Government
Office for Science

From waste to resource productivity

Evidence and case studies

Report of the **Government Chief Scientific Adviser:** From waste to resource productivity. Evidence and Case Studies

This volume comprises chapters which form the evidence for the Government Chief Scientific Adviser's Report: From waste to resource productivity, together with illustrative case studies. It should be cited as: Report of the Government Chief Scientific Adviser: From waste to productivity. Evidence and Case Studies.

The Government Office for Science would like to thank the authors who contributed evidence chapters, case studies and their time towards this report and gave it freely.

This report is intended for: Policymakers, regulators, local authorities and a wide range of business people, professionals, researchers and other individuals with an interest in exploiting the potential to unlock productivity by moving from creating waste to valuing resources.

This report consists of: Contributions received from academia and industry and others outside of government. The report is not a statement of government policy, and aspects of third-party commentary contained within it are not consistent with existing, or planned changes to policy. The views expressed do not represent policy of any government or organisation.

This report is presented in two parts: The first is the summary report of the Government Chief Scientific Adviser. This was developed as a result of seminars and the advice of the experts who provided the source of the evidence. The second part, the evidence, has been gathered from and written by a distinguished group of experts. The evidence takes two forms: chapters that consider a major aspect of the waste and resource productivity landscape; and individual case studies that illuminate points of detail and principle. The evidence section provides the views of the experts themselves, who met on several occasions during the preparation of the report and had the opportunity to help to develop the narrative and to comment on each other's contributions. Sir Mark Walport and Professor Ian Boyd are responsible and accountable for the summary report, and the experts for their individual contributions to the evidence papers and case studies. Neither should be blamed for the sins and omissions of the other!

Foreword

In this report of the Government Chief Scientific Adviser, we explore waste through the lens of science. That includes attempting to understand the nature of waste (its material contents, quantity and environmental consequences) and how we as individuals, societies and economies interact with and expend the resources of the planet.

We chose waste and resource productivity as the topic for this report for four main reasons. The most important of these is that waste is actually an enormous opportunity. Much of it is a potential resource that can be recovered and reused in a huge number of different ways. Secondly, in a country with a small land area and a large population, the sheer quantity of waste we produce is a significant and growing problem. Thirdly, some waste is harmful, and the scale of that harm has become global. Our final motivation for unpicking the area of waste is that it presents an especially complex social and political challenge. Waste is a classic example of an externality: it has economic and other consequences for people who did not generate the waste in the first place, and over which they have no control.

In producing the report, we have drawn on the knowledge of a range of experts and interested parties – in academia, industry, trade associations and elsewhere. They have provided a clear evidence base in relation to each of the four reasons that led us to consider waste and resource productivity. This volume presents that body of evidence, as well as illustrative case studies. The chapters and case studies represent the authors' personal views rather than those of Government or ourselves as scientific advisers, but their insights – for which we are greatly indebted – have fundamentally informed the messages and questions raised in our report.

Mark Walport

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SECTION: 1

Introduction

We need to move from creating waste to valuing resources. This section examines what we mean by waste, how we measure waste and the innovations that are disrupting and transforming the way we use products and services. This presents us with an opportunity to decouple economic growth from environmental impacts and improve both our economy and environment in ways that previous generations could not.

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In Brief

20%

Courtauld commitment: food waste reduction

300 million tonnes

Annual global plastics production

42

The number of elements in a microchip

120 million tonnes

Annual plastic to landfill

CHAPTER 1:
What is waste?

All societies produce waste, though its characteristics and what happens to it depend on cultural, economic and political factors at local, national and global scales. New business models, technological innovations and social enterprise have the potential to reduce waste. Policymakers have a key role to play in supporting these efforts by fostering better communication between stakeholders; through regulation that prioritises reuse and quality recycling; and by encouraging resource efficiency through education, research and manufacturing initiatives.

Nicky Gregson and Catherine Alexander, Durham University

Waste is an unavoidable outcome of all human activity, and a world without waste is impossible. Furthermore, the transition to global, dense and urban living has increased waste output and complicated our understanding of waste and its management.

This has implications. While reuse, recycling and resource recovery can delay when materials or objects become waste, there comes a point when limits are reached. The value in most stuff is eventually exhausted, be that materially or financially. There is no infinite materials loop, where all waste becomes resource. In other cases, the monetary or energy cost of transforming a given material ceases to make financial sense.

Yet, because waste is produced by human activity, there are choices. What becomes waste is not inevitable, nor will the volume of material classified as waste necessarily continue to rise. Rather, precisely because it is societies, cultures and economies that make wastes, we can change what we do to be less wasteful: in other words, to be more resource efficient. To do this requires everything from thinking about the kind of political economy we want, recognising we cannot avoid being part of a global material economy, to technical and legal decisions about collection technologies and commercial regulation. Our choices are therefore political, economic and structural; consumer 'choice' is minimal compared with these. Further, an over-emphasis on thinking about closed systems, resource efficiency and waste can mask harder political choices such as feeding hungry people with surplus food rather than turning it into energy feedstock, biofuel and fertiliser. To understand these choices we first need to understand waste. This chapter is grounded on evidence from research across the social and human sciences into the role of waste in contemporary lives.

Waste making

All human societies produce waste, irrespective of time and place, from prehistoric middens to the nuclear wastes of the developed world, such as those currently stored in the UK at Sellafield and elsewhere. The study of wastes discloses much about societies past and present. Analysing what, where, how and why a society wastes reveals how it functions[1–3].

Archaeology provides compelling evidence that the past was no waste-free nirvana, and shows that to waste is part of being human[4, 5]. Anthropology gave us the insight that culturally-specific systems, determining what is valued and what needs to be expelled, are key to the ordering of all societies[6].

Additionally, the archaeology of the near and far past reveals the changing composition and volume of waste[7]. Thus we have moved from flint axe chippings, though the giant urban dust heaps of the Victorian age, to the oil-dependent age of plastic (see Fig. 1).

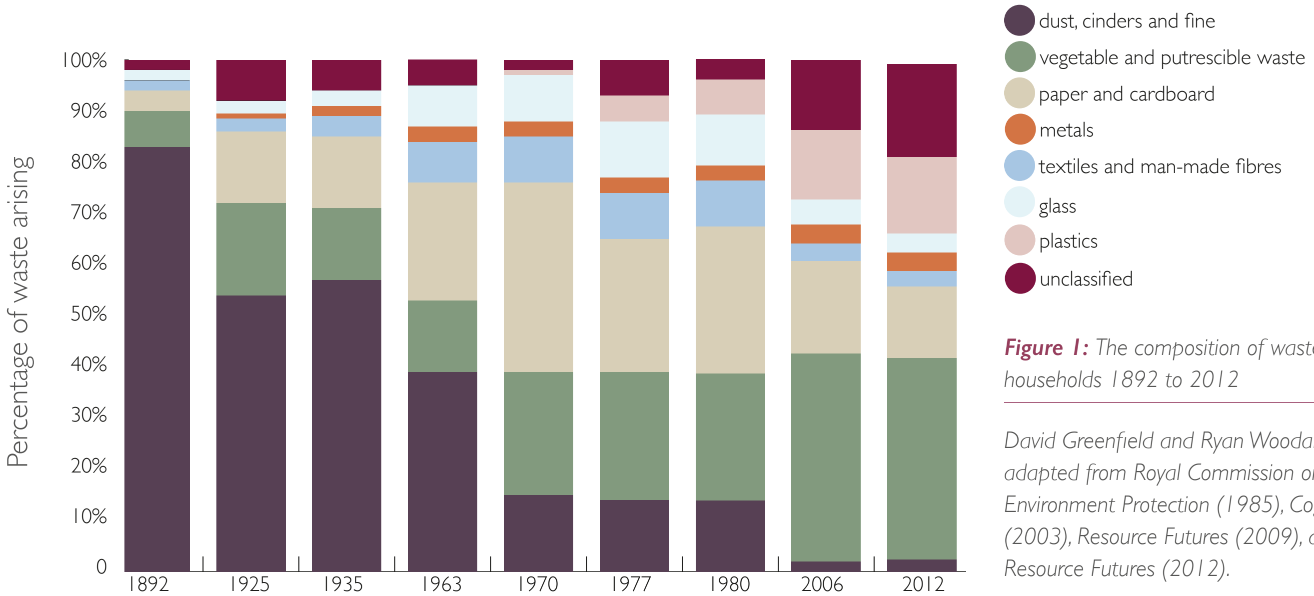


Figure 1: *The composition of waste from households 1892 to 2012*

David Greenfield and Ryan Woodard: adapted from Royal Commission on Environment Protection (1985), Coggins (2003), Resource Futures (2009), and Resource Futures (2012).

Technological and political economy changes can also be read through waste (and used to explain amount and type). Urbanisation, mass-industrial production and consumption all increased the quantity and changed the types of waste, whilst the in-built dependency of capitalism on constant expansion has contributed to increasing disposability – and yet more waste.

In economics, waste is seen as a 'negative externality', a cost that can be externalised and borne by a third party or the environment. Other areas of the social sciences have shown that waste is a key means through which societies are ordered and organised socially, while wastes are also traded and repurposed.

Key findings from these fields are detailed below.

