steel and aluminium. Products in this sector are typically used intensively, and only discarded when the physical condition is deteriorated through use. For example, electric transmission cables are in near-constant use throughout a circa 30-year life, and only discarded when they become ‘unsuitable’. The higher power demands over time causing greater transmission losses and physical weakness of a given cable.

The diverse set of metal products considered provide a short service. Appliances such as washing machines we use infrequently and one-way beverage packaging, although used to full capacity, has a life expectancy of only 6 weeks from production to recycling.

See Steel and Aluminium Product LifeWP for more details.
The different components and sub-assemblies of a product fail at different rates and for different reasons. For example: structural components (e.g. I-beams and mill stands) tend to be long lived; moving parts and those subjected to wear are not; and, those which serve an aesthetic purpose (typically casings for small products and surfaces for large products) inevitably degrade over time. Failed parts can be repaired or replaced, but in many cases, a subset of components still function when the product is ultimately discarded. Why are functioning metal intensive components being discarded due to parent product failure?

Imagine that a product is made out of different layers with longer lasting, structural sub-assemblies at the core and those that are shorter lived, e.g. aesthetic components, in the outer layers. By looking at the metal share and the cost share of each of these layers we can understand how much metal and cost could be saved by reusing the core to it’s full life. The onionskin approach, used here, is a way of describing the composition of a product and a way of understanding the likelihood of significant metal saving through component reuse: metal savings through component re-use are technically feasible for products with easily distinguishable layers and large core metal shares (on the left hand side of the onion); component re-use is more likely for those that also have a significant core cost share (on the right hand side). In this section we look at four metal intensive products: a rolling mill, an office block, a car and a fridge. We have drawn an onionskin for each based on data collected with the support of our industrial partners.

### Rolling mill

Over half of the total steel in a 4,700t plate mill lies in the structural housing and foundations. The next largest contributors are the rolls that are much smaller in size but are replaced more regularly. Some of the most short-lived components—work rolls, spindles and back up rolls—fail due to wear. The control systems and the main motors are typically replaced to improve mill performance in line with technological developments. Bearing systems, gearboxes, hydraulic systems and cooling systems have an accumulated duty and fail in line with their scheduled life—based on a statistical decision relating to their likelihood of failure. Sub-components (e.g. nozzles within hydraulic systems and gear teeth) are replaced more regularly. The steel cost share of the structural components (housing and foundations) is only 11%, however once the civil engineering in the foundations is included, the housing and foundations account for 30% of the total costs. This high cost share helps to explain why rolling mills have been successfully upgraded to increase productivity, roll higher grade steel and meet more stringent quality standards.

### Office block

A 400t office block steel frame accounts for 16% of the steel in the building but only for 10–15% of building costs. Structural components typically undergo very little degradation over a building’s life. A building façade may suffer from corrosion or failure of the seals allowing water in, or it may be replaced before this if it discoulours or a higher quality skin is required. Services fail because seals or moving parts are worn or because rival technology becomes preferable. The space plan and building content are typically adaptable and change with needs. Modern buildings tend to fail because they become ‘unsuitable’—typically triggered by a change in use or a change in desired density. Because the different layers of the building are relatively easily separable and because the vast majority of the metal is in the long-lived structural components, buildings are a good candidate for upgrade or re-use of structural parts. However, this is tempered by the low cost share of these components that means that there is a relatively small gain from component life extension that has to be weighed up against reduced flexibility.

### Car

With good maintenance, engines will last approximately 150,000–300,000 miles or about 10 years. The likelihood of a premature engine failure increases when maintenance is neglected, for example if the cam belt fails whilst driving the engine will seize and have to be replaced. Modern well-maintained structural components (the car body and chassis) can be expected to last in excess of 50 years but usually vehicles are discarded before this point due to high maintenance costs. Components within the suspension system (e.g. shocks and struts) are typically replaced over the life of the vehicle. There is a strong second hand market for vehicles meaning that the vast majority of vehicles are ultimately discarded because they are degraded beyond economical repair. Legislation restricts reuse of structural components from cars that have been damaged in accidents by prohibiting “cut and shut” techniques on safety grounds. Non-structural panels can be reused. Upgrade strategies that prolong the life of the core metal structure by allowing engine upgrades could be explored.

