Conserving our metal energy

Avoiding melting steel and aluminium scrap to save energy and carbon

WellMet 2050

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WellMet2050 is a £1.5m 5–year 7–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 analyses to reveal the emissions benefit, business opportunities and technical challenges of a raft of emissions reduction strategies.

WellMet2050 is focused mainly on long-term strategies related to material efficiency, and is currently exploring four themes:

- reusing metal without melting
- less metal, same service
- longer life and more intense use of metal assets
- compression of the metals manufacturing process chain

This report presents the research findings from the first theme.

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Must we melt used metal?

Making steel and aluminium products, even from scrap, is energy intensive and contributes significantly to global carbon dioxide emissions. Must we re-melt our scrap metal?

In 2008, we scrapped around 9 million tonnes (Mt) of steel in the United Kingdom[1]. If we had stacked it to the height shown in the picture, it would cover Hyde Park in London. Instead, we collected it in well-hidden scrap yards, and most of it was recycled by melting in electric arc furnaces. Hyde Park remains green and we can celebrate our impressive recycling statistic—provided we don't think about the melting temperature of steel.

UK steel production makes up 1% of annual global steel production[2], which, following 10 years of rapid growth driven by demand in Asia, reached a historic peak of 1,350 Mt in 2007[1]. Despite the high recovery rates of steel from consumer discards and manufacturing scrap, the supply of scrap steel is still constrained and cannot keep up with demand for new steel. Currently 35% of the world's steel is made from scrap, the rest from newly mined ore[1].

Making liquid steel from scrap requires about one-third of the primary energy of making it from ore, and on average emits less than one-quarter of the carbon dioxide emissions[3]. This makes recycling a good idea, but with a melting temperature around 1500°C, steel-making from scrap is still energy and carbon intensive, and regardless of source, the liquid metal requires extensive energy intensive processing before it is ready for final use. In total, steel-making accounts for 9% of global CO_2 emissions[4] (related to energy and industrial processes), with just under 1% of global emissions arising directly from scrap melting.

The story for aluminium scrap is similar to that of steel, but a little more complicated. Globally, we produce only 56 Mt of aluminium[5] (24 times-less than steel production), but production requires around nine times as much primary energy per tonne of aluminium, as compared to steel[6]. Aluminium production accounts for nearly 1.5% of global CO_2 emissions[5]. Producing liquid aluminium from scrap needs around 20 times less primary energy than from ore[7] making recycling particularly attractive, although again more energy is required to convert the liquid to finished products. Currently one-third of the world's aluminium is made from scrap[5].

Recycling aluminium drinks cans works particularly well, because—provided used cans are collected separately from all other waste—they can be recycled into new cans. However for most other aluminium recycling, current waste management cannot separate the purer aluminium alloys that can be shaped (wrought alloys) from the less pure casting alloys, so recycling can only make the less pure alloys unless additional primary metal is added. For example, at present the most refined aerospace alloys are recycled into basic cast engine blocks.

Recycling both steel and aluminium saves a lot of energy compared to making new metal from ore, so a drive for increased recycling rates has rightly been a core strategy throughout the metals industry. However, recycling remains energy and carbon intensive, due to the high temperatures required. If global demand for the two metals doubles over the next 40 years, as seems likely, and even if demand stabilises so that we meet future needs from scrap and not ore, the total energy required and CO_2 emitted will be greater than now[4].

If recycling is still energy intensive, is there an alternative: must we melt our used metal? This report reveals that reuse without melting is already happening, albeit on a small scale. Significant opportunities exist now for reuse of steel in construction and for diversion of manufacturing scrap, and it may be possible to reuse aluminium swarf without melting using an emerging technology. In the UK, we estimate that these strategies applied now could save about 2 Mt CO_2 emissions profitably and without significant capital investment. But, if we make the right design choices now, we estimate that in future up to 75% of steel and 50% of aluminium could be reused without melting with negligible emissions.

The basis of the claims made on this page is given in the working papers W1 and W2 referenced in the inside rear cover.

Reuse today

Reuse describes a spectrum of activities to bring discarded metal back into use without melting. In a survey, we found a wide range of examples of reuse across different length scales and by different routes. Reuse in the UK occurs in small volumes, but the limitations are due to social and business reasons, not due to degradation of the metal itself.

The examples on this page show the breadth of reuse activity found today. Reuse of end-of-life products is currently dominated by large constructions or components. Processing is required to disassemble, recondition and re-assemble products for reuse in similar applications, but much of the original shape and functionality is retained. Reuse of manufacturing scrap occurs in much smaller volumes and at shorter length scales: the scrap is processed into a form in which it can be reused, either by trimming to shape, or by joining small pieces to larger ones. We failed to find any examples of reuse in the white diagonal band on our chart.

In 2007, 22,000 tonnes of iron and steel were salvaged in the UK[8] compared to the UK structural steel market of about 1.2 million tonnes[9]. Only anecdotal evidence exists for the scale of other reuse activities, but the volumes are small, for example, Abbey Steel processes about 10,000 tonnes of manufacturing scrap per year.

Reuse in the UK is not a new concept: before the Industrial Revolution, metal reuse was normal practice. Barriers to reuse are associated with the reasons why a product reaches its end-of-life[10]: fridges may become aesthetically undesirable; cars may be scrapped because of unacceptable repair costs; ships may be broken due to changes in legislation. However, the bulk of the metal in these scrapped products is still fit for purpose: reuse is not limited by any degradation of the metal's technical characteristics. This suggests that new design approaches to facilitate reuse could have significant potential to reduce total carbon emissions in delivering steel and aluminium goods.

Reuse or life extension?

It's easier to reuse a one tonne girder than a tonne of mixed brackets. Large parts are easier to reuse than small ones, standard parts are easier than specialised ones. Is reuse appropriate for vehicles or consumer durables, which are assemblies of many smaller and specialised components? Our scoping study found no examples of post-consumer scrap reuse at small length-scales. The only reuse examples that lie in the bottom left-hand corner of the diagram involve manufacturing scrap. The key to reducing metal scrap generation for complex products is to maintain and upgrade them for longer. This already happens with some industrial equipment—many rolling mills made in the past 100 years continue to operate today and Jaguar Land Rover estimate that up to two thirds of Land Rover Defenders ever built are still on the road today[11]. The reuse and the life extension spectrum overlap with the activity of product re-sale. For this reason, many of the examples at the top of the diagram on this page are not further explored in this report. The design requirements and business case for long-lasting products will be examined in a future WellMet2050 theme.

Re-sale

Relocation

Adapt/repair/re-fill/ remanufacture

Module reuse

Component reuse

Cascading

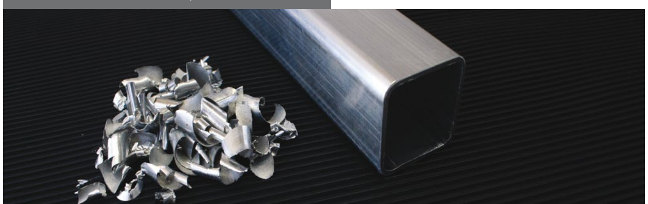
Additive

Recycling

18 million shipping containers, standardised by ISO, circulate the world in continuous reuse as the main transport option for world trade.

Reuse-a-can. Used steel food cans could technically be washed, powder coated, and refilled.

Abbey Steel has, for 30 years bought, trimmed and re-sold around 10,000 tonnes per year of process scrap from the automotive industry.



Machining processes generate large quantities of "swarf" – small chips of aluminium. Rather than recycling these chips by melting, they can be extruded directly into solid aluminium, using less than 10% of the energy to recycle. See pages 8–9 for details.

Small

Chips/ swarf

Packaging

Consumer electronics such as televisions are bought and sold, for example on eBay, and relocated to new owners.

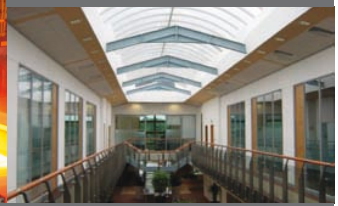
Used cars are routinely bought second-hand and relocated to a new owner. Could this practice become more widespread for other products?

Siemens' rolling mills are large, complex machines, which are routinely refurbished and relocated if they cease to be profitable at a specific site.

Portal Power is a business specialising in the relocation of portal frame buildings, including design and erection services.

Second-hand sales of consumer goods such as appliances and electronics is an obvious form of steel reuse, where a market still exists for repair.

Caterpillar collects some 63,000 tonnes of worn engines and components and returns 65% of this material to market as remanufactured goods.

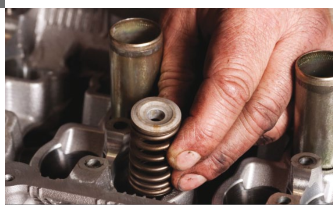


Carrwood Park, an office-park development in Yorkshire, was constructed mostly from reused steel sourced onsite.

Xerox famously has modularised their copier designs to allow high levels of reuse as models are updated.

The Swedish capped rail system, ReRail™ has two parts: a replaceable cap, made of boron-steel for wear resistance, and a base of existing conventional rail.

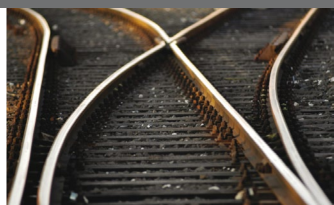
BP's North West Hutton rig was dismantled at Able UK in Teeside. From the 20,000 tonne rig, 5,400 tonnes of steel were reused.



Car dismantlers remove valuable items such as the catalytic converter, alloy wheels, engine block and electronics, before shredding.