1. 'Waste' is often a symbolic classification.
In complex, modern societies, waste is usually seen as socially contaminating. In strongly hierarchical societies, working with waste is seen as a low status occupation[8, 9]. Even in less formally hierarchical societies, such as the UK, the stigma of waste work, along with its tendency to be dirty, dangerous and demeaning, means that it is performed by unskilled and often migrant labour, from within the EU and beyond[10]. By the same token, proximity to waste is socially contaminating. Places that store, treat or dispose of waste are thus typically on the edge of homes[11] and conurbations alike, in the latter case co-located with more deprived areas. Nationally and globally, the pattern repeats itself: areas of greater socio-economic deprivation often have either concentrations of landfills and incinerators, or host recycling plants and the potentially dangerous work of disassembly. In the US, environmental justice research has long made the connection between waste management facilities and predominantly black and Latino neighbourhoods[12-14]. The socio-spatial process of distancing wastes also operates globally, and the dumping of toxic wastes generated by the developed world's industries on to developing nations (toxic colonialism) continues to be a concern, notwithstanding the United Nations' Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal[15, 16].

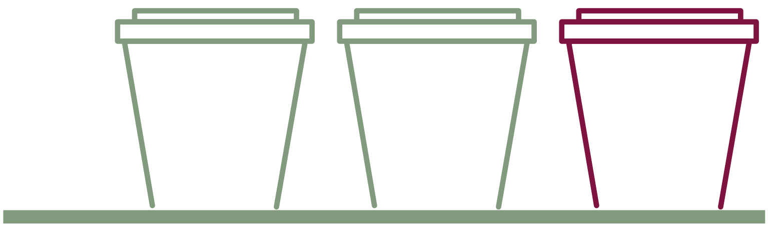
2. Waste creation is shaped by social factors.
Waste is generated as an inevitable part of daily consumption in households. This is clearest with respect to food waste in modern western contexts, where patterns of living, working, shopping and cooking intersect with concerns about food safety and risk (see Chapter 9)[17,18]. Those concerns are at their most acute for parents, and they result in the diversion of large quantities of what might still be edible food to the bin. Large volumes of bulky waste appear at crucial social moments such as death, divorce or separation, children leaving (and returning) home, and moving house[19]. In each case, people are confronted with large accumulations of goods and materials, which need to be dealt with quickly. Often, the easiest way to do this is to throw them away.

3. 'Waste' is not simply the opposite of 'value'.
Many goods and materials in households are in limbo (in attics, cupboards, garden sheds and garages), being stored for future generations or new circumstances[19]. Goods, particularly children's toys and clothes, also circulate between households, often as gifts[20,21]. The rise of digital platforms for second-hand exchange, most notably eBay, but also Gumtree, Freecycle and PreLoved in the UK, has led to household goods being seen by some as stocks with a latent financial value[22], much as pawn shops operate. While these developments are not primarily motivated by a wish to prevent or delay goods being thrown away, the effect is of waste prevention. At the same time, the category 'rubbish value' is important to waste generation[23]. Categorising something as 'rubbish', or of no worth, often has the effect of leading to it being discarded, dumped or abandoned. For example, poor-quality manufactured goods, including clothing, small appliances and self-assembly furniture, are often thrown away because they are seen to be 'rubbish things'[19,21].

4. Waste generation has been shaped by mass production and consumption.
The post-World War 2 economies of the developed world have all been based on mass production and consumption, and a corresponding emphasis on ever-cheaper goods. They have also been linear economies: take, make, use, dispose. These trends, combined with increasing urbanisation, have led to the development of industrial-scale waste management technologies and infrastructures. Waste's relation to consumption is complex. Major festivals (eg Christmas, Eid al-Fitr) are marked by significant conspicuous consumption and large volumes of waste: excess food, unwanted gifts and packaging[24,25]. Making waste is an inevitable by-product of these important cultural and social activities: the demonstration of abundance is part of what makes them festivals. The relationships between different kinds of waste and consumption are also strongly linked to socio-economic differences, particularly class and income inequalities. For example, many low-income households in the UK are only able to afford cheap, poorly made goods that rapidly fall apart.

5. Waste economies are flourishing.
The conventional view from economics is that waste and by-products have no value and therefore impose only a production cost. But things and materials declared to be waste are often repurposed as tradeable resources, goods and products. A change in context can also unlock the latent value in waste, and there are good examples of this in the history of chemistry. Polluting coal tar wastes from the industrial revolution in England were dumped in rivers until it was (accidentally) discovered that they could be used to produce synthetic dyes[26]. More recently, the trade in e-waste from North America and Europe to China[27] shows how different labour and manufacturing environments combine to allow discarded mobile phones and computers to be repurposed[28,29]. But this also raises ethical questions. Recycling e-waste can be hazardous[30,31], and it is cheaper for this to be undertaken in countries with less stringent (or no) labour, health and safety restrictions.

These examples demonstrate that some post-production and post-consumer wastes can, with treatment, become the raw materials (or resources) for other processes.



Waste is an **unavoidable** outcome of all human activity

This can happen at different scales: within a single industrial plant, where some wastes can be fed back in to the process; or in towns and cities, such as in Kalundborg in Denmark, where a power plant's by-products are all used locally by different industries and domestic heating systems in a tight-knit industrial symbiosis network[32] (which, echoing coal tar discoveries, arose by chance rather than design). More recent instances of planned Chinese eco-cities aim to move waste materials to where they can become resources within a city or industry (see Chapter 11)[33, 34]. This links to a related set of ideas, including industrial ecology, the circular economy (see Box) and 'zero waste'.

There have been many critiques of industrial ecology and circular economy thinking in the social sciences. They emphasise that a transition to a circular economy is not straightforward[37-40]. For the idea of the circular economy to become reality, a fundamental transformation in how products are designed, made, owned and consumed is needed. Further, an underpinning principle of these ideas is that if only the correct context can be found, and wastes moved there, that 'waste' becomes 'resource' and the problem effectively vanishes. However, not only are there inherent limitations to how often materials can be recycled effectively and efficiently, but the cost of collection and transportation needs to be added into the equation. Recovery costs may outweigh material benefit, as in the case of rare-earth metal recycling from e-waste (see Chapter 7).[41-43]

6. Legislative waste classifications and regulations have unintended consequences.

During the Industrial Revolution, when wastes were dumped into the open environment (eg watercourses, commons, open ground and the sea), the process of turning wastes into resources was relatively easy to achieve. Dumped wastes created high levels of pollution but they were open for anyone to scavenge, take elsewhere, salvage and experiment with. This is the situation in many parts of the developing world today, linked to high levels of inequality and endemic poverty[44]. The environmental and health consequences of dirty, messy, and dangerous waste-based innovation are not to be under-estimated. In response, environmental legislation in the developed world aimed to ensure safe management of wastes; and that this happens close to where they are generated (the 'proximity' and 'polluter pays' principles), in order to minimise environmental impact and transport cost.

One effect of this legislation is that many waste trades have been driven underground. For example, wastes destined for export are often declared as second-hand or used goods to avoid duties[38, 45]. Another consequence of the polluter pays principle is that the possibility for resource recovery can be constrained by the proprietary regime that generates them. Waste materials may be stockpiled, or put into deep storage (as has historically been the case in the UK steel industry). Alternatively, to offset disposal costs,

The circular economy

The economies of developed countries have long run on a linear model of consumption: extract, make, use, dispose. The circular economy offers an alternative approach, and although the term is used in different ways, at its heart is the general principle that economic activity can be reworked on ecological lines, by closing material loops[35]. In a circular economy, wastes are seen as resources for other processes; remanufacturing, reuse and recycling ensure that materials and products continue to circulate in the economy. They also promote resource efficiency, by maximising the value extracted from resources. Circular economy thinking has been widely promoted as an opportunity for growth, as a means to reduce (or eliminate) waste, to counter resource scarcity and insecurity, and as a pathway to enhanced resource productivity. Estimates of the potential value to the EU of shifting to a circular economy by McKinsey & Company, in collaboration with the Ellen MacArthur Foundation, were key to the establishment of the EU's Circular Economy programme[36]. In the UK, the Department for Environment, Food and Rural Affairs (Defra) has estimated that UK business could benefit by £23 billion per year through low-cost or no-cost improvements in resource efficiency.

wastes may be contracted to the organisation that can make the most of them financially, rather than organisations that might create social value.

7. Protocols are required to (re)classify waste materials as potential commodities.

As we have seen, the proximity principle inhibits the movement of material classified as waste. By contrast, commodities need to be mobile and tradable. Turning waste into commodities therefore needs a process of reclassification[40]. Typically this involves quality protocols, which apply to both processing and treatment technologies and the output(s) of those technologies. For example, the UK has invested considerable efforts in developing national quality standards for materials recovered from waste, such as bio-fertiliser. Nevertheless, the response to these standards from business has been lukewarm and the market has not yet taken off. This is particularly the case where waste materials intersect with renewable energy markets[46]. In the anaerobic digestion (AD) sector in 2012, for example, revenue from feed-in tariffs and Renewable Obligation Certificates was seen by many commercial operators as more important than gaining product certification standards for bio-fertiliser[40].

Protocols for materials recovered from wastes are new market devices. They are important for the future development of secondary resource markets, but trust is required for protocols to be accepted and used. Trust is particularly important when manufacturers are faced with a choice between primary raw materials (and the well-established global supply chains that guarantee their quality and purity), and materials recovered from wastes via new or unproven markets. The UK could potentially lead in this area, by furthering passport systems that offer appraisals of the materials content of complex wastes such as ships and buildings scheduled for demolition. These passports are currently provided retrospectively using survey techniques[47], and the UK has played a key role in their development. However, point of manufacture or assembly passports (and repair updates) on manufactured goods would give even more confidence for both the recycling industry and potential purchasers of recovered materials.