### Fridge

Most of the steel in a fridge is in the exterior paneling, the aluminium is shared equally between the condenser and the evaporator. Refrigeration tube alloys are highly susceptible to corrosion and fridges typically fail because corrosion either reduces heat transfer (forcing the compressor to work harder and burn out) or causes refrigerant leakage. Once the compressor has failed, the whole product is scrapped as one despite the fact that all parts, other than the compressor, are typically still functioning and account for 75% of the cost share. The likely reasoning here is that replacing the compressor would only increase product life by 5 years. In order to increase the likelihood of component life extension in fridges, the failure of both the compressor and of the exterior paneling has to be addressed.

This section has demonstrated that the cost and metal share of product sub-assemblies are disproportionate, with the metal in the long-lived structural components not always a significant share of the cost faced by the customer. For this reason there is relatively little value to compensate for the possible inconvenience of life extension, and as a result some components are still functioning when the product is discarded. Just because the cost savings are relatively small doesn’t mean that they can’t be profitably exploited. Can technical strategies help bring down the cost of ‘peeling’ the onion and so prevent functioning components failing due to parent product failure?
Strategies to maximize product service

The service we get from our products is maximized by extending product life or, in some cases, by increasing intensity of use. This section looks at technical strategies to achieve these goals. The strategies are grouped by stage of life running from design, to user, to post first use. In each case we discuss which failure mode applies where. It also shows how the availability of information changes across the product life stages. At the design stage there is perfect information about the original product specification, but little is known about future needs (especially for long lived products), and at the post first use stage needs are evident but information on providence and specification is typically sparse.

The choice between strategies depends on the degree of uncertainty over the cost and functionality of future rival products (that risk the incumbent product failing because it is ‘inferior’) and over changes in user requirements (that risk the product becoming ‘unsuitable’). The schematic (below right) shows which strategy applies where. It also shows how the availability of information changes across the product life stages. At the design stage there is perfect information about the original product specification, but little is known about future needs (especially for long lived products), and at the post first use stage needs are evident but information on providence and specification is typically sparse.

**Design**

**Durability:** Increasing durability guards against ‘degraded’ failures by delaying physical decline. Durability is improved by appropriate material and coating selection in design and by eliminating flaws in manufacture. More durable products require less maintenance and repair at the expense of higher upfront costs. Durability is only appropriate for products for which few changes in requirements are expected.

**Adaptability:** Adaptability guards against products becoming ‘unsuitable’ or ‘inferior’. Greater adaptability is achieved by over-specifying capacity and through design with future upgrade in mind. Co-benefits include quicker delivery times, as adaptable products are more customisable through fabrication. Adaptability is only justified if the greater flexibility it offers is later exploited.

**Modularity:** By subdividing a product and allowing its constituent parts to be removed, replaced or upgraded independently, modular design guards against all four types of failure. Modular design prevents the failure of one component from causing failure of the product as a whole. Modules can be fabricated and assembled in parallel, saving time, but must adhere to a standard architecture and interface.

**Use**

**Maintenance:** Regular maintenance and care taken in use makes products last for longer. For some products such as aircraft and transport infrastructure condition monitoring that involves routine collection and analysis of data on product performance is used to identify problems early in an effort to allow more efficient, targeted maintenance to save time and cost and reduce disruption.

**Increased intensity:** As discussed on page 2, using products to capacity makes the most of the energy that is embodied in products. Using them more frequently can shorten product life whilst delivering the same product service. The latter is preferable if there is a chance that the product will fail for reasons other than being ‘degraded’. For example if the product is likely to be discarded due to changing trends or changing needs then a shorter, more intense product life is preferable.

**Post first use**

**Restoration:** Degraded products can be restored to their original condition. Restoration can save replacement and disposal costs. However, restored products can be perceived as inferior, especially if the restored aesthetics are not ‘as new’.

**Upgrade:** It may be possible to upgrade ‘inferior’, ‘unsuitable’ or ‘unwanted’ products. Upgrade offers a cheaper alternative to product replacement and becomes more viable if the product has been designed to be modular or adaptable. Information on the original design aids upgrade but drastic changes in needs limit the scope of product upgrade.