Reused steel is commonly used for shoring and excavation, where quality and mechanical properties are less critical.

James Dunkerley Steel is a stockist of used steel, trading 3,000 tonnes per year for use in new buildings and temporary construction.



Worn mainline rails are tested ultrasonically, cut and then welded to length, before being reused as track on secondary lines.

In the Olympic Stadium, 2,500 tonnes of pipeline steel is being reused in the roof truss structure, welded to 15m lengths from 12m stock. (Image: London 2012)

Consumer goods | Vehicles | Industrial Equipment | Buildings/ Infrastructure | Large

The opportunity for reuse now

We've seen that there are plenty of examples of reuse already happening in the UK—but how much could this be extended, and what effect could it have on UK CO_2 emissions? The UK produces over 9 million tonnes of steel scrap[1] and three quarters of a million tonnes of aluminium scrap every year[12]. In order to examine opportunities for increased reuse of this scrap, we've estimated the source of current scrap arisings.

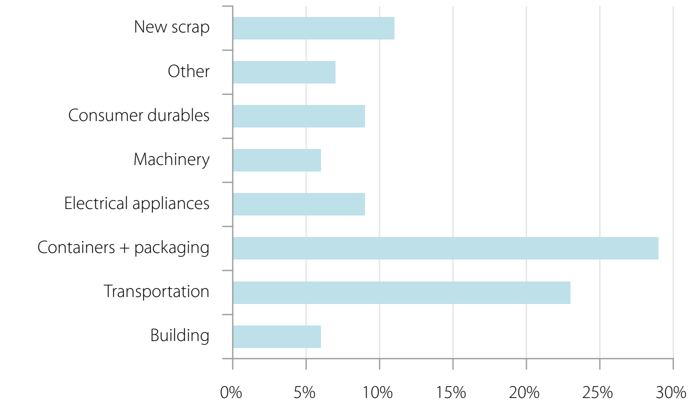
The bar charts on the right show the estimated breakdown of steel and aluminium scrap by product type, including 'prompt' and 'new' scrap that arises during manufacturing. We've discussed these categories with UK demolition contractors, scrap merchants, and each of the listed sectors, to try to identify where reuse could occur now, before any changes are made to designs to facilitate future reuse.

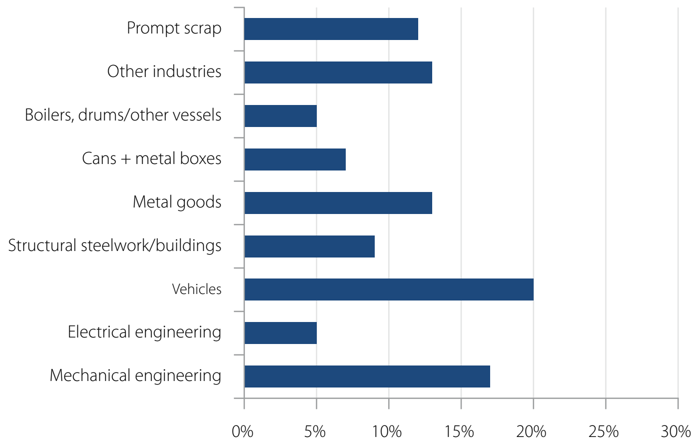
Three immediate opportunities for reuse have been identified and are pursued further within the report: reuse of structural steel; reuse of manufacturing scrap; and reuse of aluminium scrap through solid bonding.

The potential for reuse of structural steel is estimated to be just over 30% of building and civil engineering scrap, or about 3% of total UK steel scrap arisings. This would avoid up to 590 kt CO_2. Further details of this calculation are described on page 7.

The potential for reuse of manufacturing scrap, through businesses like Abbey Steel described below, is estimated to be about 10% of prompt scrap, or about 1% of total UK steel scrap arisings. This would avoid up to 350 kt CO_2.

The potential for reuse of aluminium scrap through the solid bonding process described on pages 8–9 is calculated assuming that about half of all wrought aluminium scrap could be extruded without melting into aluminium products. This is about 13% of total UK aluminium scrap[12] and would avoid up to 750 kt CO_2. The total potential emissions savings for these three options are around 2 Mt CO_2 which is about 3% of all emissions associated with steel and aluminium goods in the UK—or 0.3% of total UK emissions of 530 Mt CO_2[13]. We identified further opportunities for reuse now, such as re-rolling of ship plate and machinery refurbishment, but do not know the potential scale of these options. A complete list of references and details of calculations can be found in the working paper, *Scrap reuse potential and emission savings*[W3].

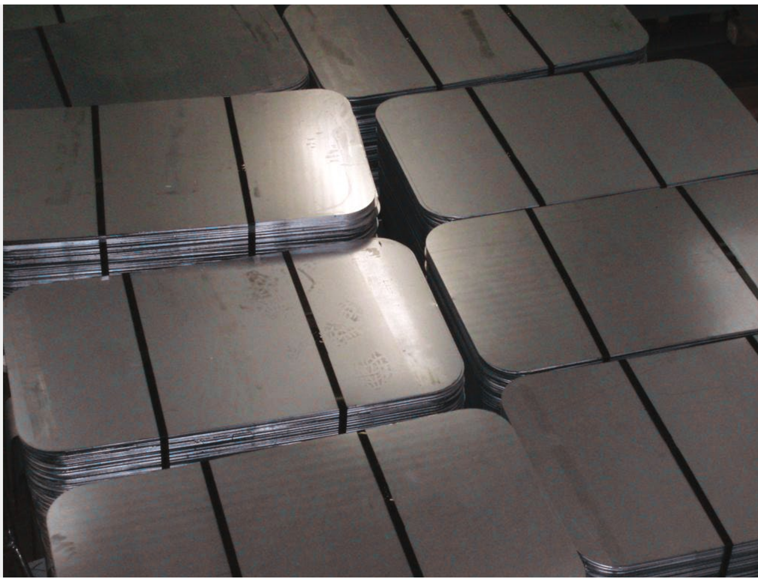




Scrap breakdown for aluminium (top) and steel (bottom)[12 14 15]

Abbey Steel

When blanks for car body parts are cut from coiled steel strip, approximately 7% of the material is wasted because parts do not tessellate perfectly[16]. When they are subsequently pressed on average 50% is lost due to cut outs (e.g. for car windows) and edge trimming[16]. Abbey Steel, a family run business in Stevenage, has for 30 years bought, trimmed and re-sold around 10,000 tonnes per year of these cut outs. They are used for noncritical parts by manufacturers of small components including filing cabinets, electrical connectors and shelving. Abbey Steel pays a premium over the scrap price to collect the cut outs, trims them into rectangles according to demand and sells them on at a discount relative to new stock. The business is constrained by the amount of scrap Abbey Steel can source from press shops due to problems with press shop design / layout which limits the space and time available to segregate cut outs for resale.



Existing reuse models	Information and certification	Design	Timing and project management
	Reuse of steel in construction		
In-situ reuse: an obsolete building is bought and either adapted, or deconstructed so that components can be reused, e.g. Mountain Equipment Co-op, Ottawa.	Reduced need for testing: possible access to engineering drawings, current loads known.	Adaptive design based on known materials purchased up front. Possibility to reuse entire building systems.	Single client manages deconstruction, design and construction. Timing naturally aligned.
Relocation: a steel structure is dismantled and re-erected elsewhere, e.g. Portal Power.	Reduced need for testing: same configuration, same loads.	Adaptive design based on steel structure purchased up front.	Buyer is tied to seller's project schedule, possibility of delay.
Direct exchange: steel sections or modules are sold for reuse without an intermediary e.g. via websites such as www.scrapmetalexchange.co.uk	Testing and certification required unless beams are downgraded or buyers trust sellers.	Material pre-ordered or design drawn up with a flexible specification in order to increase likelihood of finding suitable stock.	Buyer is tied to seller's project schedule, possibility of delay.
Stockholder: sections, steel frames or modules are bought, remediated and stocked until a demand presents itself, e.g. James Dunkerley Steels.	Testing and certification required unless beams are downgraded. May only accept standard products.	Material pre-ordered or design drawn up with a flexible specification in order to increase likelihood of finding suitable stock.	Delays can be avoided as stock is supplemented with new material if necessary in order to guarantee supply (this affects reuse content).
	Reuse of manufacturing scrap		
Stockholder: offal from the pressing process is bought, cut to regular sizes and sold for reuse, e.g. Abbey Steel.	Material properties known. No additional testing. Sold for non-critical parts.	Unaffected as irregular offal is cut into standard sizes.	Delays can be avoided as stock is supplemented with new material if necessary in order to guarantee supply (this affects reuse content).

Factors affecting the decision to specify reuse in construction and the reuse of manufacturing scrap under different existing reuse models (note the reuse of aluminium is not yet ready for market and so there are no existing business models for reuse of aluminium through solid bonding)

Exploiting these reuse opportunities can yield financial as well as environmental gains. By converting a perceived scrap into a marketable product, reuse capitalises on the embodied value and embodied energy within that product. This requires a reconfiguration of the existing supply chain and will only happen if the incentives are in place at each of the following three decision points:

The decision to specify reused material: this decision is a function of the quality of the product sold for reuse and the certification offered. For intermediary products it also affects the design process, timing and project management. These implications are explored with reference to existing reuse models in the table above. Stockholder models that are more infrastructure intensive and emphasise standardisation, result in less inconvenience to customers and so are more scalable solutions.

The decision to remediate and stock material for reuse: the opportunity to generate value through reuse of metals is bounded by the scrap price and the new product price. This value stream must be used to compensate for all costs incurred in order for a business that remediates and stocks products for reuse to be viable. Costs result from sourcing, remediating products to satisfy customer needs, certification and stocking.