8. The wastes of the developed world are secondary resources for China and many developing countries.

This is perhaps the most significant finding of recent social science research on waste. It has shifted attention on wastes from a national context to the international and global scale, and opened-up the study of the trade in wastes.

Global trades in wastes

Waste economies are global. It is essential to understand this in order to counter unrealistic expectations that waste economies can be national; and to tackle questions of waste's relation to resource efficiency.

The international trade in waste, used goods destined for dismantling, and recovered materials, is huge (see Chapter 14)[48]. Trade ranges from illegal trades in toxic wastes to non-hazardous waste streams such as scrap metal, plastics, paper and textiles. China plays a pivotal role, both as destination and intermediary[27], in the markets for recovered materials[49]. In addition, the international trade in wastes is mostly from developed countries to developing countries, and then further cascades between developing countries (see Fig. 2).

Transnational recycling networks play a vital role in the global economy. In global recycling networks, sizeable numbers of buyers and traders, particularly from China, scour the developed world sourcing scrap goods and materials (eg metals, plastics, e-scrap and paper), taking advantage of the cost economies of the 'back run' of global shipping to export these materials to the manufacturing heartlands of the global economy: China, and other parts of south and south-east Asia[29, 50].

Enhanced recycling in the UK depends on improving the **quality** of materials recovered

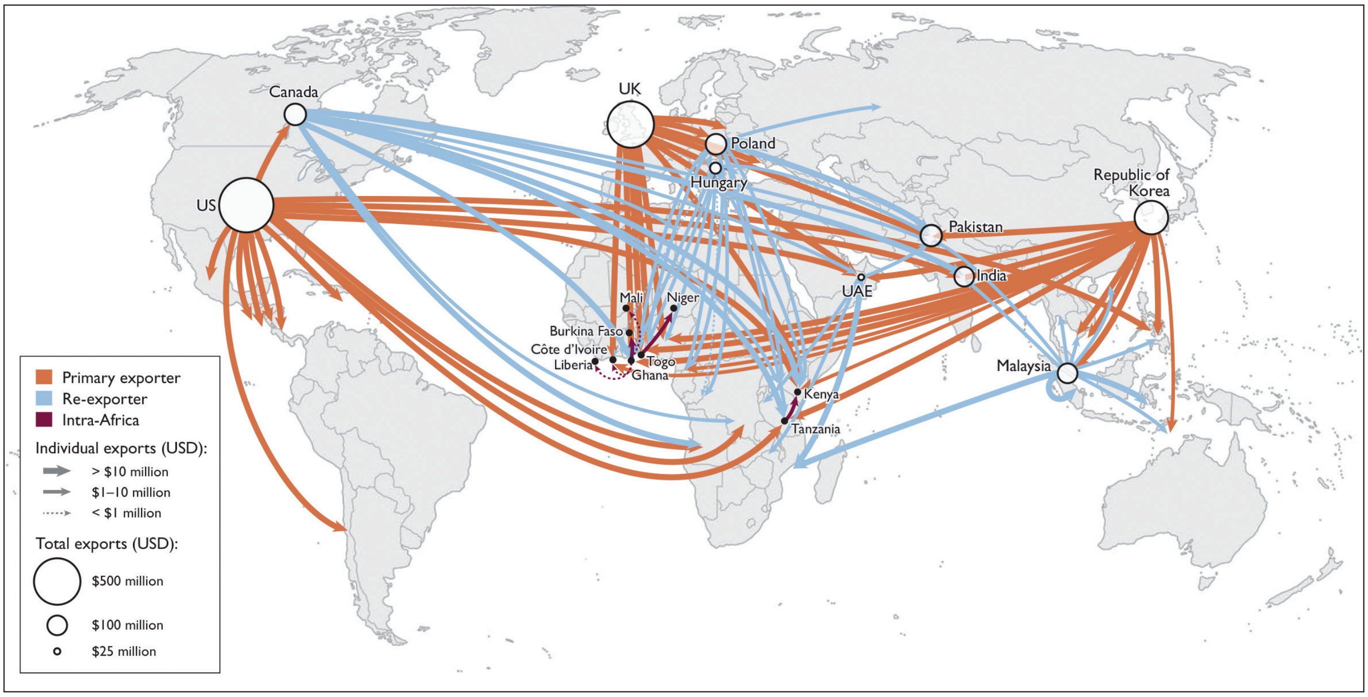


Figure 2: *Illustrative global flows of used clothing, showing how material cascades through different countries and markets. It first selects the largest exporters in each of the Americas, Europe and Asia, and the 15 largest markets for them (above $5 million). It then illustrates further flows by selecting the next two largest re-exporters and their ten largest markets (above $3 million); and finally illustrates a third level of the cascade of materials in Africa (above $500,000). All flows are denominated in US dollars (USD) and taken from UN official Comtrade data for 2014, the last year available (SITC category 6309)[48].*

Waste economies upend conventional ideas about globalisation, in which cheap goods, manufactured in new and emerging Asian markets, are shipped to the developed world for their consumption. Instead, the developed world's wastes are the resource base for many emerging economies[38], providing cheap, accessible alternatives to primary resources mined by major conglomerates (see Chapter 7). Further, the use of secondary resources is aided by abundant cheap labour in developing countries which bear the often dangerous costs of collection, sorting and (pre)treatment. There are indications that China is also becoming a source country in global recycling networks, but this time for African traders. Once imported to destinations in Africa, scrap goods and materials either enter second-hand markets (as, for example, with the used-clothing markets of Ghana or Uganda, where they form the basis for entry-level, often female, entrepreneurship[51–53]); or they are dismantled, treated and reprocessed prior to entering new manufacturing chains, producing 'new' goods for both domestic and international markets.

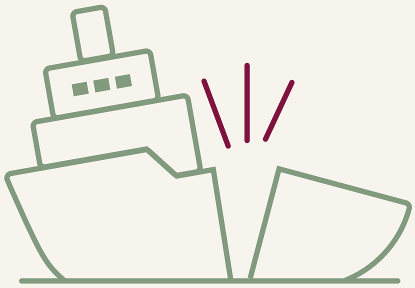
Support for such entrepreneurship is strong in the development sector. Oxfam's Frip Ethique social enterprise project in Senegal, for example, largely involves women sorting and selling clothes donated to Oxfam in the UK to local traders. Legitimate concerns remain about the appalling labour conditions and environmental costs that often accompany recycling in the developing world. Additionally, cheap imports of often undeclared or falsely declared waste goods can adversely affect domestic manufacturing in developing countries[54].

The global nature of waste is particularly apparent in ship breaking (see case study on p15). It shows that goods classified as wastes comprise the source for secondary resources for developing countries; demonstrates the importance of these wastes for some of these countries; and highlights the challenges that have faced recent efforts to rebuild ship recycling in the UK. A key lesson from this case study is that resource efficiency occurs at the global scale, and that efforts to intervene nationally in this area must acknowledge both international trades in wastes and used goods, and the nature of the UK's manufacturing base.

Demand for scrap within the UK steel industry, for example, is low given the long-term decline in UK steel manufacture and rise in steel manufacture in other parts of the world, particularly China. Further, recovered scrap contains high levels of contamination. Such materials are not of interest to UK

Case Study

Ship breaking in international perspective



Nicky Gregson, Durham University

Ship breaking in developing countries has long been a poster child for environmental and labour justice campaigners[55]. Images of vessels being broken up on beaches by armies of ant-like workers, many of them children, wielding blow torches and hammers and working without protective clothing have proved particularly powerful in exposing ship breaking as an example of the dark underbelly of globalisation, while parallel images of oily wastes contaminating the beaches and coasts of India and Bangladesh have testified to the environmental degradation being wrought by this industry.

The question of why vessels had ended up on these beaches in the first place has been less considered in NGO accounts of toxic ships, toxic wastes, endangered workers and polluted environments. Research has shown that, while the industry undoubtedly has had deleterious effects, its value to developing countries' economies lies in the materials and goods that it releases: toxic waste ships are a good source of secondary resources. This is why Bangladeshi and Indian ship breakers will pay good money to brokers and traders who buy old merchant vessels being offered for sale in the shipping demolition market. In the case of Bangladesh, studies have shown that the industry has played a key role as a source for scrap steel for secondary steel production (re-bar, for the most part – see Chapter 7), as well as for reconditioned marine engineering goods, capital goods for the domestic textile industry, and goods for furniture re-manufacturing[56,57]. The principles of industrial symbiosis are clearly observable in relation to this industry, albeit enacted in dirty and dangerous conditions.

NGO ship breaking campaigns have often targeted easily identifiable naval vessels traceable to countries in the developed world. A direct effect of exposés has been regulation that has sought to implement ship recycling policy and facilities to recycle the developed world's naval vessels, most notably in the US, France and the UK. The UK was in the vanguard here, through the development of the UK Ship Recycling Strategy in 2007 (ref. 47). Following this, some of the UK's stockpile of decommissioned naval vessels was broken up in newly-established facilities in different post-industrial areas of the UK. However, the vast majority were sold to a breaking yard in Turkey. Cheaper labour, cheaper costs of waste management and a high demand for scrap steel in Turkey, plus its membership of the Organisation for Economic Co-operation and Development (OECD), meant that the UK government could secure higher financial returns for its vessels from this yard than from competitor businesses based in Northern Europe, including the UK. So, while policy created the conditions for environmentally sound and safe ship recycling to be re-established in the UK, subsequent events have shown this industry to be transitory, and for largely economic reasons.

