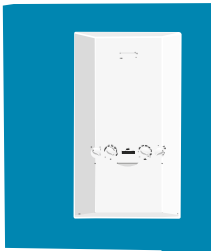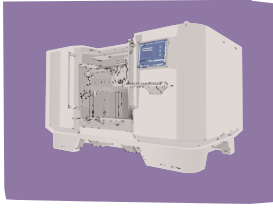ROYAL
ACADEMY OF
ENGINEERING

ENGINEERING
FOR **GROWTH**

MADE FOR THE FUTURE

challenges in creating a sustainable
domestic supply chain

Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel: +44 (0)20 7766 0600

www.raeng.org.uk/made

Registered charity number 293074

Please recycle this brochure

Contents

1. Introduction

This report is based on a series of workshops held at the Royal Academy of Engineering, which examined the environmental impact of domestic products in terms of energy use, carbon emissions and the use of non-renewable or limited material resources. The participants at the meetings were engineers and designers working in industry and academia, and researchers and practitioners in fashion and industrial design. They discussed how the ways that domestic products are designed, made, bought, used and disposed of can be adapted and improved in order to reduce their environmental impact.

The discussions were driven by two major concerns. The first was how consumers who want to make more sustainable choices can be certain that they are making the right decisions in the way that they obtain, use and dispose of a range of items – from phones to washing machines to home insulation. It is not always obvious, for example, whether it is better to keep an old appliance for as long as possible, or to

upgrade to a newer, more efficient model. However, tools for assessing the optimal lifetime of objects have been developed[1] that can help to calculate the lifetime resource and energy impact of consumer goods and work out how long they must last to 'make up' for the resources used in their manufacture. These tools guide the designer to support genuinely sustainable design, where sustainability means products that use less material resource and less energy across their lifecycle, understanding that sustainability is achieved in different ways for different sectors of technology.

The second concern was how designers, engineers, and manufacturers can help to mitigate the environmental impact of everyday living through technology. The meetings asked how technological innovations from 3D printing to newer, less energy-intensive methods of recycling could reduce the amount of material resources and energy used in the production of everyday products. They also looked at how technologies used in
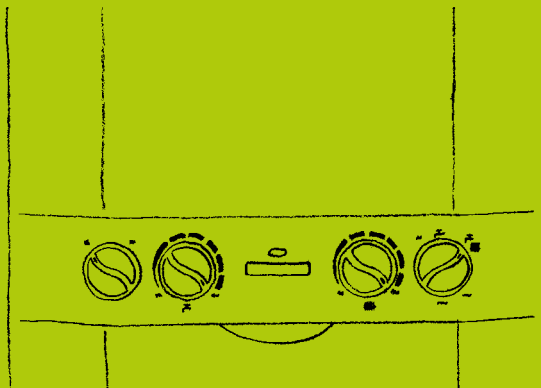
UK domestic electricity use

Since 1965, when comparative statistics were first collected, consumption of electricity alone by the domestic sector has exceeded that of the industrial sector in most years.[2] This shows that domestic homes make a significant contribution to the UK total electricity demand and therefore carbon emissions. Reducing demand for energy to supply domestic goods and devices can therefore make a substantial contribution to carbon emissions reduction.

the home itself, from smart metering and smart appliances that can manage the demands they make on the electricity grid, can have a positive impact on overall energy use.

Both of these issues together address the question of how to manage the impacts of behaviour so that everyday life makes less demand on non-renewable resources and results in less energy use and therefore reduced carbon emissions. The workshops highlighted some key issues that need further research, exploration, debate and testing by trialling new technologies and business models and by developing a better understanding of user preferences and behaviours. A major area for further exploration is no doubt getting a better understanding of consumer behaviour, of the variety of choices that people make about the products they choose, how they use them and how long they keep them.

This understanding can better inform designers and engineers to help them meet peoples' needs and create genuinely sustainably technologies.

These issues are raised in the sections below, and are intended to stimulate deeper debate and discussion on how the domestic supply chain could potentially be made more sustainable by supporting more responsive and less resource-intensive ways of manufacturing; exploring new ways of buying and owning products; and by improving ways of recycling and reusing. The nature of this study, a series of workshops, means that the sections below do not represent conclusions or recommendations as such. Rather they offer suggestions and questions that should be investigated further by a variety of disciplines from design and engineering to consumer psychology.

[1] See WRAP's 'lifetime optimisation tool': www.wrap.org.uk/content/lifetime-optimisation-tool-0

[2] DECC Historical electricity data: 1920 to 2011 www.gov.uk/government/statistical-data-sets/ historical-electricity-data-1920-to-2011

2. Making a difference

Manufacturing any product involves using material resources and energy. Manufacturing processes often create waste, and mass manufacturing can lead to overproduction of some products, or even large runs of failed products. Changes in the way we design and make things, and the ways that waste streams are managed and used by manufacturers, could significantly reduce the environmental impact of everyday goods.

3D printing and additive manufacturing – the real impacts

Additive manufacturing has come to prominence recently for a number of reasons. Additive manufacturing, or 3D printing, involves manufacturing through depositing raw materials, and is to be contrasted with subtractive methods of manufacturing, where raw materials are removed to create the desired form or structure. This process enables a significant reduction in waste, as no material is removed or cut away, and only the material that forms the finished product is used. Plastics, ceramics and metals can all be printed.

Textiles can be made through additive manufacturing processes which can be used to develop synthetic fabrics with novel properties. Instead of having to spin yarns that are then woven into a fabric, sheets of material can be printed directly, with forms such as interlinking hoops in the manner of chain mail. This means that, with further research and innovation in this area, synthetic fibres can be produced that have a much more desirable texture than those currently made, so that they could replace natural fibres in more applications. This offers significant benefits, as natural fibres such as cotton have significant environmental impact, including the amount of land needed to grow crops and the embedded water in the fabric from crop production and processing[3].

Additive manufacturing has the potential to underpin bespoke, personalised design. 3D printers are becoming ever cheaper and more accessible, with *MakerBot* printers selling for less than £900 at the time of writing and hobbyists even able to build the *RepRap* printer themselves. This
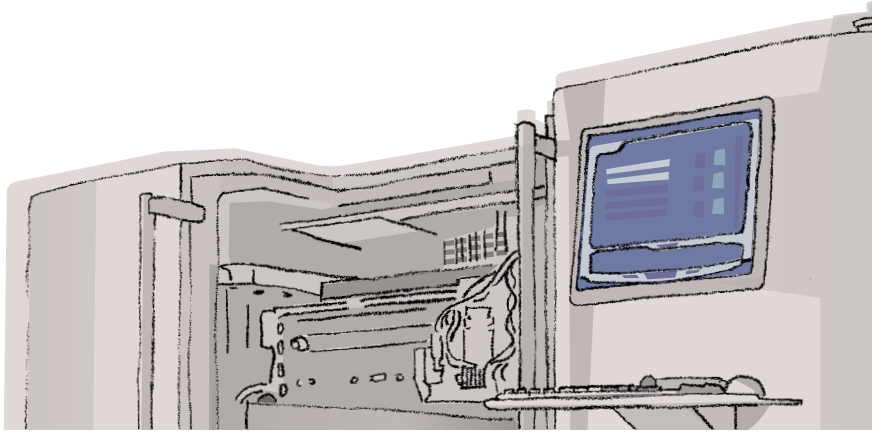
creates the scope for individuals to directly print designs themselves. While a lot of the attraction in the current market is for novelty items that appeal to collectors, business models based on a more practical philosophy could be developed. Additive manufacturing can allow the ordinary consumer to be both designer and maker, which avoids the problem of mis-predicting popularity of styles or sizes and thus avoids waste created by overstock. While it remains to be seen whether the majority of consumers are willing and able to design many products themselves, the bespoke aspect of additive manufacturing can be applied to manufacturing medical devices from dental implants to hearing aids, to fit the individual.