**Cascading:** Because all consumers have different needs, ‘superfluous’ or ‘unsuitable’ products may be passed on to a new user. This happens where restoration and upgrade are not viable. Cascaded products are cheaper but by definition of lower quality. Products that are most suited to cascading typically have many different users.

**Importance of information**

A recurring theme across all strategies is the need to have accurate documentation so that new users can have confidence in the quality of the product: modular buildings are greatly reduced in value without BAA Certificate of Approval; the Baker Street refurbishment was greatly aided by original calculations and drawings; when installing ‘flexible’ foundations Canary Wharf commissioned an additional ‘Close-out’ report from the engineers to document the exact specification of the foundations and to collate the many construction documents. Having product information readily available saves testing and certification costs and so increases the likelihood that product life is extended.

(Photos credits: Zander Olav, Make)

**Examples:**

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Fixed vs. variable costs: The benefit of long-lived assets is that high upfront costs can be smoothed over a longer life, however neo-classical economics teaches that past costs that cannot be recovered should be considered sunk and not feature in decision-making. In line with this theory one replacement decision rule demands that the average cost of a replacement asset should be compared to the marginal cost of an existing asset (including operating costs, maintenance costs, opportunity cost and salvage value). By not taking into account average capital costs of the incumbent asset, this method does not account for the benefits of durability. Where both capital and maintenance costs are taken into account in decision-making, the relative size of the two is expected to influence asset life, with more capital-intensive assets lasting longer. This relationship is explored in the chart below, which appears to show that more capital intensive assets do indeed last for longer.

Uncertainty and the value of flexibility: The pricing of more adaptable products crucially depends on the confidence that future requirements will lie within the scope of the more expensive, more durable, adaptable asset. For example dedicated packers and fillers used in the fast moving consumer goods sector have to be replaced in line with product cycles—typically every 7 years. More flexible robotic packers and fillers are available but 2 to 3 times more expensive. As they are not expected to serve in-house demand for more than 10 years (despite having an expected physical life of 20–30 years) robotic packers are not considered cost effective. The solution lies not only with bringing down the cost of the robotic packer, but with increasing the expected in-house life of the robotic packer through greater adaptability.

Time horizon: The failure to take into account the full range of costs and benefits of different durability options is in part a problem of time horizon. Bonding capital budgets and liquidity constraints lead to capital rationing and a focus on short payback periods that can be as long as two years according to interviewees. This sort of myopic decision-making is suboptimal over a longer time horizon as shown top right for case of durable rail.

Expectation of residual value: Concerns about low residual value can limit what consumers are willing to pay for longer lasting products that they expect to resell. Data on resale prices shows that around 15% of the value of a vehicle is lost on purchase with another 10% lost by the end of the first year and a further 10% lost per annum thereafter. For structural components that show little degradation as little as 20% is lost over a life that exceeds 50 years with the lower price reflecting search costs and compromises in design. Owners are in a poor position to assure future purchasers of the condition of the product as they have a vested interest in exaggerating quality. Where quality is not easily verifiable, resale value is low and buyers are deterred from buying durable assets.

The business case for upgrade of vehicles

The graph below shows cumulative profit margins for three replacement and upgrade strategies for vehicles. We assume that an upgrade costs 20% of a new vehicle and increases fuel efficiency in line with the energy efficiency technology available in the year of upgrade (using the same fuel efficiency assumptions as the box story on page 3). Regular upgrade halves annual maintenance costs and yields a 20% profit margin for the producer (this profit assumption is in line with profit margins achieved by after-sales automotive services). The upgrade strategy is found to be as profitable as the 10 yearly replacement cycle and offers more regular cashflows. If profits on the scale of those secured by after-sales automotive services cannot be achieved then the producer loses out unless they can increase market share or increase the price of the upgrade service.

The business case for longer life products

We have seen that product life extension is technically possible, so why doesn’t it happen more and what could be done to promote it? We treasure heritage objects; can we extend this sentiment to a wider range of goods, not out of nostalgia, but because these goods meet our needs cost effectively? Most uses of steel and aluminium are governed by business-to-business decisions as opposed to business-to-consumer decisions, so this section explores how different commercial purchasing and replacement decision-making rules act for or against greater durability. This section is informed by a series of structured interviews with producers and users of industrial machinery and equipment.