A key lesson from the UK experience is that the ship breaking business is much more profitable when it is located outside Europe, where there is demand from manufacturers for the materials it generates and where the costs of waste management and labour are lower than they are in Europe. Recycling businesses located in the UK struggle to compete in the small market for UK naval vessels, let alone in a merchant shipping demolition market that is global. That said, there are alternatives to the 'race to the bottom', in which labour costs are minimised at the same time as externalising environmental costs as pollution. In the EU, for example, the policy emphasis is on driving up global standards through yard accreditation, with the important caveat that beach-based yards cannot be accredited. What that means for Indian and Bangladeshi ship breaking, which provides roughly 80% of global capacity, remains to be seen. In the meantime, it is China that is endeavouring to capture the market in more environmentally-compliant ship recycling.

manufacturers concentrating on high-end, speciality steels used in precision and high-value products. Instead, recovered scrap is mostly sold into international markets, particularly those producing large volumes of low grade re-bar for the construction industry (see Chapter 8). If the intent is to increase resource efficiency within the boundaries of the UK, it makes little sense to recover materials for which there is minimal or no demand from UK manufacturers.
Instead, UK recycling policy needs to start with the realities of the UK economy, considering the demands of its manufacturers in terms of their materials inputs: the quality and grades used in the manufacturing process, their acceptance criteria, and supply requirements.

The UK's waste in a European context

The UK's waste – and its waste economy – have also been framed by the regulatory context of the EU. This framing is essential to understanding UK waste, and remains so in the immediate post-Brexit context.

Since the 1990s, European waste policy has intervened to tackle wastes generated by the linear economies of member states. It has sought to reduce the amount of material destined for landfill and to keep the wastes generated by the EU within its borders. The chief instruments of these policies are the 'waste hierarchy' and the Waste Framework Directive. The waste hierarchy positions prevention, reduction and reuse ahead of recycling, and sees energy recovery from wastes as the least desirable option but ahead of disposal in landfills (see Fig. 3).

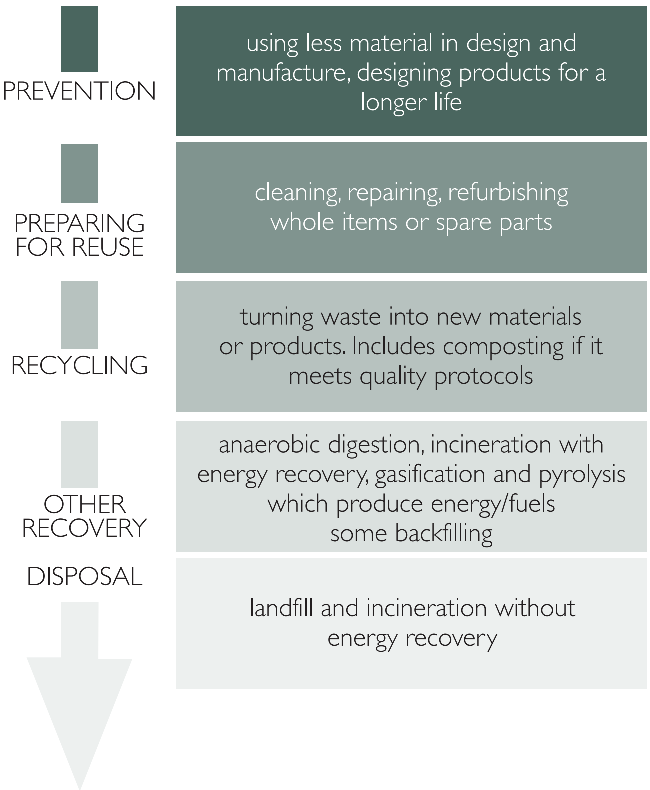


Figure 3: *The waste hierarchy aims to classify waste management options based on their sustainability.*

European Commission

In the UK, the Landfill Tax was a particularly effective driver in diverting waste materials from landfill (see Chapter 13). However, reducing the amount of waste material going to landfill meant diverting waste materials into different routes, higher up the waste hierarchy. Wastes, therefore, had to be considered not as wastes, but as potential secondary resources for manufacturing and energy generation.

There are tensions between interventions at different levels in the waste hierarchy. Interventions at one level affect possibilities at another. Nor are interventions nationally bounded: the policy choices of each EU member state can have effects on other member states. One illustration of these tensions and connections, at the lower end of the hierarchy, involves refuse-derived fuel (RDF) that is supplied to the energy-from-waste (EfW) sector. RDF is derived from municipal solid waste, and it has attracted a degree of controversy in the UK. Detractors argue that although RDF diverts material from landfill, it also undermines options higher up the hierarchy by pushing more waste into the energy-recovery market. The argument is that resources that could be recovered for recycling are being lost through RDF. Equally significant is the development of an EU RDF market, and the UK's role in this as an important exporter. This is, in turn, linked to the strong reliance on EfW in parts of continental Europe; to the influence of the UK's Landfill Tax; and to differences in recycling between the UK and continental Europe (see case study on p18 for further details).

National-level responses to EU waste policy can also create tensions. Different member states are locked into particular waste collection, treatment and processing solutions, and the UK is no exception. Following the introduction of the Landfill Tax, the policy focus has been dominated by municipal waste (see Chapter

We must **recognise** that it has not yet been proven that waste can be decoupled from **economic growth**

4), even though it is only 7% to 9% of the total waste stream (the largest waste streams are from the construction/demolition sectors, agriculture and industry). The easiest route for landfill avoidance is incineration, as practised in Sweden, the Netherlands and Denmark (see case study on p18). In the UK, however, public opposition to incineration led to the rapid development of municipal waste collection systems designed to recover material for recycling.

The key effects[40] of this policy focus are that:

- the UK waste business has increasingly recast itself as a resource recovery business, and people now think in terms of recycling, as well as rubbish.
- the UK has a municipal waste collection infrastructure that is fragmented and inconsistent between local authorities, many of whom rely on 'co-mingled' collection systems. These systems are not source-segregated ie they collect non-segregated streams of 'dry recyclables' (paper, card, plastics and glass) from households. Although they are cheap to implement, co-mingled collection systems are controversial at EU level and open to question in terms of the quality of material they recover for recycling.
- the rapid development of materials recovery facilities (MRFs) across the UK. These MRFs produce large volumes of recovered materials of relatively low grade for recycling. This is a consequence of specific collection systems; the grades and classification systems used within MRF processing plants; and contracts that favour quantity of material processed over quality. As a result, there is a considerable reliance on global export markets for recovered materials (accounting for nearly 40% of UK MRF output).
- the reliance of the UK's waste infrastructure – much of it funded through private finance initiatives (PFIs) – on the continued generation of more (not less) waste. Contracted income streams are predicated on throughput, so plants require quantity to remain financially viable.
- while major gains have been made in diverting materials from landfill, enhanced recycling has not eliminated the need for disposal options. Typically, 3% to 5% of MRF input is destined for landfill.

Recovering materials from wastes for recycling is an approach to resource efficiency that aims to maximise the utility in a given unit of material. While some materials (eg many metals) can be recycled indefinitely, there are limits on the number of times other materials, such as fibre-based matter (eg paper and textiles), can be reprocessed[62]. Technical limits are compounded by the costs of processing, which can make products derived from secondary resources less financially competitive than primary alternatives. In contrast, interventions designed to prevent waste focus on the utility of existing goods as a way to improve resource efficiency. What matters here is the continued use or preservation of resources in the form of particular goods, often through a combination of maintenance, repair and exchange in second-hand markets such as eBay, Gumtree and Freecycle, as well as car boot sales, charity shops and nearly-new sales[63].

Recently, EU policy emphasis has shifted up the waste hierarchy to waste prevention, requiring that member states move in the same direction. But policy lock-in to solutions lower down the hierarchy has made this difficult to effect quickly. It has also proved challenging to set clear, quantifiable targets for waste prevention, compared to more easily-quantified interventions further down the hierarchy. Across the EU, waste prevention policy is under-developed, but in Scotland and Wales (although not in England) waste prevention has been formalised around 'zero waste' policies that are

Case Study

Refuse-derived fuel in the UK

Matt Georges, Principal Economist, The Environment Agency

Refuse-derived fuel (RDF) is defined by the UK Department for Environment, Food and Rural Affairs (Defra) as "residual waste that is subject to a contract with an end-user for use as a fuel in an energy from waste facility. The contract must include the end-user's technical specifications relating as a minimum to the calorific value, the moisture content, the form and quantity of the RDF"[58]. Some of the available data in this sector cover the whole of the UK, but as around 80–85% of total UK RDF (if not more) comes from England, this case study uses the simplifying assumption of treating all datasets as if they cover just England.

Monthly exports of RDF from England went from zero in June 2010 to just over 268,000 tonnes in April 2016. The majority of these exports were to The Netherlands, with Germany and Sweden beginning to increase in importance from mid- to late 2013 (see Fig. 4 for annual totals).

The market began in June 2010 after a regulatory decision by the Environment Agency based on the UK Plan for Shipments of Waste, which allowed the export of RDF. It has grown rapidly due to a greater demand for energy-from-waste (EfW) capacity than currently exists in England. This in turn was caused by material being shifted from landfill by the Landfill Tax (see Chapter 13) and landfill diversion targets, and the lower cost of some continental European EfW facilities. This demand has meant that it is economical to produce RDF and export it to continental Europe, provided these routes cost less than disposal in English landfills. The Landfill Tax has therefore been a key driver in diverting waste from landfill and consequently in developing the RDF export market. This is shown by the high correlation between export levels and landfill tax rates, with continental EfW facilities setting their gate fees at a level designed to just undercut English landfill as a disposal route.