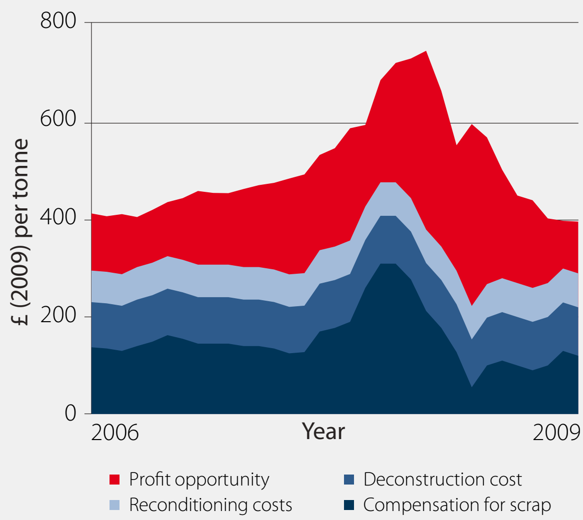
The decision to supply material for reuse: supplying material for reuse can cause disruption to the existing supply chain. In the case of manufacturing scrap this is due to problems with segregating material without causing delays in the pressing line. For reuse in construction it is a function of the relative cost of demolition and deconstruction. Both reuse of manufacturing scrap and reuse in construction are supply constrained due to difficulties in overcoming these obstacles.

Further information on these decision making processes alongside details of the calculations made can be found in the working paper, *Strengthening the business case*[W4].

The business case for reuse in construction

Based on scrap price and section price indices[17], and an estimated additional cost for deconstruction of £100/t and for reconditioning of £70/t, the graph below shows that there is an attractive business case for reuse of steel sections for low grade purposes with an average profit of £190/t. The extra £100/t paid to demolition contractors was found to cover cost and return a profit, suggesting that reuse will also be viable for the demolition contractor.

These estimates assume that steel is sold at the price of new, low-grade steel (S235JR) without certification. The business case becomes marginal if the steel is sold at a discount to the new steel price or if certification costs are incurred. Although beams are currently sold without certification, wide scale reuse will require testing and certification (or official confirmation that certification is not required) to avoid passing additional risk on to customers. Current costs of testing structural steel are estimated at £100 per section. These costs could be reduced through improved testing technology and by allowing a statistical approach to testing in order to improve the business case for large-scale reuse. Design for deconstruction can enhance the profit opportunity by reducing deconstruction and refabrication costs.



Reuse in construction

If there is one place we should be focusing our efforts it is in the construction sector, where we estimate that up to 30% of building and construction scrap could be reused.

Roughly half the world's steel is used in construction (e.g. buildings, bridges, off-shore structures) and much of this steel stays in good condition well beyond the life of the construction. If a steel beam is removed carefully from an old building, there is no physical reason why it cannot be relocated and used again in a new building. The key issues are whether structural steel can be removed quickly, safely and without damage to increase supply, and how to test, certify and manage reclaimed steel to drive demand.

Deconstruction versus demolition

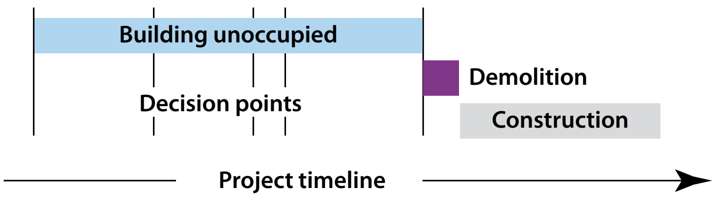
The 1990s saw the consolidation of the UK demolition industry and a shift from hand labour to mechanised demolition methods. This was driven largely by governmental pressure to reduce health and safety risks, and commercial pressure for faster demolition. For example, British Standard BS6187:2000 sets out responsibilities for demolition contractors, and states "… structures should preferably be demolished using a demolition machine operated either from a protected cab or remotely …"[18]. Typically such machines are mechanical shears, which badly deform the steel: not a problem if the metal is to be recycled by melting, as is current practice, but a major barrier to reuse without melting.

These two factors—safety and speed—led to a drop in sales of UK salvaged iron and steel from 70,000 tonnes in 1998 to 22,000 tonnes in 2007[8]. Not only did the supply of reclaimed structural steel become limited, but also a decline in the manual skills required for building deconstruction was observed. A potential solution would be to develop a remote, mechanical method for quick and safe deconstruction without damaging the sections.

Safety issues in deconstruction can be addressed, but site-owners typically prefer demolition to deconstruction because it is quicker and any delay in the construction programme leads to delayed revenue. As a result, even when connections between structural sections in an old building can be undone, and even if a buyer such as James Dunkerley Steels offers an attractive incentive, contractors are rarely allowed time for deconstruction. However, this problem of timing could be solved: many derelict buildings remain untouched until long after the new-build planning decisions are made, unnecessarily restricting the time available for building deconstruction (see graphic below). A different sequence of decisions could allow time for de-construction, rather than demolition, without delaying construction of the replacement building.

Certification and sourcing

The decision to specify reclaimed structural sections requires ready access to a trusted source of reused steel. For the client to have confidence, the steel must have *known* material properties, which can be *assured* with certificates, having passed through a *controlled* supply chain process.



James Dunkerley Steels (JDS)

JDS is a steel stockist in Oldham, which holds up to 20% used steel and sells around 3,000 tonnes of used steel sections per year. They are known nationally as a buyer of used steel and have a long-standing, established business. JDS employs a full-time buyer who visits demolition sites and quotes a price for the steel. The business pays a premium on the scrap price to cover the additional time and effort of deconstruction. To encourage careful dismantling, the steel is inspected on the ground before payment. The steel is then transported from the demolition site to the stockyard in Oldham.

All reclaimed steel received by JDS is "downgraded" to mild sections, with no testing or certification performed. Only old RSJs are rejected as there is no longer any demand for these sections. The turnover of stock is generally 3–4 months, however for steel of standard sizes this may be reduced to only one week. The main customers of the reclaimed steel are civil engineering firms, who use the steel for temporary structures and road plate. JDS also sell to local builders and developers, and have a fabrication shop to provide added value to their customers.

Truss structure in the Olympic Stadium, Olympic Park London

The truss structure for the Olympic Stadium uses 2,500 tonnes "non-prime" steel tube (redundant stock from an oil and gas pipeline project) out of a total 3,850 tonnes of structural steel used in the stadium roof. The original design had specified large diameter steel tube section, but the fabricator was concerned that the lead time for new steel, and the difficulty of manufacturing these specialised sections, might delay construction. An opportunity to avoid this risk arose when a stockpile of non-prime steel tube (ø323–1081mm, 12-metre lengths) was sourced. The Olympic Delivery Authority (ODA) and Team Stadium (the consortium building the Stadium) favoured this option because by using existing and immediately available steel the risk of delays associated with sourcing new steel tube were removed, and in addition carbon dioxide emissions could be avoided.

The second hand tubes were supplied without certification, so coupon tests, using small lengths of steel cut from each tube, were conducted to determine the mechanical properties to meet design requirements. Each 12-metre tube length was tested and then welded to 15-metre span lengths and the truss structural design was modified. However, the additional design time was modest, and despite having to over-specify certain structural members, no additional weight was added to the structure. As a result of this action, 20% of the steel used in the stadium is second-hand. Although the motivation was to reduce project risk, and despite the additional design and testing effort, they were delighted to find that reusing steel gave a small reduction in total project costs, and more broadly fitted their sustainability goals. (Image: London 2012)

Knowledge: we have identified three possible routes for determining the mechanical properties (i.e. dimensional tolerance, tensile/yield strength, weldability, fracture toughness) of a reclaimed steel section:

- each steel section can be mechanically tested according to BS EN 10025–1/2 for steel sections and plate. The cost at present is approximately £100 per section, but this could be reduced through the use of new technologies.
- if drawings from the old building are available, the grade and quality of the sections may be known (but additional statistical testing may be needed to confirm mechanical properties.)
- the steel can be downgraded to the lowest historical grade for structural steel S235JR (thus reducing the structural efficiency of the design but avoiding the need for testing.)

One option, which we plan to explore, is to reduce the cost of testing by using a portable hardness testing machine, combined with a fraction of the old sections in a batch being tested to give required levels of statistical confidence.

Assurance: the mechanical properties of the reclaimed steel can be assured with an accompanying certificate (e.g. following BS EN 10204). It may be advantageous to mark the steel at regular intervals along the section (e.g. by hard stamping) to allow the grade to be identified for future reuse. It is essential that any testing and certification process is backed by the relevant agency.

Control: the introduction of CE marking for construction products (including steel sections, bolts and fabricated steelwork) aims to ensure the quality of products and remove trade barriers within Europe. Although CE marking is currently optional and does not apply to products in the market before 1991 (i.e. most reclaimed steel sections), clients are increasingly requiring that steel be CE marked, and once fully enforced (expected May 2012), most steel products are likely to require certification. Fabricated steelwork can be CE marked provided the stockholder or fabricator is certain of the properties of the reclaimed steel.

The interaction between design and sourcing activities is important for project timing: is the building design or material sourcing done first? Uncertainty surrounding the time required to source, deconstruct and fabricate reused steel represents a contractual risk, and testing and certification can add time and cost to the project. An enthusiastic client and a flexible, iterative design process are normally required to mitigate scheduling risk before a contractor is willing to consider reused steel.