The consumer choice

There are many aspects of commercial decision making that deter purchase of durable products:

The types of costs taken into account: More durable and reliable products usually incur a higher upfront cost in return for lower maintenance costs and delayed disposal and replacement costs. In order to allow fair comparison all costs must be taken into account. Although the principle of whole-life-costing is generally understood, in practice, features such as residual value, disposal costs, replacement costs and expected future variable cost trajectories are often not taken into account in replacement decisions.

The effect of discounting: The chosen discount rate (found to be 10–20% for companies interviewed) reflects the cost of capital and the expected risk of a project, with more risky projects (e.g. rail) that can be as low as two years according to interviewees. Binding capital budgets and liquidity constraints lead to capital rationing and a focus on short payback periods that can be as long as two years according to interviewees. This sort of myopic decision-making is suboptimal over a longer time horizon as shown top right for case of durable rail.

Durable rail

Premium heat-treated rail can be used to increase rail life, reducing disruption, downtime costs and saving on cumulative long term costs. The graph below plots cumulative installed cost taking into account the price premium charged on heat-treated rail. The life of the heat treated rail is assumed to be double that of the standard rail. Because the premium rail is 12% more expensive, it will not be chosen on the basis of lowest first cost even though the average annual costs are 49% lower. If the NPV of the two streams are compared, more time is required to justify the higher investment in premium rail, for a higher discount rate. With a discount rate of 10% at least 17 years is needed to justify the change, with a discount rate of 13% the required time increases to 24 years; and, with a discount rate of 15% the change is not justified even after 110 years.

Cumulative Profit ($)

No upgrade, replace every 15 years

No upgrade, replace every 5 years

0 5 10 15 20 25 30

0 2000 4000 6000 8000

Project years

Upgrade strategy

Cycle cost savings. An upgrade strategy that manages consumer concerns (such as perceptions of inferior quality, concerns over a higher risk of failure and confidence that the upgradeable asset will be flexible enough to respond to changing needs), is likely to be interesting to consumers in markets where technology changes slowly. Are producers in a position to pursue such a policy?
Prolonging our metal life

The producer's choice

Producers make decisions on how products are designed and under what sort of contracts they are offered to consumers. Deliberate shortening of product life! Increasing product durability, keeping everything else constant, is not in the producer's interest as it reduces sales. This is the root of fears over planned obsolescence (the concept that producers may deliberately curtail product life) and is also the reason for the policy paralysis surrounding product life extension. Planned obsolescence is theoretically more likely in saturated markets (where higher sales require higher replacement rates), in concentrated markets (where monopolists have an incentive to kill off the second hand market) and in technologically dynamic industries (where increasing returns allow R&D investment to be recouped over a shorter period). In the industrial equipment sector, global competition, increasing demand from BRIC countries (accounting for 20-50% of sales of companies interviewed), and the fact that it is easy to entice replacement (rather than induce it) where technology changes quickly, all guard against planned failure. Planned obsolescence is not thought to be a problem in the sector, different products will have different durability but this is the result of a cost-quality trade-off not planned obsolescence. Competition means that deliberate obsolescence is likely to be punished with a poor reputation. Can manufacturers make money from offering longer lasting products?

Strategic, profitable product life extension! Producers can choose to offer contracts that expose them to costs and benefits away from a focus on initial sales. Only if businesses are willing to embrace this strategic shift can they profitably pursue product life extension.

The figure below maps the technical strategies to failure modes and the appropriate business models in answer to the question, ‘Which strategy applies where?’

Policy to support longer life products

There is little government policy aimed at encouraging longer life, more intensively used goods. Usually, where policies do act on the decisions discussed in this report, they are otherwise motivated and influence product life only indirectly. The focus has instead been on reducing environmental impacts in the factory, diverting product waste from landfill, and anti-competitive behaviour laws, that are mainly aimed at deterring monopoly pricing. Direct intervention on product life is rare because (1) product life extension is not universally environmentally beneficial and so policies have to be targeted for specific products/eventualities; (2) product life extension may reduce GDP growth and reduce consumer choices; (3) there is no data on time series trends in product life on which to justify intervention. A relatively new strand of economics, behavioural economics, states that not every purchasing decision reveals true preferences—just because consumer purchases contribute to the “throw away society” does not imply that this is what consumers want. It may be possible to “nudge” consumers towards purchasing longer lasting products. The table below suggests government policies that encourage: producers to design long life products and offer contracts that support this design choice; consumers to purchase durable products and use them to capacity; and both consumers and producers to make the most out of products post-use.