Bespoke replacement parts for white goods and other items can also be printed – especially helpful for repairing discontinued items where spares are no longer available. This need not involve any design or technical skills, since objects can be printed based on scans of the part to be replaced.

In addition to their use in manufacturing one-off products, additive manufacturing techniques allow the production of designs which traditional methods cannot physically create, allowing the design of hollow or lattice structures which are very lightweight. This is useful to the automotive and aerospace sectors and saves fuel, costs and emissions. However, there are drawbacks to additive manufacturing techniques. For example, when using metal powder, the powder must be made from liquid metal in an energy intensive process involving spraying and freezing; the lasers (often used for bonding) are very energy-intensive; product properties are limited and generally the products have a poor surface finish and require further process steps.

It is therefore unclear whether 3D printing technologies will lead to major energy and resource savings in the consumer sector.

[3]See: www.consideratedesign.com/projects/evolving-textiles/#more-98
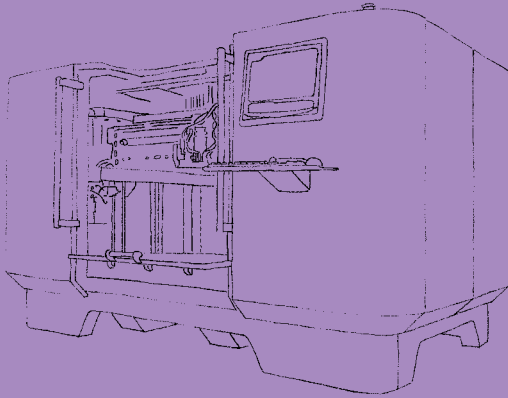
Furthermore, affordable 3D printers still produce items that need a lot of post-production finishing, and even industrial machines produce items slowly and expensively.

Addressing the impact of additive manufacturing: *will 3D printers become mass market in the next 10 years? Will they lead to greater or lesser use of resources overall?*

Customisation and short supply chains

There are other benefits that could follow from the potential for local, rapid, reactive manufacturing offered by 3D printing. Additive manufacture could lead to local manufacture, enabling smaller development runs in smaller factories which are more widely dispersed, with the potential to reduce distribution networks and overall energy demand. For instance, particular regions could specialise in a particular area of manufacturing to satisfy local markets. Related to this are concepts such as rapid prototyping – ultimately

perhaps in the home, but certainly closer to the customer. If manufacturing is done closer to the intended market, this is another way of reducing waste created by product overrun – items can be made quickly in response to sales rather than large volumes being manufactured but failing to sell. Of course, these benefits are not unique to additive manufacturing, and are rather the result of efficient information flow, and the potential benefits need to be carefully weighed against the considerable economies of scale of mass manufacturing.

There is scope for companies to work with a business model similar to that of ARM, the chip designer, where designs are licensed for manufacture by other companies - potentially very small local fabrication units. Furthermore, there is application beyond the consumer setting, with, for example, parts for military vehicles manufactured in situ when they are needed rapidly. It could also allow manufacturing to take place where there is no existing infrastructure, such as in remote locations.

While there are many predictions about the use of 3D printers in homes, it is more likely that consumers will have bespoke products printed for them by a third party. There are already companies that will fabricate designs sent to them by individual consumers, such as 3T RPD in the UK and Partsnap in the US.[4] Such business models could employ an 'open source' approach, where designs could be evolved by consumers uploading their variations on designs which other consumers could then select for manufacture. Thingiverse is a website that allows this kind of sharing of designs.[5]

This kind of direct-to-consumer manufacturing does raise some issues. For example, intellectual property is threatened if items can be manufactured based on scanned copies of other products. Establishing standards for printed products and understanding who is liable for product failure is important,

especially when making spare parts that will have a function within other devices. The Work Foundation has looked into these matters and called for government to take action to prepare for this new market.[6] This should be taken seriously as 3D printing grows as a method of manufacture and as a service to consumers. And there are clear benefits to standardisation as opposed to customisation, as standardised parts make repair and recycling a great deal easier.

Customisation over mass production: *Does shortening supply chains lead to increased resource efficiency? If so, is 3D printing/additive manufacturing a good way of doing this? Are there other models that can work better? Does customisation threaten the benefits of standardisation, which include easier ways of reusing and recycling?*

**Additive manufacturing in industry**

There are a number of areas where these processes are already being used. In aerospace and automotive, 3D printing has been used in applications such as aircraft wings by EADS and to build a bespoke steering wheel created to exactly fit the grip of the driver of the Bloodhound supersonic car. Such industry sectors can benefit from the way that additive manufacturing can create objects that are simply not achievable through traditional manufacturing processes. But they can also make savings in materials used, ultimately allowing significant cost savings. In his Hinton Lecture at the Royal Academy of Engineering, Tom Enders, Chief Executive of EADS, claimed that using additive manufacture drastically curbs the amount of titanium that is wasted in parts manufacture - from 90% of the material wasted in a subtractive manufacturing process, to only 5% in additive manufacture.

Source: Royal Academy of Engineering, Hinton lecture 2012 and Additive Manufacturing roundtable 2013.

---

[4]*www.3trpd.co.uk/; www.partsnap.com/*

[5]*www.thingiverse.com/*

[6]*See Three Dimensional Policy, the Work Foundation 2012 www.theworkfoundation.com/Reports/322/ Three-Dimensional-Policy-Why-Britain-needs-a-policy-framework-for-3D-printing*
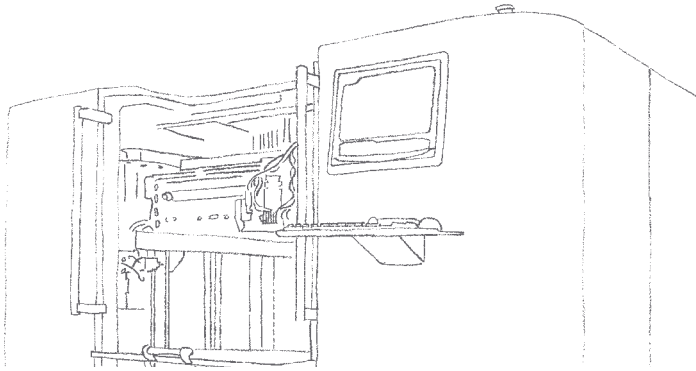
Tailor-made?

The fashion industry produces substantial waste both in terms of fabric offcuts and unwanted clothes disposed of at the end of life. One potential way to avoid waste in the textile and fashion industries is through greater personalisation. This could be achieved by: designing items to a precise fit to avoid waste through fabric offcuts; creating more bespoke items to avoid overstock of unpopular items; and designing items to change or upgrade to mitigate against obsolescence.

Designing to fit involves creating clothes for an individual, manufactured to their size and specification on printers that can produce a whole garment. This avoids the traditional method of cutting to patterns, which creates waste material through offcuts.

Personalisation and customisation need not rely on high-end technology. A number of large and small companies allow simple customization – Nike, Adidas and Puma all allow consumers to specify exact colour and material combinations for trainers. This does not involve specific techniques, but makes use of digital interfaces to allow customers to 'design' and order a personalised item. Jewellery designers Tatty Devine have based a

brand on micromanufacturing Perspex jewellery that is laser-cut to order with the customer's own name or message.