Potential emissions savings

In the UK, about half of all current construction scrap cannot be reused, e.g. bridges that have experienced cyclic loads or reinforcing bar embedded in concrete. The remaining scrap is structural steel from single-storey industrial buildings (45%) and nonresidential multi-storey buildings (55%)[9]. Single-storey buildings are mostly of portal frame construction with low height, accessible moment connections and purlins made from cold-formed steel. These can be deconstructed more easily than more complex multi-storey buildings. The recent uptake of structurally efficient composite steel and concrete floor systems may also limit the future recovery of steel from multi-storey buildings, as these systems cannot be separated easily. We estimate that 80% of current single storey building scrap and 50% of multi-storey buildings scrap could be reused. This would be nearly 30% of the UK's annual building and civil engineering scrap or 3% of total steel scrap arisings.

If the steel sections were not reused, and instead melted down, new steel sections would be required. The typical UK emissions factor for steel sections 1.8 kg CO_2/kg section. Reusing 330 kt of structural steel could thus avoid up to 590 kt CO_2. This calculation assumes that any additional emissions from reconditioning the steel are insignificant and that reuse does not lead to over-specification. Details of this calculation can be found in the working paper, *Scrap reuse potential and emission savings*[W3].

Solid bonding: swarf reuse

Solid bonding is an emerging process that can bond aluminium chips into solid material without the need for melting. Ongoing trials by the WellMet2050 team in collaboration with Technische Universität Dortmund are evaluating the technique, with the aim of promoting solid bonding as a mainstream alternative to recycling by melting of aluminium.

Conventional recycling

The production of metal components by machining is widespread, particularly in high performance applications such as aerospace. The most common manufacturing route is to machine a final part from a large rectangular block of aluminium, generating large quantities of "swarf"—small chips of aluminium. Separately, in beverage can making, the blanks used to form the cans are punched from a wide aluminium strip, leaving behind approximately one quarter of the material as "skeletons".

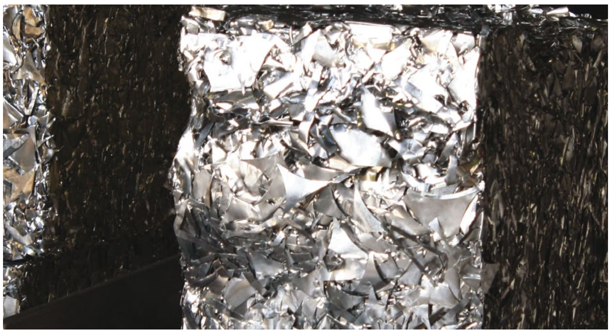
Conventional recycling of swarf and skeleton material involves melting the scrap aluminium in a secondary aluminium production process, which uses 10–20 times less energy than primary aluminium production[19] to make liquid metal, but can have a material yield as low as 54%[20]. An innovative alternative to recycling is a new process called 'solid bonding', through which a further reduction in energy requirement of 10–20 times, over conventional recycling, may be achieved with a greatly increased material yield[W5].

Solid bonding process

In the solid bonding process, clean chips of a single alloy are compacted into a billet, which is then fed into an extrusion press under high pressure, at temperatures of 450–500°C. The high pressure and extension causes the surface oxide layers to crack, revealing the reactive aluminium metal which, in intimate contact with adjacent chips, welds into a solid product. The resulting extruded profile is of high quality, comparable with one made from a primary billet. A detailed analysis of the mechanical and microstructural properties of extruded aerospace alloy (AA6060) chips is available in the literature[21] and some of our trials are reported here.

Manufacturing profiles from solid bonded chips consumes around 100 times less energy than manufacture from billets of primary aluminium, or equivalently gives a 96% saving in CO_2 emissions compared to production from billets made by conventional recycling of process scrap.

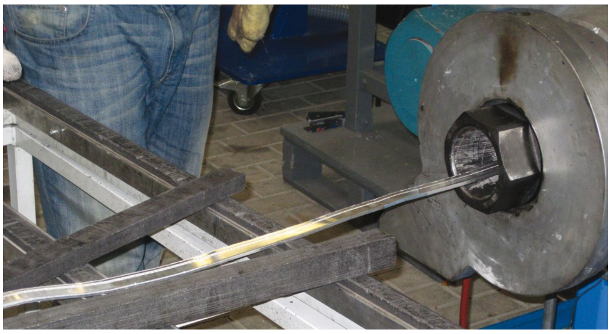
In order to evaluate the potential of this process, the WellMet2050 team in collaboration with the Technische Universität Dortmund, Boeing and Alcoa have conducted a series of tests on aerospace machining swarf. In parallel, trials with Novelis and Crown Packaging have aimed to determine whether drinks cans, produced from AA3104, could be manufactured using solid bonded material: solid bonded bar is produced from can making skeletons, then rolled to blank thickness prior to cup drawing.



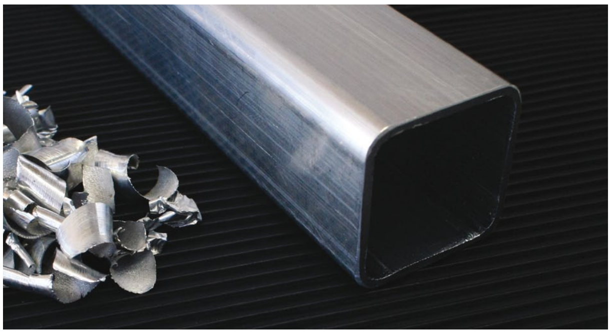
Beverage can skeletons from Crown

Machining swarf from Boeing

Making briquettes from clean dry scrap



Extrusion trials in Dortmund



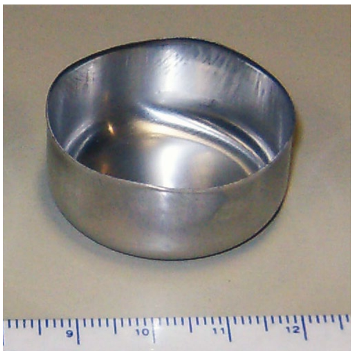
Material testing at Alcoa

Results

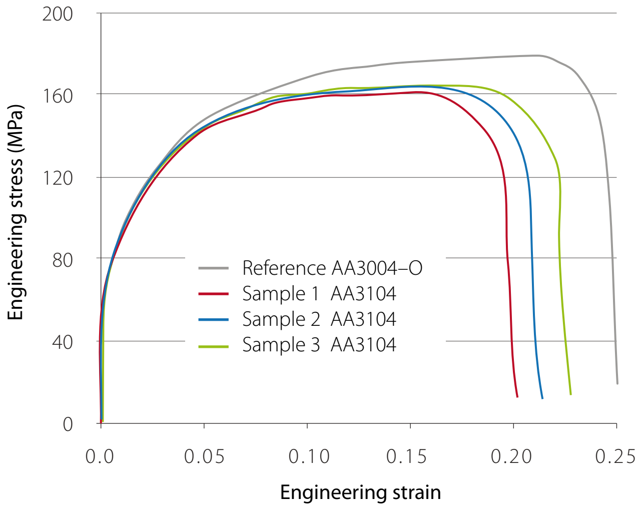
The process has been tested using AA3104 (beverage can body-stock) and AA6061 and AA7050 (aerospace alloys), and all tests have produced specimens of high quality. On average, 20 times less energy was used in the solid bonding process, when compared to conventional recycling. The graph (right) presents tensile test data derived from samples of extruded AA3104 chips. The solid bonded material shows similar performance to the reference material, with a reduction of around 10% in ultimate tensile strength and 15% in ductility. Further development will aim to reduce these differences, and evaluate repeatability of the process.

The photograph (below) presents a cup produced as part of the can-making trials at Crown Packaging and Novelis. Solid bonded bar produced from AA3104 can-making scrap has been cold-rolled to blank thickness. Initial trials have included low temperature reheating (<200°C) of the resulting sheet. This lowers the yield strength of the material by approximately 25 MPa, sufficient to allow the drawing of cups in an earing test. Further trials will attempt to deep draw such cups into can bodies.

The image (bottom) is the result of a microstructure study at Alcoa. The surface quality and bonding of the bar pieces is generally very good. However, in these initial trials, some inclusions (such as spinels) were observed and the AA6061 hollow profile showed some surface blistering and internal poring. These features would limit process applicability, but appear to be mainly due to the imperfect purity of the chipped scrap. Better contamination control will overcome these issues.



The solid bonded AA3104 material, after rolling and heat-treatment, was formed into a promising drinks can cup (top). The material displayed generally good bonding and surface quality (bottom).



Tensile test data from AA3104 solid bonded material. Note, the reference data line is taken from mechanical property data[22] for AA3004–O (of which AA3104 is a compositional subset).

The results of these initial trials indicate performance characteristics comparable with new material, and further trials will extend the range of alloys and continue to improve overall performance. Approximately 30% of all aluminium[W5] is extruded to produce finished or semi-finished products. Many applications (such as aluminium window frames) do not demand the full strength and ductility of as-cast aluminium, allowing solid bonded material to be used instead. Hence, there appears to be potential to establish a pilot-scale business around the technology of solid bonding, allowing a ramp-up of the trials and a near to market evaluation of product properties.

For more details on the extrusion trials performed with our partners in Dortmund, refer to the working paper, *Solid bonding of aerospace and packaging aluminium scrap*[W5].