The RDF export market has continued to grow despite the fact that Landfill Tax in the UK has not increased above inflation since April 2014 (ref. 59). The most likely reason for this is that the market is still adjusting to the level of the tax, which increased from £7 per tonne in

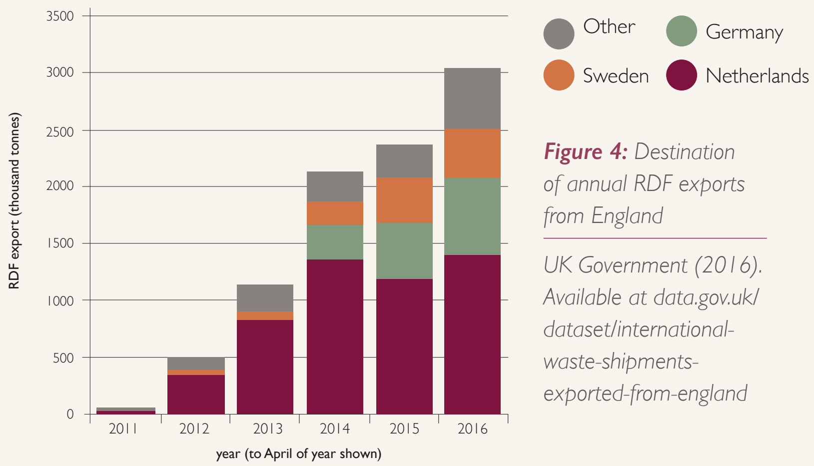


Figure 4: *Destination of annual RDF exports from England*

UK Government (2016). Available at data.gov.uk/dataset/international-waste-shipments-exported-from-england

1996 to £80 per tonne in 2014, with most of that increase occurring since 2007. For example, there is evidence from Sweden that new EfW plants are being built solely to burn imported RDF[60]. At the same time, new EfW plants are being built in the UK and in other northern European countries, leading one industry commentator to suggest that there will be too much EfW capacity in northwest Europe by 2026 (ref. 61).

The RDF export market is dynamic and complex. It is experiencing a transition from multiple closed, national markets to a single regional market. Meanwhile, policies are being implemented both to reduce demand for EfW facilities (for example, by increasing recycling rates) and to increase it (by encouraging diversion from landfills, for instance). In a situation such as this, economic theory suggests that multiple suppliers will enter the market, attracted by super-normal profits; but that as the supply-demand balance tightens, higher cost suppliers will be forced out. This 'shaking out' process may have a national dimension, as the fleet of older EfW plants in The Netherlands have lower running costs compared to newer plants in countries such as Sweden and the UK. Such a situation could lead to pressure on governments to introduce policies to restrict the trade in RDF, which would have the benefit of keeping domestic EfW facilities open but at the cost of higher prices for residual waste disposal.

allied to circular economy principles and seek to eliminate the need for landfill and incineration.

If the UK is to make interventions that significantly reduce or prevent waste, we must recognise that it has not yet been proven that waste can be decoupled from economic growth. Further, interventions in reducing or preventing waste force the political question of what kind of economy we want: constant growth or a 'steady state' economy; shareholder value or a redistributive economy; pluralist or business-led.

As with interventions lower down the waste hierarchy, there are challenges, contradictions, choices and opportunities associated with waste prevention. These differ according to the lenses and sectors highlighted in this report (see Chapters 4 to 11). We focus next on how they play out with respect to consumers, the third sector, and business.

Waste prevention in the UK

For consumers, a policy emphasis on reuse and waste reduction, rather than recycling, assumes either reduced levels of consumption and/or an increased reliance on the various second-hand markets mentioned above. However, the relatively cheap prices in second-hand markets mean that consumers often buy more than they need through these channels, so it is not a way of reducing consumption per se[64]. Goods purchased second-hand often return quickly to these markets, or are thrown away, precisely because they are seen as cheap, 'rubbish' and highly-disposable items. Reuse can turn out to be a very short pause before items are destroyed. In the UK, it is also important to recognise that second-hand consumption is profoundly inflected with class distinction. The 'chic', 'alternative' middle-class purchase of second-hand items is very different for more economically disadvantaged people where second-hand is a shameful marker of poverty, and where buying new, even if poor quality, symbolises class ascent[63, 65].

Since the 1980s, the third sector has initiated many innovative community schemes for waste recycling (kerbside collections being the best known). It continues to be in the vanguard of ways to reuse discarded objects and materials, the commonest of which are furniture, clothes and food, although there are also many specialist organisations around paint, compost, wood, bicycles, and electrical goods[66, 67]. Third sector reuse organisations typically address multiple social aims alongside waste reuse, reduction and prevention: these include reskilling, rehabilitation, and providing for people and charitable organisations in need by furnishing rooms and flats. These multiple benefits are both a strength and a weakness.

Contracts with local government or businesses are an important income stream for third sector organisations. Such contracts are vital for the survival of these organisations, which find it easier to secure capital start-up than ongoing, stable income streams. However, the accounting methods used to determine the value for money these organisations offer are currently inadequate. Contracts between local authorities and community organisations for waste prevention activities typically do not also account for the multiple benefits offered by the organisation, and may thus appear more uncompetitive than commercial offers that simply focus on addressing one service (eg furnishing council lets or collecting recyclates). If local authorities had a more flexible and accurate method of accounting for the full value offered to them, across multiple service areas, by such community organisations, the latter would be in a more competitive position to apply for the steady income stream they need and to provide an effective waste prevention service[68].

40%

Amount of UK MRF output going to global export

Case Study

Food: surplus or waste?

Catherine Alexander, Durham University

As the gate costs of landfilling organic wastes have increased, food retailers have been hunting for ways to reduce the cost of their waste. Once food can no longer be sold to the public or to staff, the range of non-landfill options are: compost or bio-fertiliser, anaerobic digestion plants, animal sanctuaries, donation to a local charity and, increasingly, food banks, highlighting links between austerity measures and waste prevention.

In all cases, the retailer loses the added brand value of the food items but when surplus edible food simply becomes a feedstock for fertiliser and/or energy, the 'food' value is also lost. Donations to charities and food banks ensure that the maximum potential value of edible food is extracted. However, the transaction costs of these options can be high. Locating local charities, overseeing the regular transference of food, and ensuring that the food is stored and prepared safely, all take time and money. The reputational risk to the retailer of donated food causing food poisoning is also considerable.

One way around these problems is to have an arrangement with a brokering organisation such as FareShare, a charity that collects food, assures food standards, and gives it to other participating charities. They prefer to call such food 'surplus' rather than waste. In addition, some large retailers such as Tesco and Asda have hosted in-store food collection points for customers to donate bought food.

There are multiple reasons for edible food becoming 'surplus' before it reaches the consumer: non-perishable foods can be mislabelled, orders can be cancelled, and retailers may simply not want to sell end-of-line runs, out-of-date promotions, or items that have damaged or incorrect packaging. In addition, surplus food results from: seasonal ordering, over-ordering, new product testing or developments, manufacturing error, insufficient shelf-life, unpredictable events such as sharp weather changes, and poor quality-control[69].

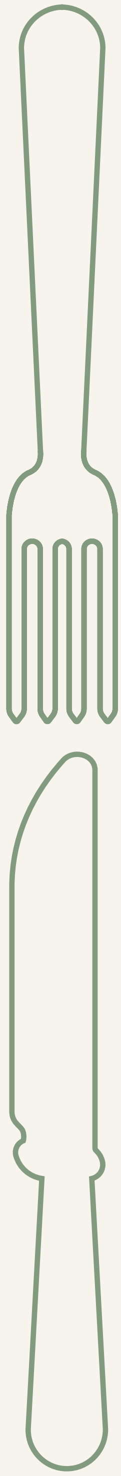
The bonus for companies such as Tesco, Asda, and Sainsbury's is in the brand value of the donation itself, which indicates corporate social responsibility. Increasingly, supermarkets are giving surplus food items directly to emergency food banks, or sending them via the Trussell Trust. With increasing numbers of people in poverty, demand for charitable food donations is growing[70-74].

Donating surplus food to those in need seems a perfect solution. In 2015 to 2016, over 9,000 tonnes of food were donated to FareShare, which passed the food on to about 1000 charities that in turn provided over 18 million meals. In the same period, the Trussell Trust reported that it gave out over 1,100,000 3-day emergency food packages.

Nonetheless, problems and tensions remain. Recipient organisations require a range of simple food items to create menus for large numbers of people. Instead, what they often get are small runs of food items – a lobster, sticky toffee pudding and instant coffee, for example – from which it can be hard to concoct and cook large scale, healthy meals. Although apps are increasingly helping to match food availability with need more effectively, edible but aesthetically imperfect food can also be rejected. Donations can be erratic in other ways. Asda, for example, suddenly withdrew its in-store donation points in 2016 to the consternation of many recipient charities. One reason given was the lack of volunteers to explain where the food was going.

Amongst retailers, tensions exist between profit maximisation, waste minimisation and brand control. Typically, retailers try to maximise the value they can extract from a food item before donation. But the higher up the food supply chain that fresh and chilled food is donated, the better quality it will be. The tension for the donor is that if objects have not yet been branded, there is less reputational risk – but they also receive correspondingly less monetary value in terms of offset disposal costs. Retail donors may also opt for the financial benefits and simpler logistics of contracting food waste to anaerobic digestion or bio-fertiliser plants as a feedstock for 'green energy'.