Other ways of reacting to taste involve leaner manufacturing and distribution, with more local manufacturing and supply centres to provide goods that are selling well in local shops. This is the business model used by the clothing company Zara, where use of IT and close management of logistics and monitoring of sales allows for better stock control and more rapid response.[7] However, while this might limit waste in stores, the resulting rapid turnover of stock can promote the kind of 'fast fashion' culture that can encourage consumers to buy clothes very often which are worn little, if ever. [8]

Enduring fashions: *will we see 'automated tailors' on the high street, printing out clothing to exact size and specification? Books and art prints can be printed on demand, allowing greater choice with less stock on the shelves – can the same move be made for fashion?*

The Cambridge Well-dressed? *report and WRAP's* Valuing our clothes *recommend extending clothing lifecycles. How can this be achieved given the pace and price of high street fashion?*

Watching our waste line

The *Well-dressed?* report identified the major environmental impacts of the clothing and textiles sector, illustrating the need to cut out fashion waste. They include:

Toxic chemicals are used widely in cotton agriculture and in many manufacturing stages such as pre-treatment, dyeing and printing.

Waste volumes from the sector are high and growing in the UK with the advent of 'fast fashion'. On average, UK consumers send 30kg of clothing and textiles per capita to landfill each year.

Water consumption – especially the extensive use of water in cotton crop cultivation – can also be a major environmental issue as seen dramatically in the Aral Sea region.

Source: Well-dressed?*, the Institute for Manufacturing at the University of Cambridge*

"If you look at natural materials such as cotton, it takes a lot of energy just to grow a crop that is usable and user-friendly, often using a lot of water and pesticides which have to be leached out using even more water. These natural products are not as environmentally friendly as it might first seem."

Quote from the *fashion, textiles and synthetic* biology workshop

Fashion is an area where even an individual's tastes can change quickly, leading to rapid obsolescence. Royal College of Arts graduates Oliver Poyntz and Alexander Bone[9] are carrying out research into printing t-shirts and are exploring systems where a customer would buy a printed t-shirt and, if they decided that the design was no longer attractive, they could take the t-shirt back to be washed in a specific process to separate out the ink from the t-shirt. The ink could be captured again, and a new design could be printed on the t-shirt. In this way, fashion can still be fast and reactive to trends, without clothing being disposed of after relatively few wears. If a service could be made viable as a business for reprinting and generally reviving clothes in this way, fashion could be fast without being throwaway.

[7] *See 'Why Zara's business model is paying dividends': www.retail-week.com/sectors/fashion/comment-why-zaras-business-model-is-paying-dividends/5041586.article*

[8] *WRAP's report Valuing our Clothes estimates that UK households own £30bn worth of clothes that have not been worn in the last year – however this is often due to poor fit: www.wrap.org.uk/content/valuing-our-clothes*

[9] *www.rca.ac.uk/Default.aspx?ContentID=512731&CategoryID=36646*
www.rca.ac.uk/Default.aspx?ContentID=512653&CategoryID=36646

A factory for infinity:[10] use and reuse of waste in manufacturing

Traditional manufacturing processes tend to be high-heat and high-energy, and can be characterised by the 'heat it, beat it and treat it', mode of production, which is heavily energy-intensive. One way to move towards a more sustainable manufacturing system is to reduce reliance on the extractive sector, and to produce feedstock by recycling and re-using waste materials. The ideal would be a 'closed loop' factory, where goods were manufactured from recycled materials, with products that end their functional life returning to the factory to be recycled and remade.

'Waste not...'

A recent EEF survey found 80% of senior manufacturing executives considered limited access to raw materials to be a business risk and a threat to growth. For one in three companies it was their top risk. *Source: EEF[11]*

Alternatively, a new era of extraction could be introduced by a process of 'landfill mining', retrieving materials from waste rather than extracting pure materials from natural sources. The section on recycling below explores further the concept of using recyclate as a resource.

Efficiency can be improved if one company has end-to-end oversight of products. This allows exactly the right number of products to be made, and potentially enables easier recycling of used parts and systems and the products they are made from. The design process is crucial to ensuring that items can be taken apart for their elements to be reused or recycled.

Industrial symbiosis, where waste from one process is used as raw materials in another, is also considered to be a useful means for reducing the footprint of manufacturing. There are complexities in such an arrangement in that it holds manufactures in a web which is mutually dependent, with failure or rapid growth in one manufacturer affecting another. However, there are also environmental and potential cost benefits where this can be made to work.[12]

[10]Concept courtesy of Jessi Baker, Oliver Bone, Alex Poyntz: www.factoryforinfinity.com/

[11]www.eef.org.uk/releases/uk/2011/GOVT-MUST-TAKE-STRONGER-ACTION-OVER-LOOMING-RAW-MATERIAL-SHORTAGE.htm

[12]See www.nispnetwork.com/
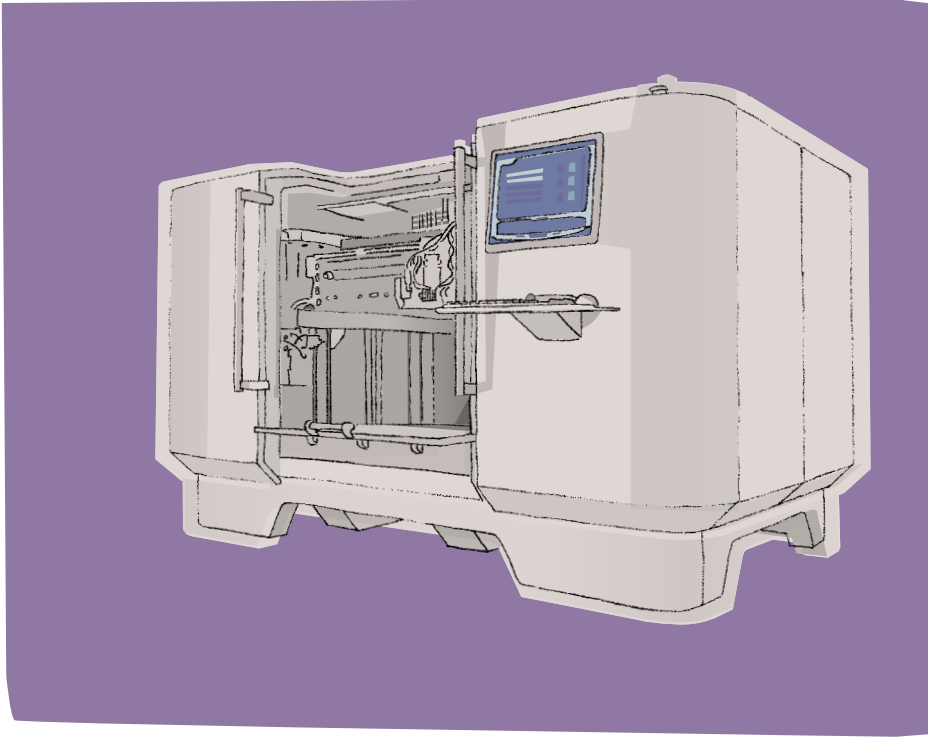
"The rate of increase in resource consumption means that business as usual is not an option. I believe that the only solution to this challenge is improving and rolling out digital infrastructure and digital services."