Emissions benefits of solid bonding

Using the data from the European Aluminium Association's scrap recycling model[23], 55% of new scrap is sent for remelting and 45% is sent for refining. Only material that is sent for remelting is suitable for use in extrusions as material sent for refining is typically contaminated, of unknown composition, or a casting alloy. If only half of the UK's new aluminium scrap could be reused, that would be just over 100 kt of scrap. This is about 13% of total scrap arising. The reused scrap will displace new aluminium extrusions, for which the typical UK emissions factor for is 8.2 kg CO_2/kg extrusion[24], compared to 0.7 kg CO_2/kg extrusion for the solid bonding route. Reusing 100 kt of aluminium scrap would therefore avoid up to 750 kt CO_2.

The *Scrap reuse potential and emission savings*[W3] working paper provides the references and analysis used to calculate these results.

Design for future reuse

So far in the report, we have considered only reuse options that could be applied to today's mix of steel and aluminium scrap. Included in this mix are many discarded products, which although they may still contain metal in good condition, cannot be reused because of their design. What if today's products were designed with future reuse in mind? What could reuse tomorrow look like?

The vertical bars in the centre of this page give our estimate of the final destinations for current global production of steel and aluminium[W6]. This breakdown points to the high-volume metal goods that could be re-designed to improve future reuse.

Design principles

We have already learnt from documenting examples of reuse today (page 2–3) that large metal goods and components have more potential for reuse than smaller ones, because they are easier to manage, have higher residual value, and if necessary can be further cut up. Products designed with many applications in mind—such as the famous Meccano kit—can be reused in ways unanticipated by the original product designer. Design and identifiable material properties also influence the future flexibility and adaptability of the product and the level of effort required for disassembly.

Modular design in construction offers several known advantages over on-site construction including standardised components, a more controlled and safer working environment, reduced waste and environmental impact, and faster on-site erection and deconstruction. In addition, modular design allows for future flexibility and adaptability, which may enable the building lifetime to be extended or the module to be relocated. However, the modular building suppliers will need to increase sales volumes, standardise designs, improve business continuity and release more detailed design information to the public, if future reuse is to become a viable business.

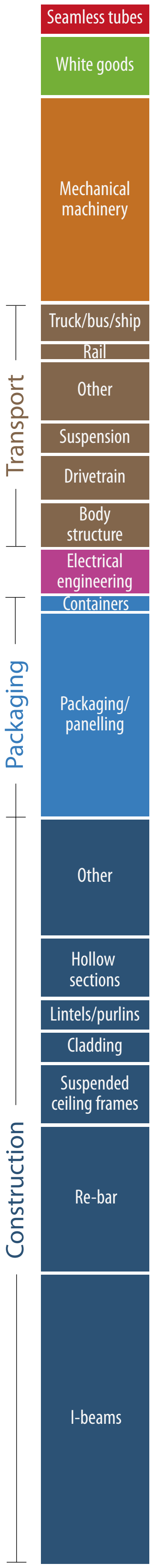
The reuse of construction steel would be simpler and less costly if the material properties of the steel were known. We recommend that the physical marking of steel sections be regulated, with sufficient information to determine the steel size, grade and quality being hard stamped or scribed at regular intervals along the section. Marking steel would eliminate the need to test and certify reclaimed structural steel, provided the marking was still visible at the product end-of-life.

In analysing products and buildings that have been designed with reuse in mind, and reviewing published studies on this topic (CIRIA[25], SEDA[26], BioRegional[27], WRAP[28]) we have identified several design principles that can be applied to reuse, as shown in the table below.

Design case studies

The following case studies identify specific areas where the design principles could be applied to current design, to allow more steel and aluminium to be recovered from products in the future.

Composite floor systems consist of profiled steel decking working together with in-situ reinforced concrete. Pre-cast systems use prestressed slabs supported on steel beams with in-situ topping. Both floor systems give sufficient shear bond so that the two materials act compositely together, and due to their structural efficiency dominate the multi-storey building market. However, the shear bond in these systems is difficult to separate, making the future reuse of the structural steel unlikely. Dry floor systems—such as truss floors, panel systems and timber floors—

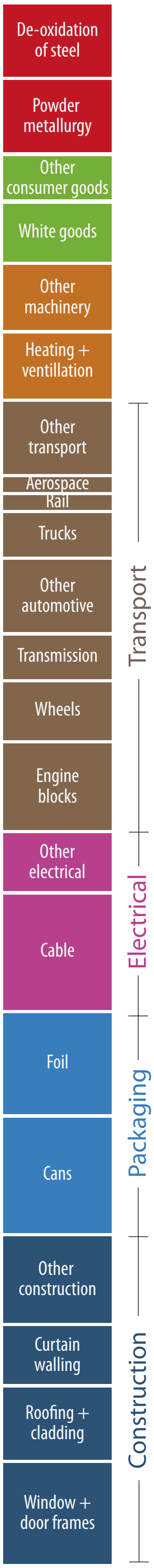


1330 Mt
2008

End-uses of global steel production

Principle	Design feature	Aims
Adaptability	Flexible structures separating strength from function	Design 'open' structures that allow the interior to be used for different purposes
	Standardised parts	Standardise cross-sections (as already happens in construction), lengths and joints
	Minimal use of specialised parts	Use specialised parts only at exterior locations (with use of standard fixtures), ensuring they can be removed
	Design for upgrades	Anticipate possible future upgrades and design to allow their incorporation
Easy repair and deconstruction	Avoid use of mixed materials	Where possible, avoid use of coatings, composite steel-concrete flooring, etc.
	Reversible joints	Allow easy and quick part replacement or separation of the product or structure
	Localise wear surfaces / sources of failure	Localise wear damage / sources of failure to small easily replaced components
	Deconstruction plan	Development of a deconstruction plan could become part of all design processes to enhance the end-of-life value of material content
Traceability	Product marking	Physical marking of alloy grade and quality on components (such as structural beams) aids identification at end-of-life, and removes testing / certification requirement for reuse

The table presents the design features that will increase the reuse of products and components in the future. The features have been split into design principles, although there is significant overlap between the design features of all three principles.



56 Mt
2008

End-uses of global aluminium production

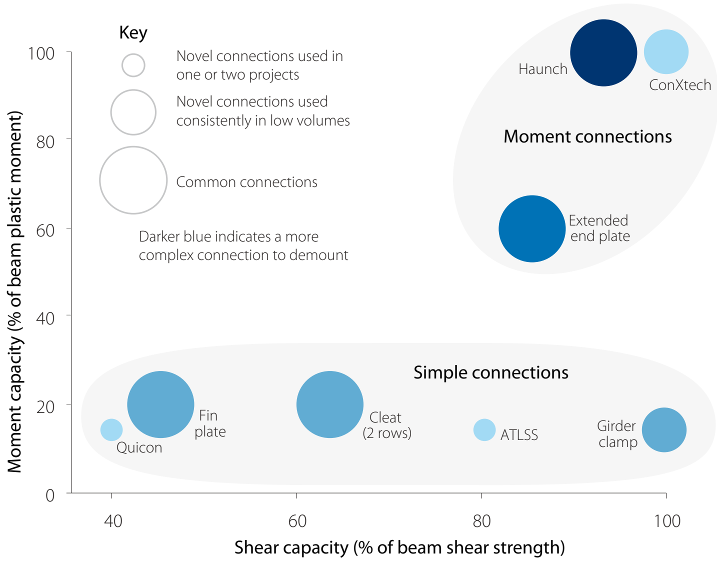
can be separated, allowing for the recovery of steel at the time of deconstruction. Further work is required to compare the potential carbon savings of the more efficient composite and pre-cast floor designs, versus the opportunity for reuse with dry floor systems.

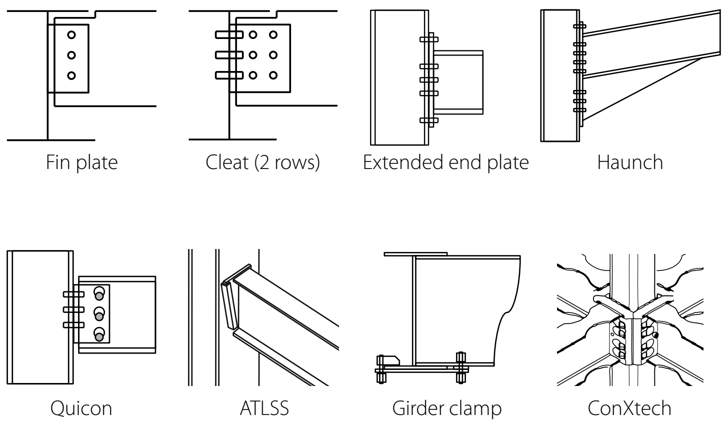
Reversible joints with inherent stability and fewer bolts to unfasten may allow for quicker and safer deconstruction. The chart (right) presents a range of common and novel structural connections. The joints are grouped into two families—shear force resisting simple connections (as commonly used in low-rise buildings) and moment connections (as used in portal frame construction). Novel joints such as Quicon, ATLSS, and ConXtech simplify demounting of the beams. Quicon offers simple removal, and ATLSS and ConXtech provide stability with male-female interlocking secured with bolts. Specifying these more novel joints may allow greater reuse in the future. More details on these connections may be found in the working paper, *Novel joining techniques to promote deconstruction of buildings*[W7].

Driven steel piles have been almost completely replaced by steel-reinforced concrete piles in complex building foundations and retaining wall structures. The material properties of steel allow piles (either H– or Z–) to resist tensile as well as compressive forces, making them suitable for extraction from the ground when the building is demolished. In contrast, concrete piles, if they can be extracted at all, are damaged in the process, giving no option to reuse the steel. Specifying steel piles has potential to reduce lifecycle carbon emissions for foundations, provided the difference in material efficiency is accounted for.