Ultimately, donation does not entirely prevent food waste; it displaces it from retailers' accounts to those of recipients. Although much is eaten, there may be some preparation waste and

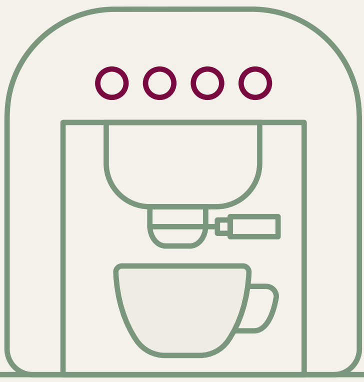


discarded items, while uneaten food and scraps are thrown away.

The UK's Courtauld Commitment is a voluntary agreement that aims to bring together all sectors involved in food and drink production to increase sustainability. Signatories to the commitment's most recent version, stretching to 2025, have pledged to reduce food waste by 20% over the next decade, principally through diversions outlined above. The UN Sustainable Development Goal 12.3, however, is to reduce food waste by 50%. Rather than relying on goodwill, in 2015 the French National Assembly banned supermarkets from throwing away or destroying unsold food. Supermarkets with a footprint exceeding 400 square metres will be fined if they have not signed donation contracts with charities. A combination of such a clear policy stance in the UK, together with revised regulations on property obligations for food items, would substantially eradicate food waste and increase steady supplies to those in need.

20%

Courtauld commitment: food waste reduction



9,000 tonnes

Amount of food donated to Fareshare 2015-16

Waste prevention has to make financial sense for businesses to take it up. Successes include the leasing of aircraft engines by Rolls Royce (see Chapter 3); closed-loop bottling by food and drink manufacturers, through 'bring back' or return schemes; and the repair of capital-intensive goods by firms such as Caterpillar, which makes construction and mining equipment. But examples remain thin on the ground.

Efforts like FareShare, a charity that aims to ensure that surplus food is used to feed those in need, rather than repurposed as fertiliser or fuel, illustrate the financial tensions of waste prevention (see case study on p20). Yet studies of food waste in the developed world continue to position it within a linear economy framing, seeing food waste as a 'farm-to-fork' issue that spans producers and supermarkets and ends with consumers[25, 75]. While many of the reasons for wastage lie deep in the supply chain, an emphasis on resource efficiency in relation to supermarket food waste will require consideration of the trade-offs between up-cycling interventions such as Fareshare, and downcycling ones that include AD.

Post-Brexit, it is important to recognise that the EU remains the primary framework of environmental governance in the UK, at least in the short-to-medium term. Fifteen years of waste policy and all key policy drivers have been formulated in relation to this regulatory context, in the UK and the devolved administrations. Key stakeholders – particularly local authorities and businesses – will require assurances that waste policy will be 'business as usual', at least for the immediate future. This will be essential to ensure continued profitability, to avoid costly contractual terminations and renegotiations, and to continue to fulfil statutory obligations with respect to municipal waste services. Having developed an infrastructure that has succeeded in diverting materials from landfill, a return to landfill as the UK's primary waste disposal option is no longer a possibility for municipal waste.

That said, Brexit provides the UK with a unique opportunity to assess and potentially re-orientate policy. Some areas of EU waste policy have been difficult for the UK to implement, or have attracted controversy in the manner of their implementation (eg co-mingled collection systems). There are widespread concerns about the country's ability to meet targets, such as the revised goals for municipal waste recycling and packaging in the EU Circular Economy Programme. Local authorities have already highlighted the challenges of meeting these targets, given that evidence suggests a flat-lining of recovery for recycling (see Chapters 4 and 12).

New horizons

Beyond Brexit, new technological, political and economic developments are reshaping the waste landscape in the UK in terms of resource efficiency. Some of these are discussed in more depth in other chapters of the report. They are:

1. The emergence of new business models, some linked to circular economy thinking. These include leasing v ownership, and the so-called 'sharing' economy, both of which are argued to reduce waste through increasing the reuse of goods (see Chapter 3).
2. Emerging economies, increased global demand for resources including recycled materials, and the growth of consumer markets in developing countries (see Chapters 7 and 14). The long-term trend – more economies chasing resources – is compounded by resource insecurity, where key resources are concentrated in a small number of states, some of which are politically unstable.
3. The volatility of commodity markets. The current depressed state of commodity markets has created major financial difficulties for businesses in the resource recovery sector (see Chapter 4).
4. Technical innovations offer both possibilities and limits. Key developments include:

- Smart and big data. Smart technologies combined with big data offer opportunities to predict waste generation, rather than merely responding to it (as with current municipal waste collection). 'Smart bins' could give real-time data on content and fill status, and so offer municipalities and their contractors the opportunity for more resource-efficient collection systems, as well as smarter forms of materials collection. If rolled out to households, they will raise ethical issues, notably in relation to privacy.
- Better materials characterisation. Describing materials more accurately may make it easier and cheaper to recover those materials.
- New materials present new end-of-life challenges and opportunities. Although there are exceptions such as 'green chemistry'[76], technology still tends to focus on making things (often from new materials), with less consideration given to their end-of-life fate. Sustainable design principles are being taught in architecture, design and fashion degree programmes in UK higher education institutions (HEIs), but they need more widespread extension into business and management degrees as well as science, technology and engineering. Resource efficiency thinking needs to be mainstreamed. This is an area where science, technology, engineering and mathematics (STEM) education in UK HEIs could potentially contribute.

Nonetheless, a key lesson is that new technologies, along with economic and political changes, will not eliminate waste but rather alter its volume, nature and composition. Similar to geological deposition, new technologies and new materials will add new waste streams to both the 'legacy wastes' produced by older industries and technologies, and to the wastes which continue to be produced by industries such as steel, oil and gas, or clothing and fashion. Anticipating and researching resource recovery options for new materials (such as graphene) and new technologies, rather than waiting for these materials and technologies to reach end-of-life (typically after 25 years), is an area where the UK could potentially lead, drawing on its expertise in research and innovation.

It is vital to acknowledge that enhancing resource efficiency does not spell the end of disposal routes. Nuclear waste is perhaps the exemplar case, where the Committee on Radioactive Waste Management (CoRWM) has yet to deliver a UK Deep Geological Facility[77–79]. In general terms, enhanced resource efficiency will have implications for the nature and composition of residual waste, perhaps rendering that category smaller in volume but more toxic, and requiring potentially different disposal routes to those currently available in the UK. To understand the trade-offs that accompany enhanced resource efficiency, it is imperative therefore to understand what waste is, what causes it and how it continues to evolve. Waste and enhanced resource efficiency need to be thought of in tandem and not decoupled.

Key policy messages

Post-Brexit, there is a need to engage key stakeholders in a wide ranging dialogue to establish the relationship between waste policy in the UK (and devolved administrations), and EU waste policy such as the Circular Economy Programme. Guiding questions might include:

- What parts of EU waste policy have either worked well, or will work well, for the UK and devolved administrations? What might be retained?
- Conversely, what elements of EU waste policy have proved more problematic for the UK to implement? What might be dispensed with?
- Where are the key dependencies on EU member states for export markets, both for products derived from wastes and for waste goods?
- What are the implications of losing those markets, and are there alternative markets? If there are no alternatives, what are the implications for national waste infrastructure?

Resource efficiency occurs at the global scale and is international in scope. Nonetheless, there is scope for the UK to act nationally.

Existing resource efficiency interventions can be improved via better local recycling initiatives. Enhanced recycling in the UK depends on improving the quality of materials recovered. If this is not achieved, the UK will continue to rely on global export markets for its resource recovery sector – and as demand for quality increases in these markets it may become reliant on a 'race to the bottom', selling into markets where neither labour conditions nor environmental concerns are high priorities. Improvement can be achieved, for example, through a change to collection methods (an end to co-mingled collection is imperative); by increasing the quality of outputs from UK MRFs; and through the application of smart technologies and big data to waste collection (eg by using smart bins).

Increased UK resource efficiency means asking UK manufacturers what kind and what quality of resources they want, and when. Improved resource efficiency requires that recycling provides manufacturers with the materials they need. In the short term it would be beneficial to engage UK manufacturers and the UK resource recovery sector in a wide-ranging dialogue over the type, volume and quality of materials required by UK manufacturers. In the medium term, a closer alignment between the UK's manufacturing base and resource recovery sector is desirable. This may be achieved through a revised industrial symbiosis programme.