Mike Perry, principal consultant at BRE
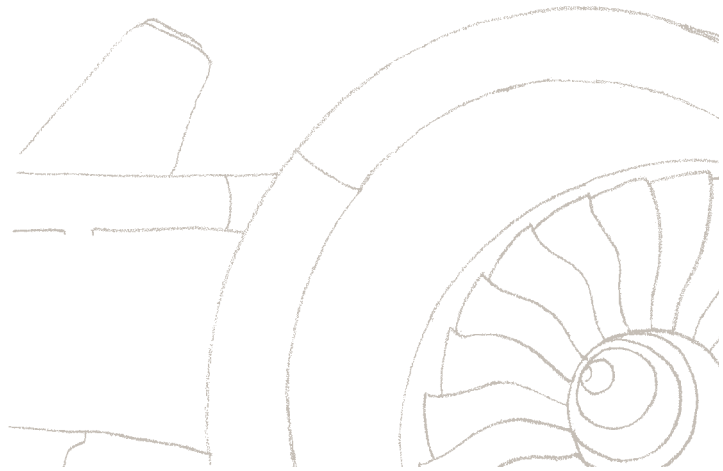
3. From Radio Rentals to Rolls-Royce

The environmental impact of the lifecycle of domestic technologies extends beyond design and manufacture to how they are marketed, owned and used. While businesses based on consumer retail models focus on the selling of products themselves, business-to-business models, such as those employed in aerospace, focus on the service provided rather than the goods produced. For decades, Rolls-Royce has based a business on selling flying time rather than on selling engines, offering airlines a service where engines are leased from and maintained by the manufacturer. The basis for this model is that an airline requires functioning engines to keep its aircraft in service, and do not necessarily need or want to own and maintain the best engines themselves. Service-based models such as this create an incentive for manufacturers to design and make items with a longer lifecycle, to limit their maintenance and replacement, rather than having an incentive to 'design-in' obsolescence to keep the market stimulated. If the service were to encompass not only installation and maintenance, but the costs of running products, then there would also be an incentive to manufacture and provide products that are more sustainable in use. How could this model work in the domestic sector, and how long should products be kept in service to achieve optimal use of energy and resources?

How could service-based business work?

The 'Rolls-Royce' model could potentially extend to a range of brown and white goods, including boilers, fridges and dishwashers. One option could be offering a whole-kitchen service where appliances were leased, maintained and repaired as needed, with the service provider responsible for recycling and replacement at the end of their optimal lifespan. This could extend to building services, with companies managing not only appliances but lighting and heating systems in buildings. This would create an incentive to invest in energy-efficient low–maintenance lighting such as LEDs, and keeping heating systems running efficiently.

Design for obsolescence – is the two-year phone contract a bad thing?

While phones are frequently upgraded, this rapid obsolescence may have benefits, as described by the Department for Environment, Food and Rural Affairs:

"For ICT products that are currently experiencing the highest levels of innovation, of which the mobile phone is an example in this research, a limitation of the modelling is that the benefits of product convergence is not quantified in the analysis. In essence, the mobile phone is an example product that has the potential to rapidly dematerialise product/services provided by multiple existing products in the marketplace (eg camera, diary, entertainment, videoconferencing, satnav, maps, banking services etc). **It is hypothesised (although not tested) that within a short timeframe, extending the life of some products such as Smart mobile phones has the potential to hinder the potentially significant environmental benefits of product convergence (ie not having to supply multiple products, since the phone fulfils many functions/products/services).** However, for the mobile phone it is also shown in the current research that the second hand cascade reuse of such products in different markets results in benefits."

However, whether the fact that a smartphone can take pictures and provide navigation tools really means that consumers do not buy further devices is unclear. Research into whether smartphones really do displace other devices could provide an answer.

Source: Defra, Longer product lifetimes [13]

The rental model is already offered for a variety of products, from cars to ball gowns. Is it, however, a way of achieving a longer product lifespan? In order to establish this, it is important to understand what products it would be valuable to a consumer to hire rather than own, and what kinds of products will be leased for long periods of time. For example, white goods may be rented for a long period, and it would be worthwhile building washing machines to last if they are leased on this basis. However, people are likely to feel very differently about cars, phones and televisions and may prefer to own and trade-up frequently, or to lease on short-term contracts. Indeed, the consumer's reason to lease may be very different to that of a business, and this classic business-business model may not work in the business-consumer sector.

It is also important that, when something is sold as a service, the service provider really buys into this idea. This means taking responsibility for the goods provided as a part of the service, including taking them back for re-use or recycling when the consumer no longer requires them. For example, while set-top boxes are often provided as part of a satellite or cable TV package, they are often not actively taken back by providers when contracts end or packages are upgraded.

Yours for life?*: Are consumers open to a service-based model of product 'ownership'? Is renting outmoded or resurgent? What will the net impact on energy and resource be in comparison to ownership?*

[13]www.randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&Project ID=17047
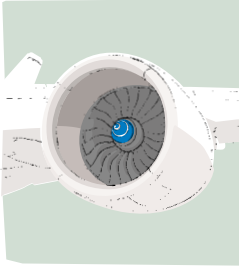
What could service-based models achieve?

The way that products are supplied through a service contract can influence their lifespan. For example, the capital value of smartphones has led to phone providers offering them on longer contracts and they are eligible for upgrade less often than earlier models. A service-based business model could encourage businesses to manufacture and supply goods built to last for longer – and as shown through research by Defra reported in the box opposite, products with longer lifecycles generally offer gains in terms of resources saved and reduced global warming potential (GWP). For some items, perhaps designer clothes and baby items, the lifespan of products can be extended by passing them on to new owners after they are no longer needed.

However, lease-based models can also conceivably lead to shorter lifespans. If consumers are renting a television, and pay a monthly charge rather than the full capital cost, it may make it easier and more desirable to have the latest (or largest) model as soon as it becomes available. There is a need for more research into how service models influence product 'turnover' – there may still be an incentive for service providers to install cheaper goods and replace them entirely if they fail rather than maintaining better quality goods. They may also be poorly looked after by users who know they can get a repair as part of their contract.

When considering this business model in terms of sustainability, it is important to distinguish between cases where leasing is an alternative to owning (and in which case it might be more sustainable), and cases where it allows people access to goods that they would not otherwise own, such as through short-term rental schemes. For example, some car rental schemes are aimed at people living in cities who do not want to own a car but would like to use one for occasional journeys. Such car rental schemes might therefore be creating additional car journeys for people who would usually take public transport

The net gains of longer-life goods

"The modelling indicates that extending product lifetimes is likely to result in environmental benefits in most instances. Manufacturing and supply chain impacts are saved when products are kept in service for longer. These were not outweighed by the additional impacts associated with refurbishment /increased servicing or additional impacts of increased product durability.

From an environmental perspective there is an argument for optimised lifetime extension strategies for all consumer products and in particular, for products in which manufacturing, supply chain and waste management impacts dominate over the life cycle."

Source: Defra, Longer product lifecycles, *Chapter 2[15]*

or who would share a car with someone else. Similarly, high end clothes-hire is not necessarily going to lead to people buying fewer clothes. One expensive dress bought and worn several times might still be a better option than renting several dresses on different occasions if the dresses are only rented out a limited number of times and are packaged, transported and dry cleaned each time. More research is needed into the carbon and resource-per-use of an item that is leased versus a similar item that is owned by one individual or family in order to understand whether this model has the same impacts in the consumer market as it does in the business services sector.