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## Actions and opportunities

The table below summarises actions that could be taken by suppliers, designers and users of durable goods and by government to deal with each of the four types of obsolescence identified at the beginning of the report.

<table>
<thead>
<tr>
<th>Absolute</th>
<th>Relative</th>
<th>Inferior</th>
</tr>
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<tbody>
<tr>
<td>Degraded</td>
<td>Suppliers should:</td>
<td>Suppliers should offer product upgrades:</td>
</tr>
<tr>
<td></td>
<td>look at warranties and leasing contract business models</td>
<td>Designers should provide adaptability to cater for changing input and product market conditions and technological development of rival products. They should also pursue modular design to reduce the cost of upgrade.</td>
</tr>
<tr>
<td></td>
<td>include information on durability at purchase e.g. labelling</td>
<td>Clients/users should employ whole life costing of replacement options over a long time horizon.</td>
</tr>
<tr>
<td></td>
<td>improve maintenance guaranteed availability of spare parts, modular design to reduce maintenance costs, condition monitoring to understand performance and plan maintenance</td>
<td>Developers of product rating systems and regulations should introduce incentives or requirements for appropriate adaptable features.</td>
</tr>
<tr>
<td></td>
<td>Designers should practice durable design and pursue quality fabrication.</td>
<td>Government should:</td>
</tr>
<tr>
<td></td>
<td>Clients/users should consider upgrade and restoration.</td>
<td>• incentivise more intensive use to induce early physical failure</td>
</tr>
<tr>
<td></td>
<td>Government should:</td>
<td>• coordinate with insurance industry to provide greater clarity on legal requirements for upgrade</td>
</tr>
<tr>
<td></td>
<td>• mandate minimum durability and eco-design standards</td>
<td>• address tax distortions that favour replacement: capital allowances, VAT</td>
</tr>
<tr>
<td></td>
<td>• implement innovative fiscal measures – e.g. varying VAT depending on length of guarantee</td>
<td>• enact emissions standards that consider embodied energy</td>
</tr>
<tr>
<td></td>
<td>Industry bodies should instigate voluntary minimum durability and eco-design standards.</td>
<td>• avoid scrappage schemes</td>
</tr>
<tr>
<td>Unsuitable</td>
<td>Designers should:</td>
<td>Suppliers should market longevity.</td>
</tr>
<tr>
<td></td>
<td>• implement adaptable and upgradable designs to cater for changing customer needs</td>
<td>Designers should pursue iconic design and design against aesthetic degradation.</td>
</tr>
<tr>
<td></td>
<td>• customise and design for emotional attachment</td>
<td>Where product bans are necessary, e.g. UK Control of Asbestos Regulations and the accelerated phase-out of single hull oil tankers, government should aim to minimize the metal loss by ensuring that targets for conversion and/or use of metal subcomponents are built into legislation that prohibits use.</td>
</tr>
<tr>
<td></td>
<td>Clients/users should consider cascading reuse</td>
<td>The WellMet2050 team will raise awareness on embodied carbon, including recommendations on how embodied emissions should be included in analyses.</td>
</tr>
<tr>
<td></td>
<td>Government should:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• coordinate with insurance industry to provide greater clarity on legal requirements for upgrade and cascading reuse</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• introduce take-back legislation and fiscal instruments to reduce the cost of upgrade</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• incentivise more intensive use to induce earlier physical failure</td>
<td></td>
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</tbody>
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WellMet2050 working papers

The working papers contain more detailed analysis to support the findings of this report, and are available for download from www.wellmet2050.com

WP1 Cullen (2011): Making the Environmental Case, WellMet2050
WP2 Cooper D (2011): Life Expectancy Trade-Offs with Product Weight, WellMet2050
WP3 Cooper D (2011): Steel and Aluminium Product Life, WellMet2050

References with colons refer to a specific location within a working paper, e.g. WP4:5 refers to section 5 in working paper 4.