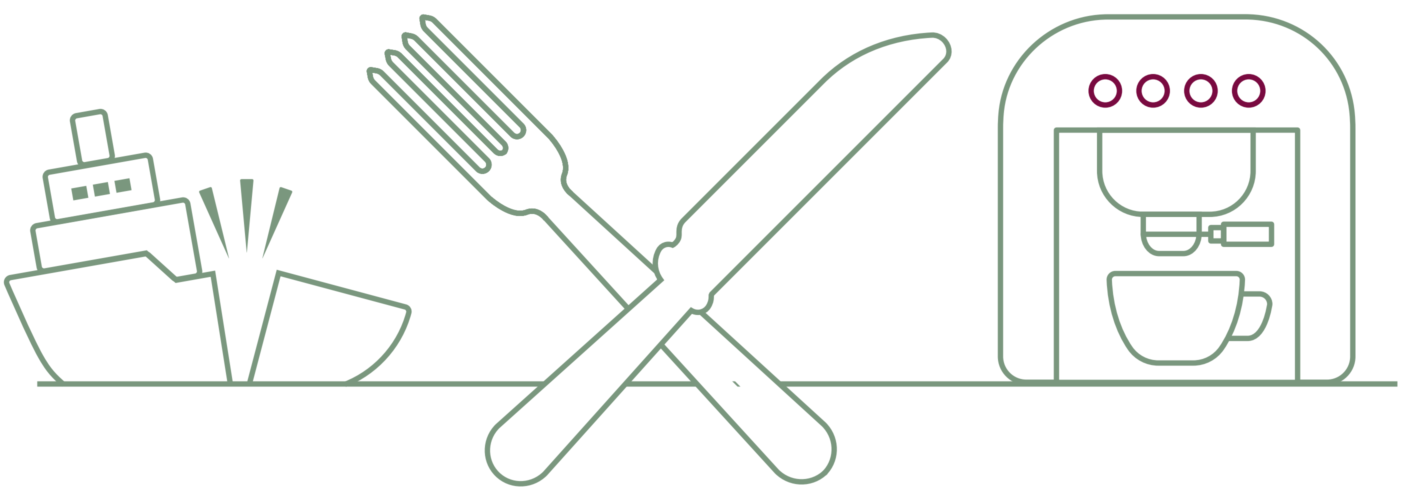
The **Landfill Tax** was a particularly effective driver in diverting waste materials from landfill

Increasing resource efficiency requires products to be designed with their end-of-life in mind; this will also aid recyclers. There are various ways by which policy might encourage this further:

- **In education.** Building on innovations in higher degree programmes in design, architecture and fashion, sustainable design principles might be mainstreamed in teaching in the STE(M) subjects.
- **In research and innovation.** Policies could support further research in resource recovery by extending the research done with some materials (eg concrete) to consider all materials as part of a resource chain. It would be useful to pay more attention to recovery processes for new and emerging materials and technologies, and there is a continued need to support research on problematic legacy wastes, especially from the nuclear industry.
- **In manufacturing.** There is a clear need on the part of all recycling businesses to know what materials, where, and in what quantities, are in the things they work with. **A product passport system** comprising such information should accompany all goods manufactured in the UK, or by UK-registered manufacturers, and should be updated on repair.

Better resource efficiency can also be achieved through increasing levels of reuse. However, this form of resource efficiency is often in tension with enhanced recycling. As a result, these options are likely to involve political choices. Often these choices are stark: between policies that would encourage redistribution linked to a social justice agenda and those that would encourage innovation and growth. A good example of such tensions is the question of what to do with surplus and waste food. Should we keep it as food, and use policy levers to ease its connection to redistributive organisations so that it can help to alleviate food poverty? (In 2013 to 2014, over 20 million meals were given to people in food poverty in the UK by the three major food redistribution agencies, the Trussell Trust, FareShare and Food Cycle[80]). Or should we turn it to bio-fertiliser, fuel or energy feedstock to feed the bio- and energy economy?

Increased resource efficiency does not mean we won't need disposal options. Some materials are not good to keep in circulation. There is a continued need to landfill certain legacy toxic wastes (eg asbestos). The UK's capacity for such wastes needs to be assured. There is also a need for the policy process to deliver a UK Deep Geological Facility, to house the high-level radioactive wastes currently stored at Sellafield.



CHAPTER 2:

The data gap

To increase resource productivity, and maximise the flow of waste back into the economy, businesses need more information about the nature and quantity of waste. Other data are essential to monitor national progress and the impact of policy measures. Gaps in these data could be filled through better data-sharing between the waste management industry and government; increased reporting by waste management practitioners; and a mandatory Electronic Duty of Care (edoc) system.

Nigel Naisbitt, Naisbitt Resource Management Ltd

In 2012, the UK generated an estimated 200 million tonnes of waste across various sectors (see Fig. 1). The ability to maximise the recovery of these wastes is constrained by the quality, granularity and availability of waste management data, and there are notable gaps in our knowledge. For example, we cannot be certain about the total amount of commercial and industrial waste, or construction and demolition waste because we currently do not capture data from all waste management facilities, or data about waste producing sectors. Moreover, there were significant methodological differences in waste data collection before 2010 compared to today, so the trends seen in Figure 1 must be treated with some caution.

In the 1990s, when waste prevention and efficient production became a real business priority, there was a recognition that in order for businesses to become more resource efficient they needed to understand the nature and quantity of waste they produced. Production efficiency was often a focus for individual businesses, with the aim of delivering greater sustainability and increasing profitability.

Over the past 20 years, as individual businesses have become more resource efficient, there has been a greater realisation that society as a whole needs to manage resources more effectively. This has led to greater levels of waste prevention, reuse and recycling and the emergence of concepts such as industrial symbiosis, where one company's waste becomes another's raw material (see Chapter 11, case study on p157).

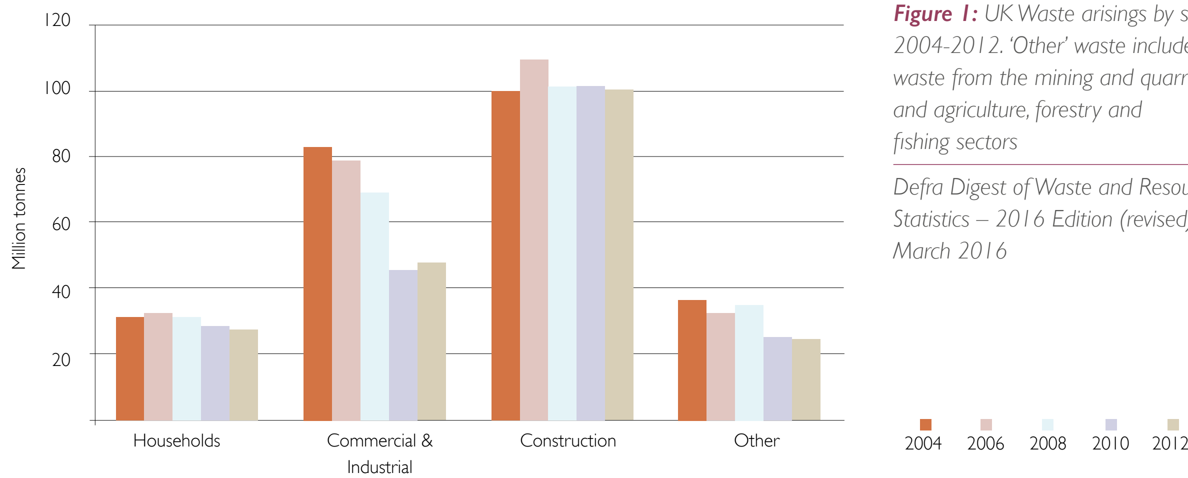


Figure 1: *UK Waste arisings by sector, 2004-2012. 'Other' waste includes waste from the mining and quarrying, and agriculture, forestry and fishing sectors*

Defra Digest of Waste and Resource Statistics – 2016 Edition (revised), March 2016

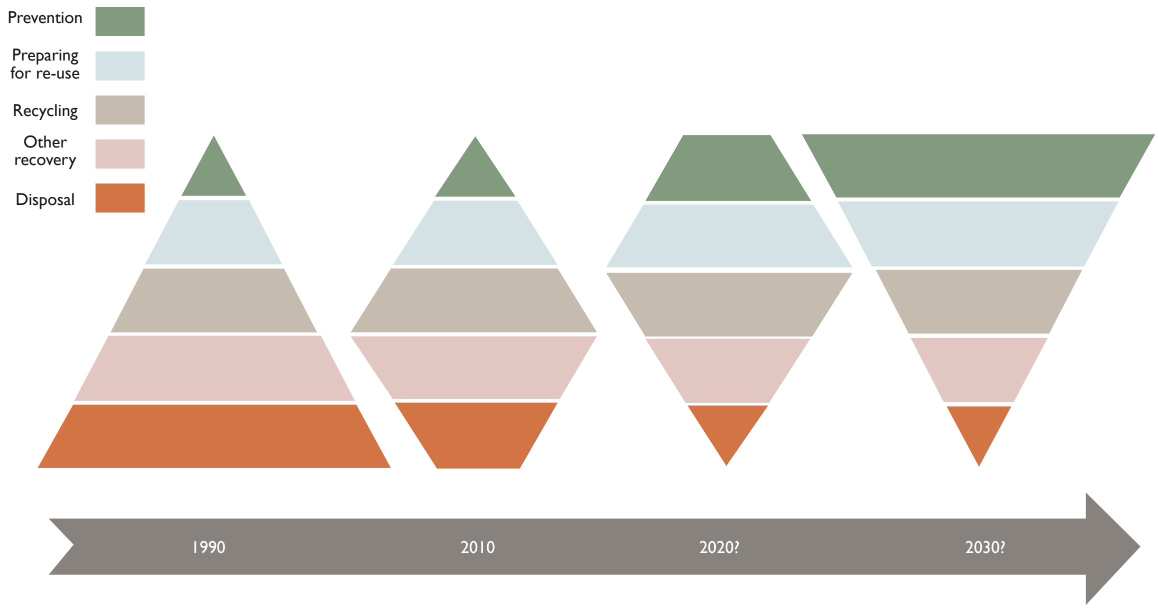


***Figure 2:** Evolution of Waste Management Practices: In the past, most waste was dealt with by disposal, but over time that will shift increasingly to recycling, reuse and ultimately prevention.*

Nigel Naisbitt

Meanwhile, waste management practices have continuously evolved, moving from the disposal-based practices of the 1980s and 1990s towards the recognition that waste is a vital resource (see Fig. 2).