Can leasing lengthen life?*: Would a service-based business model reduce or increase technological obsolescence? Are items that are leased on a short term basis likely to be used more frequently in their lifetime or less frequently than individually-owned products?*

How long should your washing machine last?

Do consumers understand how long products are supposed to last, or how long they want them to last? Should products be living long beyond their warranty? While the lifespan of a product is usually understood to end at the point where it fails beyond repair, the end of a product's useful life can be dictated by either absolute or relative failure. A product may no longer perform its intended function, or it can be rendered obsolete by the emergence of new technologies, or more efficient versions of the same technology, or the disappearance of a medium – thus a perfectly functional exposure-based camera, twin tub washing machine or minidisc player may be taken to have reached the end of its useful life. Different kinds of failure will apply more or less in different sectors. For example, we are likely to use a heating boiler

[14]*www.zipcar.uk.mediaroom.com/pay-as-you-live*

[15]*www.randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&Project ID=17047*

> "We know that prolonging product life allows up front embodied energy in the product to be spread across a longer period, reducing the energy required per unit service. But we also know that prolonging product life reduces the opportunity to exploit advances in use-phase emissions that might be offered by newer products."

Quote from *metals, plastics and white goods* workshop

until it no longer functions, but a mobile phone may become obsolete while it is still functioning, and indeed while its constituent parts (the processors that power it) may have decades left in their design life. The challenge is therefore to not only tackle the technical but also the socioeconomic barriers to long-life products.

Engineers need robust information about the embedded carbon and resources used in making a product, and the energy and resources consumed in use, in order to create products with an optimal life. Defra's report *Longer product lifetimes* and WRAP's work on their lifetime optimisation tool[16] have been created to help designers develop goods that will have a longer, more efficient lifespan. However, the focus should not be solely on longer lifespans because this is not right for all kinds of device. Newer, more efficient boilers have shorter lifespans compared to much older systems, but the efficiency gains outweigh the disadvantages of the quicker

replacement rates (though of course it would be important to try to extend the life of the more efficient models).

It is therefore important to think in terms of optimal life. Designing for optimal life is a slightly subtler proposition compared with designing for long life. Designing for long life suggests increasing durability, which generally means increased material use and more embedded energy. Over an extended period, if the consumer continues to use that product as opposed to buying several new ones, this can be more sustainable overall in terms of total resources and energy used. However, the longer-life product will not be taking advantage of the latest innovations in the field, so at some point its performance may become sub-optimal – this is especially a risk for items such as cars where step changes in efficiency are possible.[17] Also, if a long-life product breaks prematurely, the added costs of the extra material, both financially and environmentally, are no longer 'paid back' over an extended

lifetime. However, research does suggest that overall, longer-lasting products do reduce carbon emissions.[18] Furthermore, if products can be designed to be easily repaired, this can ensure they achieve their expected lifespans, especially if it is easy to replace those parts that are most likely to wear out or become inefficient, such as the motor in a washing machine.

It is important to recognise that optimal lifespan is not a fixed period for either all items or all people. A product might suffer 'absolute' failure when it no longer performs its function, but 'relative' failure depends on the availability of other technologies to perform that function better and on the attitudes and choices of individuals. Some people prefer to keep their basic mobile even while the mass market moves on to smartphones, perhaps even cherishing it or being proud of sticking with their older technology. An item becomes obsolete not only when it no longer works or is superseded, but also if its owner loses interest in it. The notion of 'emotionally durable design' was coined by Professor Jonathan Chapman at the University of Brighton.[19] This is the idea of extending the lifetime of products, especially electronic devices, by making them in such a way that they continue to appeal over time, potentially gathering more appeal as they age.

Achieving this will no doubt require a great deal of deeper understanding of consumer behaviour and psychology. Different people have different attitudes to ownership, with some preferring to invest in items that will have a long life, and others more likely to buy for the short term. We also need to understand better the effect of social norms, trends and fashion on peoples' decisions, to understand how and where it is possible to work with these influences rather than against them. One potential area to explore is how to prolong the life of materials already in use by finding ways to make items such as clothing 'feel new' or by recycling and reusing items that we upgrade frequently, as will be discussed in the next section.

Cradle-to-cradle calculator

WRAP has produced a 'lifetime optimisation tool' for weighing embedded energy and resource in a product against its expected lifetime, which allows designers to:

Analyse the optimum life for carbon, energy, water and resource depletion for 10 common products, or use your own lifecycle data to analyse new products

Test and save different lifetime options

Analyse scenarios for changing lifetime, manufacturing impact, and energy-efficiency of a new product, and the refurbishment and energy-efficiency for the original

Produce a final report with suggestions on reducing product impacts for a given scenario – and for the indicator of interest (e.g. energy or water).

Source: WRAP[20]

[16]*www.wrap.org.uk/content/lifetime-optimisation-tool-0*

[17]*Defra, Longer Product Lifetimes, chapter 2*

[18]*See Sustainable Materials with both eyes open, Julian M Allwood and Jonathan M Cullen, Cambridge 2012*

[19]*This idea was explored at the 'The Future is Here' exhibition at the Design Museum (2013)*

[20]*www.wrap.org.uk/content/lifetime-optimisation-tool-0*

4. Does recycling work?

Welcome developments have been made in the technology and practice of recycling over the last two decades, diverting waste from landfill and reducing demand for raw material. However, is there further to go with recycling?

### As good as new – what are the efficiency savings of recycling?

It is not always the case that material efficiency and energy efficiency go hand in hand. For example, one way of ensuring material efficiency and limiting resource use is by manufacturing from recycled material. However, the process of recycling can, depending on the materials being recycled and the ways that products are assembled, be complex and energy-intensive, approaching the energy demands of manufacturing from raw materials in some cases.

Two choices exist when recycling: cheaper 'brutal' methods, and more expensive 'smart' methods. The brutal methods break up discarded products into small pieces, which are then sorted and melted to retrieve any useful materials. For example,

cars are recycled by shredding the car and using magnets to sort the metals from other materials. Such methods are energy-intensive and are unlikely to get the most of the material they aim to recycle, in particular they are unlikely to retrieve the higher-value metals used in electronic systems. It is this feature of recycling that often creates a tension between energy and resource efficiency. One example of more efficient recycling is non-destructive recycling methods such as re-rolling sheet metal. For white goods in particular, there is potential for metal to be re-rolled and re-used almost directly, rather than being melted down and re-processed as though it were a raw material.

Reuse and recycling practice

As well as the availability of technology for recycling efficiently, there needs to be an incentive for re-use and recycling. Most household waste is now recycled by local authorities, but it is not so simple for electronics or white goods – even less so for building and decorating materials such as carpet or flooring.
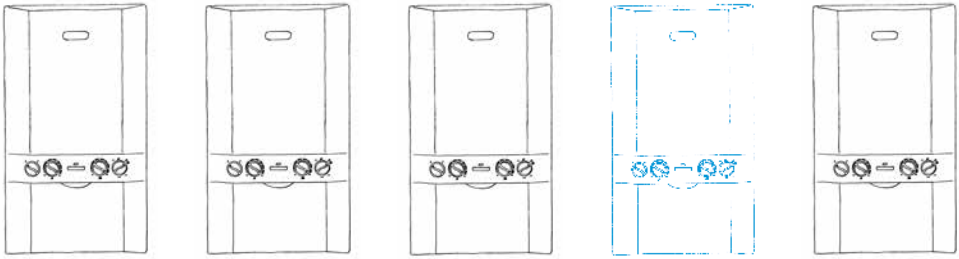
Boiling it down: recycling boilers

The Worcester Bosch Group has reached 100% recyclability for all its products. Its zero-to-landfill objective was achieved in 2010, only two years after implementing a new business system designed to effectively and efficiently recycle all its scrap appliances.