The **Swedish capped rail system ReRail™** has two parts: a replaceable cap made of boron-steel for increased wear resistance, and a base of existing conventional rail, milled down to allow the cap to be retrofitted. Separating the wear and structural functions of the track reduces the material needs of the new rail to about 20%[29]. Cracks in the railhead arising from rolling contact fatigue cannot propagate into the foot, reducing the risk of failure. Design for reuse introduces new design challenges, in this case designing a joining system that allows separation of the cap and base, while withstanding the operational force.

Car body press lines are currently designed to prioritise the stamped part (i.e. the car door) over the cut out scrap steel. Yet if offal scrap could be collated separately, this waste material could be reused in smaller sheet metal products; alternatively two parts could be pressed simultaneously, one inside the other. Both options require changes to the press design to allow more careful management of material. These ideas warrant further investigation.





Potential for reuse in the future

Dissipative losses of metal during manufacturing and use, such as corrosion and grinding, limit the maximum recovery potential for steel and aluminium. A maximum reuse rate of 90% for steel and aluminium is based on Ayre's[30] prediction of the limits to steel and aluminium recycling. For some products, reuse will not be possible: step-changes in technology remove the need for the product, and products valued largely for their appearance may become undesirable as preferences change[10].

Using the breakdowns of steel and aluminium products (centre of page), we have made an estimate of potential future reuse assuming that products are completely re-designed to maximise reuse. Our estimate of the reuse potential for each product type was based on the importance of form over function in the product: if current end-of-life is determined mainly by loss of style over time, we assume a lower potential for design for reuse. In 2008, if all products had been designed for maximum future reuse, approximately 75% of steel scrap and 50% of aluminium scrap could have been reused without melting. Details of these calculations can be found in the working paper, *Design for future reuse*[W2].

Emissions savings from reuse

The reuse of steel and aluminium has the potential to reduce CO_2 emissions by avoiding the melting process in recycling. If reuse had no associated emissions, reusing one tonne of steel and aluminium would save 1.8 and 8.2 tonnes of CO_2 respectively[24]. Is this a reasonable assumption, and if not, what emissions should be associated with reuse? To address these questions, we examined nine case studies of reuse without melting as listed in the box below.

Evaluation of reuse case studies

Reusing metal implies no emissions if four assumptions hold true. The first is that **one tonne of reused metal displaces one tonne of new metal**. Two issues challenge this assumption: over-specification and strengthening. Over-specification occurs when stock availability leads to use of a beam of strength beyond the original design. The main causes of over-specification are availability and uncertainty. In the University of Toronto (UfT) project, the dimensions of the beams available for reuse at the time were deeper than required. The steel members used in the Carrwood Park development were one size larger than those specified in the original design, to reduce the risk associated with uncertainty over the exact characteristics of the beams being reused.

Strengthening is required when the available stock as supplied has insufficient strength and must be augmented. Strengthening with new steel may be specified required when reusing steel due to either relocation or building code updates. In the Roy Stibbs project, the steel required new bracing to meet the greater seismic requirements in the new location. In the BMW Sales and Service Centre project, the steel frame was reused in situ, but still required significant strengthening to comply with the latest seismic regulations.

The second assumption is that **emissions savings can be calculated using the emission factors given at the beginning of this section.** These values are specific to the average product, production and energy mix in the UK. However this may not always be representative.

Many of the construction case studies took place in Canada, where there is a different energy and production mix to the UK. Data from the Canadian Steel Producers Association[31] gives an emissions factor of 1.0 kg CO_2/kg steel, compared to 1.8 kg CO_2/kg steel in the UK. Even for the UK case studies, emissions savings can be calculated more accurately by using production specific data. For example, a structural section made via the BOF route in the UK, would have an emissions factor of 2.3 kg CO_2/kg steel, assuming a 20% scrap content.

The third assumption is that any **emissions saving or penalties arising from differences between conventional and reuse processing are not significant.** However, there are differences in processing route, including: demolition vs. deconstruction, cleaning, testing, certification, rail grinding and re-fabrication. Our analysis suggests that these emissions are always small compared to embodied emissions so the emissions associated with conventional or reuse processing are approximately equal.

Reuse without melting case studies

University of Toronto, Toronto: 16 tonnes of structural steel was recovered from the deconstruction of the nearby Royal Ontario Museum and used in one wing of the student centre (see photo above).

Mountain Equipment Co-op, Ottawa: About 90% of the original structural steel in the old grocery store was reused in the construction of the Mountain Equipment Co-op store on the same site.

Parkwood Residences, Oshawa: During the adaption of an old office complex into a new residential development, about 90% of the original steel frame was reused.

BedZED, London: 98 tonnes of structural steel were reclaimed from local demolition sites and used for a housing and commercial development.

BMW Sales and Service Centre, Toronto: During the adaption of an old factory into a BMW Sales and Service Centre, about 80% of the original steel frame was reused (see photo opposite).

Roy Stibbs Elementary School, Coquitlam: Following a fire, the Roy Stibbs Elementary School was rebuilt incorporating 466 steel joists recovered from a deconstructed school to speed up construction.

Carrwood Park, Yorkshire: An office-park development reused 60 tonnes of structural steel from existing structures on site and from a private stockpile.

ReRail™ track system: A prototype rail system with a replaceable boron-steel cap, which allows about 80% of the rail to be reused.

Solid bonding: Aluminium swarf is compacted and extruded directly.

The fourth assumption is that **reuse only has emissions implications at the time of construction or manufacture.** However, there may be emissions implications for transport, maintenance and cascading. These implications are likely to be case specific, for example, when assessing the emissions impact of transport for reuse versus transport for conventional processing. The maintenance impact is highlighted in the ReRail case study. The retrofitted rail cap is made of boron-steel, which has a higher wear resistance than conventional steel. This means maintenance emissions can be reduced by increasing the time interval between rail-grinding maintenance.

The impact of reuse on product cascading is highlighted in the solid bonding case study. The solid bonding process allows closed-loop reuse for wrought swarf, unlike conventional recycling, where swarf is used in castings. Cascading of wrought to cast material is not currently a problem as casting demand is greater than scrap availability, but if casting demand equals cast scrap availability, cascading of wrought scrap will become undesirable.

Impacts on emissions savings

So what impact do these assumptions have on the potential emissions savings from reuse? The graph (right) shows our estimate of the reuse emissions savings for each of the nine case studies.

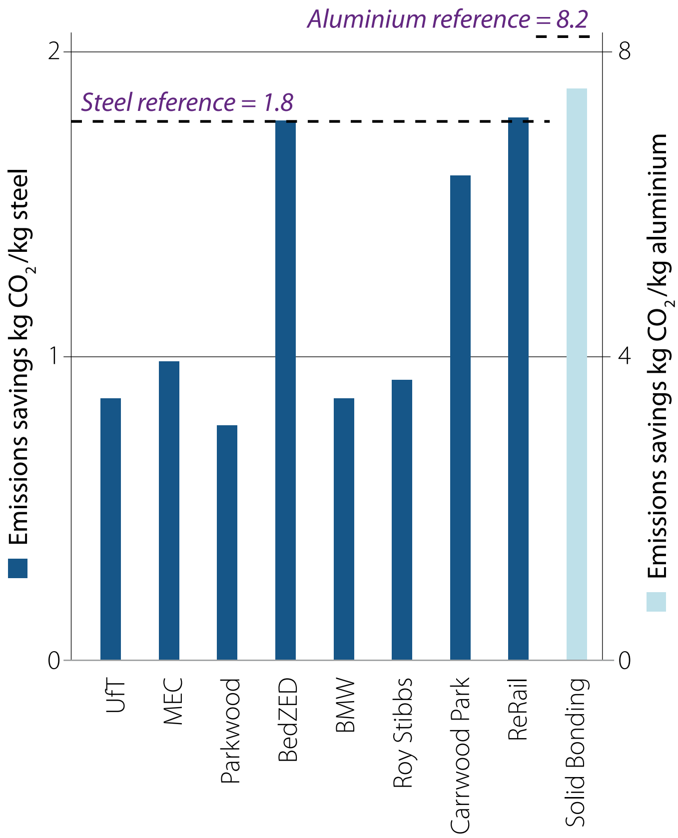
For most of the case studies, the actual specific emissions savings (per kg reused) are lower than the reference value due to differences in mass and emissions factor. The Canadian case studies (UfT, MEC, Parkwood, BMW, Roy Stibbs) all have lower emissions savings as the embodied emissions of new Canadian steel is lower than that of UK steel. Case studies where extra mass was used due to over-specification or strengthening (UfT, Parkwood, BedZED, BMW, Roy Stibbs, Carrwood Park), also have lower emissions savings.

Our analysis has shown that embodied emissions savings dominate overall emissions savings, therefore, the more material that is reused, the greater the emissions savings. So what limited steel reuse in the case studies?

In the UfT project, steel reuse was considered a new, and potentially risky concept, so was limited to one small wing of the project. In the BedZED project, nearly all the steel was reused, with the exception of some curved members as the fabricator did not want to process reused steel through particular equipment. For other projects, like the Mountain Equipment Co-op, Parkwood Residences and the BMW Sales and Service Centre, the new buildings required more structural steel than was available from the existing site so new steel was brought in.

This analysis considers the emissions avoided within the system boundary of each project; this is a life cycle perspective. If a tonne of material is reused, one tonne less scrap is available for recycling. The products that would have been produced with that scrap must then be produced with metal from primary production. On a global scale, reuse of metal will displace secondary production and the global emissions savings will be 0.4 and 1.7 tonnes of CO_2 per tonne of steel and aluminium, respectively.

Analysis of these case studies has shown that emissions savings from reuse are possible, but vary case by case. The limits to reuse are often linked to uncertainty and issues of supply, but high reuse fractions and emissions savings have been achieved in some projects. A complete list of references and details of calculations for this page can be found in the working paper *Emissions savings from case studies*[W8].



Estimated emissions savings for reuse without remelting case-studies

Strengthening the business case

This report has shown that reuse is technically feasible, offers emissions savings and has been profitably exploited. However, reuse in the UK occurs at present only on a small scale. How can the business case for reuse be strengthened? We need to build on existing expertise and remove barriers that inhibit the supply, specification and stocking of material for reuse. This section focuses on the role of government in improving the business case for reuse.

Increasing supply of material for reuse

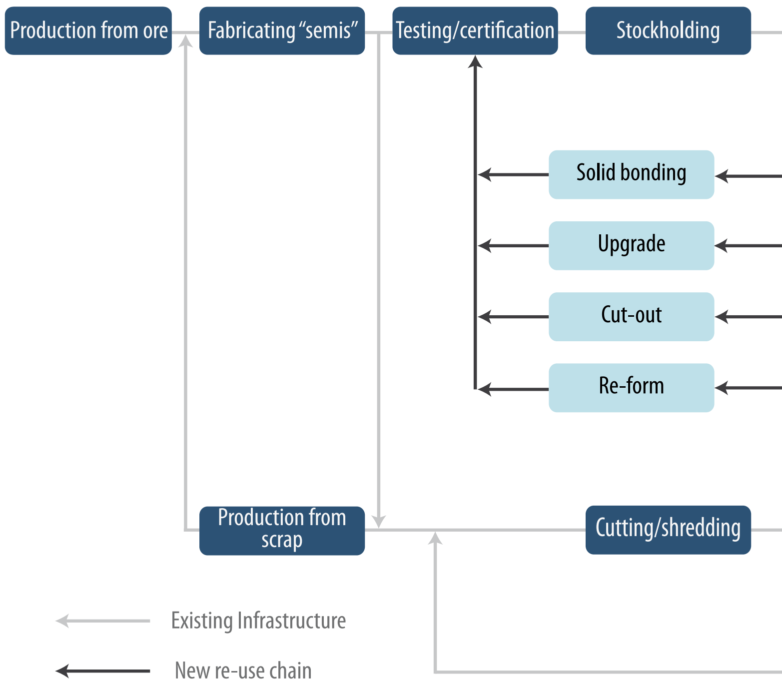
The incentives for supplying materials for reuse are bounded by globally determined prices—the scrap price and the new material price. Carbon prices can influence these financial incentives in favour of reuse. Models that make assumptions about technological progress predict carbon prices as low as £20/tCO_2 in order to reach stabilisation at 450 ppm CO_2[32]. The direct effect of this price change would be to decrease the cost of reused steel relative to melted steel by £35/t and that of aluminium by £165/t[33]. The UK government can further promote the supply of material for reuse through non-market instruments:

- The Waste Strategy (2007) sets targets for the diversion of material from landfill and for the observation of the waste hierarchy as a whole. These targets place equal weight on recycling and reuse despite the greater emissions savings associated with reuse. The revised Waste Strategy (currently under consultation) could stipulate specific targets for reuse of metals.
- The regulatory framework is in place to extend Building Regulations to cover demolition[34]. It may be possible to use this instrument to encourage deconstruction over demolition and so prevent damage to components.
- End-of-life legislation can be used to force companies to retrieve products post-use using reverse logistics. This extended responsibility improves the incentives for design for reuse as manufacturers recoup the residual value in products.
- The whole life costing principle outlined in the Green Book[35], which defines a depreciation methodology for project evaluation, can be used to enhance residual value (e.g. through reversible connections, standardised components, modular design and up front disassembly plans).

Infrastructure and technology requirements

Larger scale reuse of metals requires a reconfiguration of the existing supply chain. This calls for improved infrastructure for reuse and the promotion of specific technologies. The government could use existing schemes such as eQuip (WRAP), zero interest loans (Carbon Trust), capital allowances (WRAP) and waste handling credits (Waste Disposal Authorities) to support these businesses. Particular needs referred to by this report include:

- Support for the development of technologies that effectively segregate multiple offal streams from the pressing line, and so allow companies such as Abbey Steel to expand their operations.



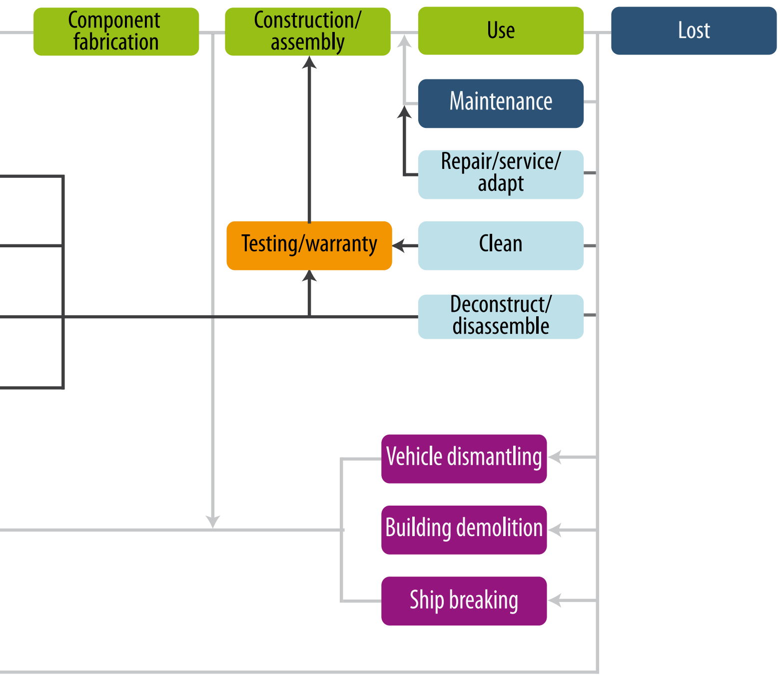
The existing supply chain to meet demand for steel and aluminium

Improved information and certification

Multiple guides have been written, for example CIRIA[25], SEDA[26], BioRegional[27], WRAP[28], to help companies and government bodies engage in reuse through better design, procurement and waste managements. Despite this apparent wealth of information, further clarification is required on the topic of certification. While certification can evidently be avoided by smaller scale enterprises, the issue must be formally tackled if reuse is to become mainstream, to reduce the risk associated with reuse. Such formal certification presents a commercial opportunity to add value to waste.

Clarification is required on the implications of the revised EU Construction Products Directive (currently under consultation) on reuse. On the one hand, harmonized standards that demand a declaration of performance for products may aid future reuse by improving traceability. On the other hand there are concerns that CE marking may hinder reuse by imposing product standards that prohibit reuse of material by increasing certification requirements beyond commercially viable levels.

- Support for further solid bonding pilots to test the technical feasibility of this method for different products.
- Support for the development of technologies that allow remote deconstruction of buildings to overcome health and safety concerns.
- Support for stockholders to encourage the stocking of new steel alongside used steel, e.g. to reduce tracking and certification costs.
- Support for rapid non-destructive testing technology to allow low cost assessment of the material properties of structural steel.



services with a reuse loop that would allow large scale reuse of metal.

To address these issues:

- The revised EU Construction Products Directive must be interpreted for reuse e.g. clarity is required on when it is permissible for manufacturers to state "No Performance Declared".
- Certification bodies should consider statistical methods of testing that could be used alongside traditional coupon testing and would greatly reduce certification costs.
- Certification bodies should consider the potential for remote testing technology which would reduce the cost and the operational complexity of certification.

In addition, it is important that government advertises the embodied emissions savings that can be achieved through reuse. Such publicity would help companies build 'green' brand advantage by improving their performance with respect to reuse.

Increasing demand for used material

Demand for reuse can be increased directly through government procurement standards. Existing standards include the Common Minimum Standards for Construction and Government Buying Standards. These standards favour reuse (in particular via the recommendations of the Achieving Excellence in Construction Initiative[35]) but have not been widely implemented despite being centrally mandated.

- Government should ensure the implementation of existing procurement priorities.

The Common Minimum Standard for Construction includes the requirement that all new builds are rated BREEAM excellent. BREEAM is an environmental standard offered by the Building Research Establishment that can be used by public sector and commercial developers to gain accreditation for the sustainability features of buildings. Reuse is included as one of the main issues and the "materials" category issues awards for the "embodied life-cycle impact of materials". As the BREEAM issues can be traded off against each other, accreditation does not necessitate reuse.

- Government could set specific targets for reuse alongside accreditation requirements.
- Government could mandate reuse through Building Regulations that currently focus on energy efficiency and safety.

Finally, in order to help construction companies specify reuse:

- Industry-wide specification standards for reuse should be set in accordance with certification requirements in order to allow construction companies and fabricators to specify reuse without incurring undue risk.
- Construction companies should engage in flexible design to allow used sections to be sourced and/or purchase used steel up front where possible.

An overview of current policy relating to reuse and options for government and business to promote reuse, is provided in the working paper, *Strengthening the business case*[W4].

Actions and opportunities

Our preoccupation with re-melting metals in order to reduce emissions is misplaced. The processes involved are emissions intensive and lend false environmental recognition to activities that replace products unnecessarily. Yes, recycling offers vast and important emissions savings compared to primary production but we can do more—reuse, where it is possible, is better.