Individual recycle 'bins' were introduced on its factory floor. Each piece of waste from the factory's scrap boilers was dismantled, broken into the varying different materials and sorted into the appropriate 'bin'.

By the start of 2009, based on the boiler components' strip-down weight, a total of 91.6% of Worcester's boilers were able to be recycled using this initiative, including the plate heat exchanges, the aluminium heat blocks, copper and wiring.

Worcester identified the remaining 8.4% of waste being sent to landfill, and by 2010 was able to break down parts even further to achieve 100% recyclability. For example, the large cast-aluminium block wrapped in stainless steel casing was separated releasing the heat cell for recycling.

For the plastic waste Bosch could not recycle, a partnership with a Swansea-based company now transforms this previously non-recyclable waste into an eco-friendly concrete replacement.

Customers can return all end-of-life boilers to Bosch free of charge via the merchant. Collections are made on the same transport and at the same time as deliveries so not to increase their carbon footprint. Approximately 400 appliances are recycled each year and none of this goes to landfill.

Source: All figures from the Worcester Bosch Group

There are lots of issues at play here – where and how products are recycled and upcycled; who takes responsibility for this; and how to incentivise it. But largely these reduce to the issue of the ease of re-use and the efficiency of recycling methods. There can be significant benefits for retailers to recycle goods they supplied, if they can earn through recycling – such as selling on smartphones to be reused in other countries, or selling 'scrap' to be recycled. Similarly, if white goods can be easily recycled by low-cost, low-energy re-rolling of metals, there is an incentive for the manufacturer who could have, in effect, a closed-loop factory remaking from old goods. In this way, recycling is part of the broader issue of using waste as a resource.

All of this depends on getting back the product from the consumer, and again, there is an incentive for the consumer if there is value in the product that they return. Smartphones are returned to retailers more often than older mobile handsets were, as there are significant cashback schemes in place.

The need for a recycling culture is not just limited to consumers, but also includes designers and manufacturers. Recycling can be made easier and more economic if devices are designed to be recycled. Research and development is needed into

[21]www.guardian.co.uk/environment/2013/jun/11/recycling-industry-10000-jobs-2020

the ways that devices can be designed and manufactured, and their parts reused, so that elements that still have a useful life can be retrieved and reused. There will be technological limitations on how far this is possible, but innovative solutions to finding economic ways of making products reusable and recyclable are essential.

Another challenge in supporting recycling practice is for manufacturers to consider recyclates as a source of raw material. Manufacturing from recycled material can reduce dependence on new materials and potentially deliver savings. But this is dependent on the quality of the recyclate. The ESA (Environmental Services Agency) report *Going for Growth* reports the need for greater confidence in the quality of feedstock from recycling to make it a less risky choice for manufacturers. A key issue is material, and alloy-specific separation during manufacture and at end of life. For example, mixed aluminium alloys have to be down-cycled to engine blocks. Mixed plastics at end of life become very difficult to separate out with sufficient precision for them to be successfully recycled.

Improvements in recycling technology and methods could help to achieve this better quality feedstock.

Designing for recycling is a challenge when the recycling technologies themselves are changing. A clear analysis of the trajectory of recycling research would help designers create objects that will be recyclable, using the best available (low-energy, non-destructive) methods, at the end of their lifespan.

Debate: does recycling currently make the savings in energy and resource we need? What changes are needed to maximise the potential of recycling?

Retrofit for purpose?

To renew the UK housing stock through replacement (at 2011 rates of building) would take 236 years. While this was a year when building rates were low, it is certainly the case that homes that now stand will have to remain in service for many decades. During that time, they will need to be modified to achieve the best levels of energy efficiency. Given also that building
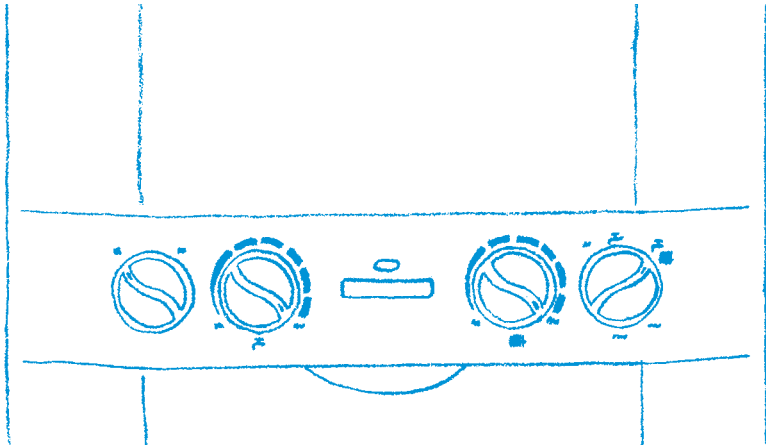
a new home uses significantly more resource than an equivalent refurbishment, refurbishing homes to make them energy-efficient is far better than replacing old homes with modern, energy-efficient versions.

Research is needed into the kinds of refurbishment and retrofit that will deliver the most benefit. For example, while solar panels and wind turbines might be a visible 'green' addition to the home, they have been described as 'eco-bling' by Doug King FREng, because they may not deliver as much benefit as good insulation. The less obvious improvements need to be marketed to homeowners as well as conspicuous sustainability modifications.

Consumers stand in general need of information about the kinds of retrofit that will benefit them. There are many modifications that could be made to an average home, many costly, and the consumer needs advice about which offer the most benefit as well as project management direction on which to do

first. Surveys are part of the government's Green Deal, and it is important that the information given to consumers can guide them in making the most high-impact changes to their home.

The technicians providing retrofit also need access to information. There is a challenge to skilling-up the technician workforce when the technology is constantly changing. Expert advice lines for technicians, such as the programme organised by the Belgian Building Research Institute, can help ensure that those carrying out retrofit have the most up to date technologies at their disposal. There is a 'zero carbon home hub'[22] for new homes, but a similar way of sharing and pooling knowledge about how to retrofit and improve homes would help both consumers and technicians.

However, information is not the only barrier to homeowners making upgrades for energy efficiency. The necessary changes are often expensive, requiring many homeowners to need financial support.

[22]www.zerocarbonhub.org/

Pre-loved and re-loved

The lowest-energy form of dealing with waste and unwanted items is simply reusing or 'upcycling' used items.

The British Heart Foundation is the largest second-hand furniture and electrical retailer in the UK, with over 140 dedicated furniture and electrical stores across the UK.

The BHF scheme is a prime example of how furniture can be used optimally by being recycled through second-hand use. Furniture is collected for free and the charity offers a house clearance service. By selling good quality donated items, the charity not only prevents unwanted furniture ending up in landfill, but is also able to raise vital funds to help heart patients across the UK. In 2011 alone, £31 million was raised which funds much of the charity's work. Overall, BHF shops prevent over 25,000 tonnes of textiles and furniture going to landfill each year.

A proportion of wooden and upholstered furniture which cannot be resold is recycled. These items are disassembled manually by contractors into separate materials (wood, metal, textiles) and then sent on to UK reprocessors. BHF are looking into other markets such as supplying beds and mattresses to manufacturers of carpet underlay and automotive lining.