Based on a series of site-visits to companies in the UK metal supply chain, workshops on the subject of reuse and a trial of novel solid bonding technology, this report has explored the opportunities and challenges associated with reuse. Collectively, it is estimated that without any change to design, melting 4% of current UK steel scrap and 13% of current UK aluminium scrap can be avoided by three reuse strategies alone—reuse of structural steel in construction, reuse of manufacturing scrap and solid bonding. We have found that much of this opportunity remains unexploited, despite evidence that small-scale businesses are operating profitably in reusing structural steel and manufacturing scrap.

Governments have a role to play in promoting reuse by: increasing supply of material for reuse through better target setting and by encouraging careful disassembly and/or take-back of products; offering clarification on certification requirements; supporting the development of technology and infrastructure that improves segregation of scrap and reduces certification costs; increasing demand for used material through government procurement and improved specification standards. However, ultimately it is the decision of companies (as intermediary consumers, designers and producers) and consumers that will drive growth in reuse. The following actions have been identified by this report:

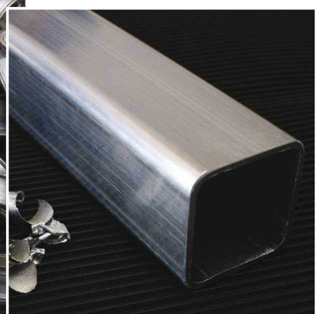
- Developers and land-owners should improve the phasing of decisions in demolition projects in order to allow time for deconstruction
- Manufacturers should exploit the residual value in scrap by optimising segregation of scrap metal by size and material composition
- Products and buildings should be specified with a view to reuse in accordance with the design principles outlined on page 10
- New business opportunities should be exploited to create a regional network of stockists of steel and aluminium for reuse
- Technology should be developed for solid bonding, non-destructive testing and remote deconstruction of steel buildings.

Wider development of reuse will not arise from peripheral changes to company policy but requires a fundamental reconfiguration of the supply chain. For many businesses this will present an opportunity. Companies that believe reuse might be a threat could reappraise their role in a low carbon economy. In doing so they must reassess the boundaries of their operations—should a steel company make steel (by primary and/or secondary production) or supply steel (by these methods and by reuse)?

To continue fostering reuse, the WellMet2050 team and consortium will:

- respond to the revised waste strategy call for evidence and recommend targets that promote reuse specifically
- investigate opportunities to maximise the residual value of offshore construction through design
- set up a pilot-scale business to move solid bonding closer to market
- investigate the application of rapid non-destructive testing technology for determining the material properties of reclaimed structural steel
- collaborate in providing clear guidance for the testing and certification of reused structural steel
- convene a workshop to interpret the implications of CE marking for reuse and disseminate findings
- identify the design and other features that define opportunities for reuse in existing scrap streams, and seek to clarify and demonstrate the principles of design for future reuse.

If you are interested in joining us as we develop this work, please contact us.



References

Must we melt used metal?

The working paper entitled *Steel and aluminium facts*[W1] explains the calculations and assumptions for the facts presented in the report introduction.

1. World Steel Association (2009) *World Steel in Figures,* provides 2008 steel production, consumption and scrap figures by country, region and globally.
2. UK Steel (2009) *Key Statistics 2009*, gives more detailed breakdowns for UK steel.
3. International Energy Agency (2008) *Energy Technology Perspectives 2008*, provides estimates of the primary energy and CO_2 emissions from steel and aluminium production, broken down by primary and secondary routes.
4. Allwood et al. (2010) Options for achieving a 50% cut in industrial carbon emissions by 2050, *Environmental Science & Technology*, 44:1888–1894. This paper calculates the global CO_2 emissions attributable to steel and aluminium production, and argues that production efficiency measures alone, for steel and aluminium, are insufficient to meet the carbon targets.
5. International Aluminium Institute (2008) *Aluminium for Future Generations/2008 Update*, gives global aluminium production figures and CO_2 emissions data.
6. International Energy Agency (2007) *Tracking Industrial Energy Efficiency and CO_2 Emissions*, calculates the primary energy requirement for making steel and aluminium.
7. International Aluminium Institute (2009) *Aluminium for Future Generations*, contrasts the primary energy requirement for ore versus scrap production of aluminium.

Reuse today

8. Construction Resources and Waste Platform (CRWP) (2007) *BigREc Survey: a survey of the UK reclamation and salvage trade*, documents the decline in the salvage trade for iron and steel between 1998 and 2007.
9. Dowling J. from Corus (2010) *personal communication.* This reference provides a summary of the UK steel sections market. The figure quoted refers to a typical year, i.e. before the latest economic downturn.
10. Ashby M. (2009) *Materials and the environment: eco-informed material choice.* This reference includes a description of six reasons why an object will reach its end-of-life.
11. Lees R. from Jaguar Land-Rover (2010) *personal communication.*

The opportunity for reuse now

The working paper *Scrap reuse potential and emissions savings*[W3] contains details of the CO_2 emissions savings for the three reuse options considered in this report.

12. Dahlström et al. (2004) *Iron, Steel and Aluminium in the UK: Material Flows and their Economic Dimensions.* This report records the new and old scrap flows for steel and aluminium in the UK.
13. UK Department of Energy and Climate Change (2010) *UK climate change sustainable development indicator: 2008 greenhouse gas emissions,* gives final figures for UK CO_2 emissions.
14. Hatayama et al. (2009) *Assessment of the recycling potential of aluminium in Japan, the United States, Europe and China.* This paper presents a breakdown of aluminium scrap by product category based on dynamic material flow analysis.
15. Davis et al. (2007) *Time-dependent material flow analysis of iron and steel in the UK Part 2: Scrap generation and recycling.* This paper presents a breakdown of steel scrap by product category, based on material flow analysis for the UK.
16. Corus Automotive (2010) *Personal communication,* from site visit 14 June 2010.
17. Steel Business Briefing (SBB) is a global, independent steel sector news agency that collates price indices.

Reuse in construction

18. British Standard BS6187:2000 *Code of practice for demolition.*

Solid bonding

The working paper *Solid bonding of aerospace and packaging aluminium scrap*[W5] gives details of the solid bonding process and testing results.

19. The Aluminium Federation www.alfed.org.uk.
20. Gronostajski et al. (1997) Direct recycling of aluminium chips into extruded products, *Journal of Materials Processing Technology*, (64:149–156).
21. Tekkaya et al. (2009) Hot Profile Extrusion of AA-6060 Aluminium Chips, *Journal of Materials Processing Technology* (209:3343-3350).
22. Alu Matter (2001) *Alu Select, mechanical properties: AA3004*, http://aluminium.matter.org.uk/aluselect/09_mech_browse.asp?
23. European Aluminium Association (2008) *Environmental profile report for the European aluminium industry*, provides CO_2 and energy data for aluminium production processes in Europe.
24. Hammond and Jones (2008) *Inventory of Carbon & Energy Version 1.6a.* This reference reports embodied energy and emissions for different materials in the UK.

Design for future reuse

The working paper *Steel and aluminium products*[W6] shows how the end-use product breakdowns for steel and aluminium were calculated. *Novel joining techniques to promote deconstruction of buildings*[W7] describes different connection systems for steel fabrication in buildings. *Design for future reuse*[W2] provides the calculations for the future potential emissions savings from reusing steel and aluminium products.

25. Addis and Schouten (2004) *Principles of design for deconstruction to facilitate reuse and recycling*, CIRIA, London.
26. Morgan and Stevenson (2005) *Design and detailing for deconstruction*, SEDA Design Guides for Scotland (No.1).
27. Kay and Essex (2009) *Pushing reuse: towards a low-carbon construction industry*, BioRegional and Salvo, London.
28. WRAP (2010) *Designing out Waste – A design team guide for civil engineering*, Part 1: Design Guide, Part 2: Technical Solutions.
29. Anders Sundgren (2010) *personal communication.* This reference confirmed the mass and performance characteristics of the track system.
30. Ayres R (2006) Turning point: the end of exponential growth, *Technology Forecasting and Social Change* (9:1188–1203). This paper gives an estimate of the limit for future recycling of steel and aluminium.

Emissions savings from reuse

The working paper *Emission savings from case studies*[W8] contains the calculations and assumptions used to estimate the CO_2 emissions savings for the case studies considered in this report.

31. Canadian Steel Producers Association (2010) *Environmental Performance Report.* This reference reports the environmental performance of the Canadian steel industry, including emissions factors.

Strengthening the business case

The working paper *Strengthening the business case*[W4] provides an overview of current policy relating to reuse and options for government and business to promote reuse.

32. Barker & Jenkins (2007) provides a meta-analysis, comparing the results of economic models of climate change. The figure quoted is for stabilisation at 550 ppm $CO_{2\text{-eq}}$ approximately equal to 450 ppm CO_2.
33. Based on the emissions estimates in working paper, *Emission savings from case studies*[W8].
34. *Sustainable and Secure Buildings Act* (2004) is an enabling act that defines the purposes for which Building Regulations can be made.
35. Office of Government Commerce (2007) *Achieving Excellence in Construction*, provides a framework for incorporating reuse into the building procurement process.

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

W1 Cullen J (2010) *Steel and aluminium facts.*

W2 Milford R (2010) *Design for future reuse.*

W3 Milford R (2010) *Scrap reuse potential and emissions savings.*

W4 Patel A (2010) *Strengthening the business case.*

W5 Cooper D (2010) *Solid bonding of aerospace and packaging aluminium scrap .*

W6 Cooper D (2010) *Steel and aluminium products.*

W7 Cooper D (2010) *Novel joining techniques to promote deconstruction of buildings.*

W8 Milford R (2010) *Emission savings from case studies.*

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