References: All figures gained from the British Heart Foundation

There should be scrutiny of the Green Deal in terms of its attractiveness to consumers. While it offers savings on energy bills, those savings are used to pay for the changes to the home which may take many years to pay off. On that basis, homeowners who live through the upheaval of building work can wait decades to receive any financial benefits from those modifications. There is also the potential complexity of selling-on a property with what is essentially an associated debt for refurbishments carried out in the past.

Given these disincentives to homeowners upgrading their properties, it may be that the priority should be to provide schemes that encourage retrofitting in the public rather than the private housing sector, or at least for landlords and developers rather than private home owners. Retrofitting is easier to do when large areas of housing are empty and being upgraded and the impact on energy bills may be more significant for public housing where there is more opportunity for shared heating schemes in large properties. But again, while not all consumers will want to retrofit their homes, for those who are motivated a resource of information and skilled technicians are critical to enabling them to make the most sustainable choices.

Another aspect of retrofitting is to integrate smart systems into buildings. Smart metering is on the horizon with EDF aiming to install smart meters in all homes by 2019. Connected devices in the home could help to achieve greater energy efficiency for the grid, by managing and levelling energy use across the devices in a home. A smarter grid, with dynamic load balancing and greater responsiveness to demand, could allow charging where demand is low and cutting off inessential devices when demand is high. This can allow better use of renewables, leading to reduced carbon emissions across the UK. Smart devices in the home, such as lights or appliances that switch off when no one is in the room, could also reduce the energy use in an individual home.
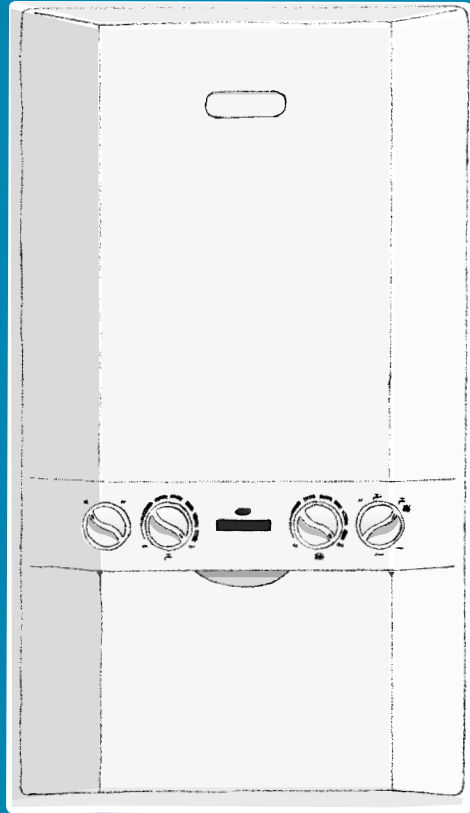
Why retrofit?: *what can encourage homeowners to make their houses as efficient as possible through retrofitting? What kind of financial support would work best?*
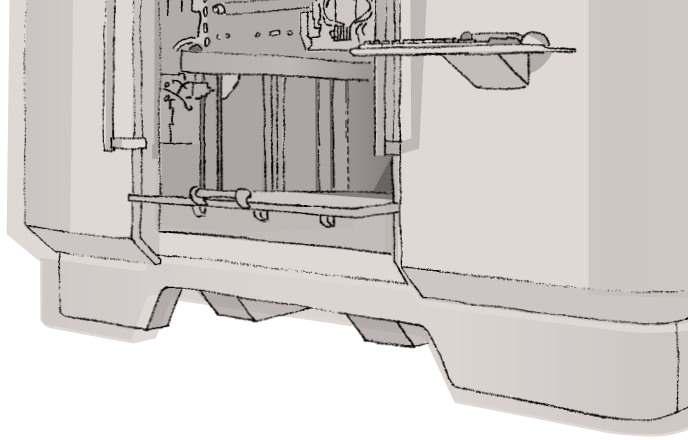
5. Research for the future

It is no doubt desirable for us all to adapt our behaviour in order to live more sustainable lives, but many people are busy juggling other demands and cannot afford to make drastic adjustments in their ways of living. It is also important to be realistic about the power of trends, marketing, and social conventions in affecting people's decisions and driving the urge to consume more and to acquire new things while they remain desirable and affordable. The role of the engineer is to improve quality of life, and creating low-impact technologies to mitigate the effects of everyday life without excessive demand on the user is a valuable role that engineering can play.

Not only will designers and engineers be required, but also technicians to fit, maintain and dispose of the products. The type of training these engineers and technicians receive will also need to be developed. Rather than just being taught how to make new things, they should also be trained in how to retrofit, reuse and upgrade.

This report is intended to ask what engineers can do to drive the move towards greater sustainability. It has identified the need for greater research into efficient and economic ways of recycling. It has also shown that the impacts of advanced manufacturing methods need to be carefully scrutinised to understand their role in creating more sustainable goods.

This report also shows that there are many open questions about consumer psychology and behaviour, and the factors that influence it, that need to be better understood. Greater understanding is needed of attitudes to ownership and how these vary across social groups. There are many dialogues to be had between designers and social scientists in order to identify the best ways to create appealing goods that are efficient, long-lasting and desirable over the long term.

6. Acknowledgements and method

Study Chair:

Professor Nigel Gilbert FREng

We are grateful to the following for their contributions to the shaping of the project:

Steve Keeley, Worcester Bosch Group

Professor Raymond Oliver FREng, Northumbria University

Dr Paula Owens, Paula Owens Consultants

Gerard Fisher, WRAP

Jane Wernick FREng, Jane Wernick Associates, founder

Professor Tim Cooper, Nottingham Trent University, Professor of Sustainable Design and Consumption

David Scuderi, Environmental Affairs Manager, Samsung Electronics Europe

Professor Will Stewart FREng, University of Southampton

Professor Rachel Cooper, Lancaster University

Dr Claire Barlow, University of Cambridge

Sandy Patel, University of Cambridge

Dan Cooper, University of Cambridge

Workshop Chairs and participants:

Devices and communications: Professor William Stewart FREng

Metals, plastics and white goods: Dan Cooper, University of Cambrige

Fabric, clothing and synthetic biology: Professor Raymond Oliver FREng, Northumbria University

Construction, the home and smart buildings: Jane Wernick FREng, Jane Wernick Associates

The following people also participated in the study through workshops:

George Adams, Spie UK; Gary Atkinson, ARM; Dr Claire Barlow, Institute of Manufacturing; Pilgrim Beart, AlertMe; Andrew Bentley, Worcester, Bosch Group; Dr Katie Beverley, University of Huddersfield; Alex Bone, Alex Bone; David Bisset, iTechnic Ltd; Thomas Blower, Dyson; Lauren Bowker, PHNX; Dr Jos Boys, Northumbria University; Nigel Catlow, GfK; Naomi Climer, Sony Professional Solutions Europe; Paddy Conaghan, Hoare Lea; Sebastian Conran, Sebastian Conran associates; Sarah Coop, Artichoke; Philip Delamore, London College of Fashion; Anne Dye, Royal Institute of British Architects; Fraser Edwards, Cambridge Consultants; Lise Edwards-Warrener, Burberry; Robert Hodge, 3DS; Professor Susanne Kuechler, University College London; Jermaine Legg, Samsung Electronics Europe; Nick Massey, Boxclever; Professor Joe McGeehan FREng, University of Bristol; Robert McNamara, Intellect; Thomas Møller Jensen, æsir Copenhagen; Dr James Moultrie, University of Cambridge; Malcolm Morgan, University of Cambridge; Dr. Craig Murphy, NPL; Robin Nicholson, Edward Cullinan Architects; Niamh O'Conner, XOStudio; Paula Owens, Paula Owen Consulting; Claire Pajaczkowska, Royal College of Art; Victoria Pearson, Which?; Mark Pedley, Smartlife; George Pegasiou, Howdens Joinery Co.; Ashley Pocock, EDF Energy; Oliver Poyntz, Oliver Poyntz; Professor Simon Saunders, Real Wireless; Crispin Semmens, ARM; Malcolm Smith, ARUP; Professor Dale Southerton, University of Manchester; Jasper Startup, Startup Designs; Pamela Stathaki, Dyson; Dr Scott Steedman CBE FREng, The British Standards Institution; Katie Steiness, The Ellen MacArthur Foundation; Louis Stephen, Worcester, Bosch Group; Lynne Sullivan, sustainableBYdesign; Lynn Tandler, Lynn Tandler Textile Design; Nick Taylor, Smart Meter Programme DEFRA; Nancy Tilbury, Northumbria University; Caroline Till, Central Saint Martins; David Tonge, The Division; Anne Toomey, Northumbria University; Bob Towse, Building & Engineering Services Association; Diego Trujillo, Royal College of Art; Gareth Turpin, Institution of Engineering and Technology; Dominic Vergine, ARM; Simon Vaitkevicius, Nokia; Johan Vyncke, Belgian Building Research Institute (WTCB); Philippa Wagner, Philippa Wagner Consultancy; Professor Judy Wajcman, London School of Economics; Elanor Warwick, Technology Strategy Board; Martin Wickham, NPL; Professor Robin Williams, Research Centre for Social Sciences, University of Edinburgh; Adrian Wilson, Smart Textiles and Nanotechnology; Nathan Wrench, Cambridge Consultants; Jeonghwa Yi, University of Cambridge

Academy staff:

Dr Natasha McCarthy

Dr Frances Downey

Philippa Shelton

Terms of reference for study

- To consider the current social and environmental impact of creating, using and discarding goods found within the domestic environment (the house and its contents).
- To ask whether the way we create, use and discard goods within the future domestic environment can be made more sustainable than it currently is.
- To make recommendations for individuals, government, industry and the engineering design profession:
  - for minimising the future social and environmental impact of creating, using and discarding the things found within the domestic environment,
  - to capitalise from changes to the way the things within the domestic environment are created, used and discarded.

Roundtable meetings were held covering each of these topics.

Questions for each meeting

- How are things made, used and disposed of currently?
- What are the future ways to make, use and dispose of things? What aspects of these processes can be made more sustainable?
- What barriers are there to creating a more sustainable domestic environment? (the rebound effect, lifetime carbon emissions, practicality)
- Can we overcome these barriers and create a more sustainable future for our domestic environments? Who needs to be influenced? (behavioural change, different business models, greater collaboration between designers and engineers)

The discussions at each roundtable formed the basis of this report which was then discussed and refined by the working group.
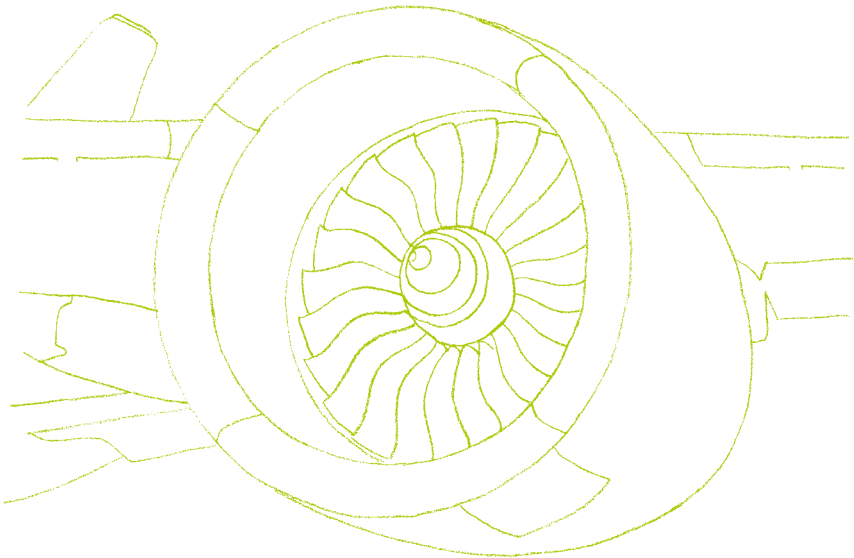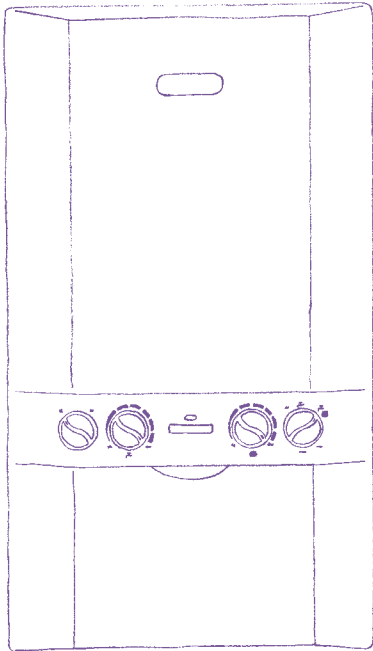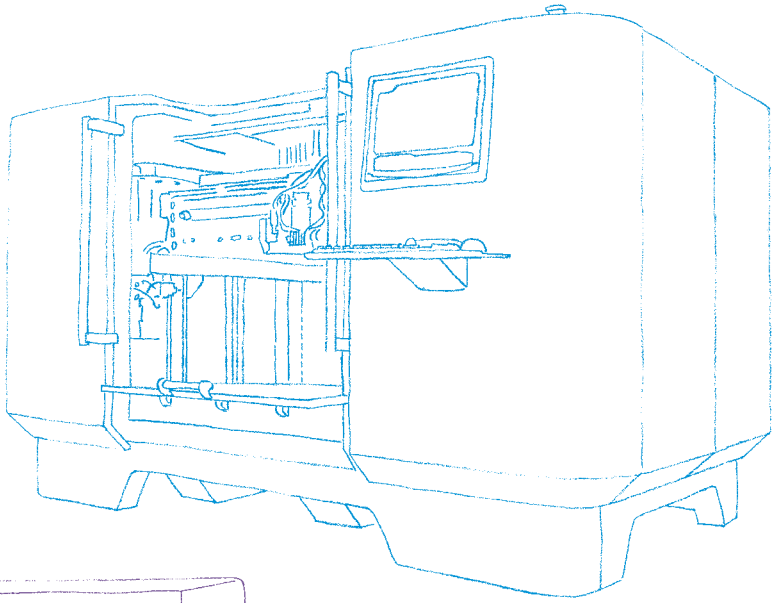
Royal Academy of Engineering

As the UK's national academy for engineering, we bring together the most successful and talented engineers for a shared purpose: to advance and promote excellence in engineering.

We provide analysis and policy support to promote the UK's role as a great place to do business. We take a lead on engineering education and we invest in the UK's world-class research base to underpin innovation. We work to improve public awareness and understanding of engineering. We are a national academy with a global outlook.

We have four strategic challenges:

Drive faster and more balanced economic growth

Foster better education and skills

Lead the profession

Promote engineering at the heart of society