But this has also increased the complexity of the systems used to manage and recover resources. There is now a wider range of options available, including designing products for re-use, anaerobic digestion, mechanical biological treatment and many more. For every one of these options, those involved in resource recovery need to understand the practicalities inherent in these processes, and their ability to deliver outputs that can be used in re-manufacturing or as secondary raw materials.

This increasing complexity, and the need to link material consumption with process outputs, highlights the importance of high quality, reliable and available data for evidence-based decision making. To drive a more resource-efficient economy, we must understand how to move something from being waste to a raw material. That means we need greater granularity about the nature of the waste generated to track how materials can flow back into the economy. Without an understanding of what materials are available, it is difficult to establish systems or business models that recover them economically.

Data needs

Wastes can be described or categorised in a number of ways:

- By its origin eg household waste, industrial waste etc. Although this assumes that waste produced from the same source will be similar, they are terms that people can easily comprehend.
- By the type of original product eg packaging waste, waste electrical and electronic equipment (WEEE) etc. Such categorisations allow waste streams to be easily identified and understood by a wide range of people.
- By the material it consists of eg paper, glass, plastics etc. This provides simple, accessible descriptions of waste, but it hides the complexity associated with different materials, such as the range of types of plastic; and the ability to return a material to a production process eg colour segregated glass v mixed glass.
- By its physical and chemical properties ie the material components within a waste, as well as the nature of any hazards they pose.

Data about these wastes can be used for:

- measuring and reporting against policy measures and targets
- recovery and management of waste
- environmental protection, and the prevention of harm to human health

Table 1: *Stakeholders' data needs*

Stakeholder	Key data needs
Citizens	Most residents do not require detailed quantitative information; instead, they need qualitative information about local and specific benefits, and how materials are transformed into other items[1]. However, there are times when residents seek detailed information about the types and quantities of waste generated with their area (eg during strategy consultation periods or waste infrastructure planning applications), in order to support or counter claims that are being made.
National Government	Government recognises the need to "ensure that decisions are based on sound science and evidence"[2] and in terms of waste management this drives data needs in two key areas: ■ data to inform policy development on sustainable resource management, including the types and quantities of waste; the nature of the waste; and material demand and consumption ■ data related to environmental protection and the prevention of harm to human health In addition, government needs data to meet reporting obligations and monitor progress against targets and commitment.
Local Government	There are two distinct areas of waste data for local government: ■ data needed to plan and deliver effective recycling and waste services. This covers a broad spectrum of information, including: levels of waste generation; detailed breakdowns of the type and composition of different waste streams; social/demographic data to understand the characteristics of a local authority area; waste management infrastructure; recyclate market specifications, locations and commodity prices etc ■ data to inform the planning process, by determining the need for waste management infrastructure or the ability of existing infrastructure to cope with waste from new developments. As with national government, local government needs access to data to meet reporting obligations and monitor progress against targets.
Commercial business	Businesses require data on waste recovery, treatment and disposal options – and their costs – to enable cost-effective management of their waste. However, this sector relies heavily on the waste management industry to provide the option that best suits their business needs. Businesses that have legal obligations under 'producer responsibility' legislation need data to meet reporting requirements. Information about an individual business's environmental performance can also be used in its corporate social responsibility programme.
Manufacturing business	To drive a circular economy, the manufacturing sector not only needs all the information required by the commercial sector; it also needs information about the potential availability of secondary raw materials, and the quantity and quality of those materials. This requires an understanding of the types and quantities of waste generated, where they are generated and their physical and chemical properties. This level of detail informs decisions about potential material substitution, availability and security of supply, and investment in handling or processing equipment. These all contribute to the cost-benefit analysis of using a secondary raw material when looking for industrial symbiosis opportunities.
Waste management business	This sub-sector generates the majority of the information needed, with individual businesses holding the data on the waste they control. But they are reliant on nationally reported data to inform investment decisions, in terms of the types and quantities of waste that need to be managed (ie the feedstocks) and the range of options for managing the outputs (ie the end markets) along with commodity prices.
Regulators	Waste-management regulators need data about: ■ the types and quantities of waste handled at waste management facilities (which may or may not require a permit) ■ the nature of different waste streams and their potential to cause environmental pollution or harm human health ■ whether material has achieved 'end of waste' status ie when the waste ceases to be waste, and is instead classified as a product or a secondary raw material by meeting specific criteria ■ information to help identify illegal activities

For measuring performance and reporting, the first three waste categories above are normally sufficient for providing the level of detail needed to understand how much waste is generated and how it is managed. But these categories often do not provide the level of detail or granularity needed to increase the material flow back into the economy; that requires information from the fourth category, about specific physical and chemical properties. Table 1 summarises the data needs from difference stakeholders' points of view, taking these factors into consideration.

Classification of waste

The List of Wastes[3] (LoW) system is the standard method for classifying waste, and most waste regulatory and data reporting systems are required by law to use it. Designed to cover almost all wastes, it is divided into 20 chapters. Some are based on the type of industry, process or activity that produced the waste, while others are based on the type of waste. The chapters are further divided into sub-chapters under which individual wastes are identified by a six-digit code and a description. An individual waste is therefore defined by reference to the chapter, the sub-chapter and the description accompanying the six-digit code (see Box 1).

Box 1: List of Wastes examples

A secondary aggregate producer would describe concrete from a demolition site using LoW code 17 01 01:

Chapter 17: Construction and demolition wastes (including excavated soil from contaminated sites)

Sub-chapter 17 01:
concrete, bricks, tiles and ceramics

Waste description 17 01 01:
concrete but a plastic reprocessor looking for feedstock would need to consider a range of LoW codes covering plastics from different origins. For example:

02 01 04: waste plastics (except packaging)
07 02 13: waste plastic
15 01 02: plastic packaging
16 01 19: plastic
17 02 03: plastic
19 12 04: plastic and rubber
20 01 39: plastics

A series of rules outline how to use the LoW, and determine whether a waste is covered by a particular waste entry[4]. The key element of the rules is the order in which the different chapters of the LoW should be considered to find an appropriate code. This process is not necessarily definitive and can lead to different interpretations of the waste descriptions, which can result in different codes being selected for the same waste.

While the LoW provides definitive descriptions for certain wastes, others have broad descriptions that do not fully define the physical and chemical properties, as shown in Box 1. This is a limitation within our waste classification systems, as it does not always provide sufficient granularity to identify secondary raw materials.

Over the past 20 years... there has been a **greater realisation** that society as a whole needs to manage resources more effectively

Case Study

The Electronic Duty of Care (edoc) system

Nigel Naisbitt, Naisbitt Resource Management Ltd

Section 34 of the Environmental Protection Act 1990 outlines the 'duty of care' for waste[6]. Enacted in 1992, it requires anyone who has a responsibility for controlled waste – including producers, importers, carriers, waste managers and brokers – to ensure it is managed properly and recovered or disposed of safely. Key elements of the duty of care are to:

- prevent the escape of waste in your control
- transfer it only to someone who is authorised to accept it
- ensure that it is handled lawfully by others
- upon transfer, provide details of the waste including a written description including an appropriate List of Wastes (LoW) code. This duty was implemented through a mandatory system of Waste Transfer Notes (WTNs). These notes must be in place when waste is transferred between two parties and be retained for 2 years.

The duty of care was designed to be a self-regulating system based on good business practice, and it is estimated that there are 25 million WTNs produced per annum across the UK. As business practices have increasingly involved the use of electronic media, it has been recognised that an electronic system for producing and storing WTNs would be consistent with current business practice. The Electronic Duty of Care (edoc) system is a free online portal designed to give businesses an alternative to current paper-based WTNs[7]. It was developed by the UK's four environmental regulators in partnership with the waste management sector and UK government bodies. It allows all data to be stored online, which means companies can search and retrieve information, and run data reports for business planning or waste and resource management.

edoc has the potential to provide better information on all types and quantities of waste generated, and their movement. However, this potential has still to be realised because the use of the system is voluntary, and to date the take-up has been limited.

Assessment of data sources and quality

Different data sources provide a varied level of detail about the waste produced in the UK, and data sets often need to be combined to understand a particular sector (see case study on p32). Even when all the data sets are combined, gaps often remain. In addition, most of the data originate from regulated waste management activities, which differ between the countries of the UK. That means each country takes different approaches to data reporting. Table 2 summarises the key waste management data sources, what they cover, and their limitations. Aside from these, a range of other measures can be used to inform and monitor progress towards the 'circular economy'. These include domestic or raw material consumption, which can highlight the materials need in the economy; the gross value added (GVA) by each waste management sector; and the ecological footprint.

Despite this plethora of data sources, it is difficult to identify appropriate raw material substitutions (or increase the GVA of the sector through increased resource recovery) without fundamental data about the specific types and quantities of waste materials generated.

To help understand the gaps in our knowledge, Table 3 shows how the key data sources contribute to the data needs across different waste streams and uses a basic red, amber or green assessment to highlight data availability and quality.

Information on waste management facilities is also needed to understand the capacity available to manage waste, by either bringing it back into use or recovering value from it. Such data are available for permitted facilities (covering type of facility, permitted waste streams, capacity and actual throughput) but ease of access to these data varies across the UK.

The same is not true for exempt activities, though: for most of the UK, the number of exempt activities may be known but the quantity of waste that can be handled through such facilities can only be estimated based on the tonnage limits for each exemption. In Scotland, operators of 'complex' exemptions (eg storage and spreading of sludge on non-agricultural land) are required to report on the type and quantity of waste handled.

Waste definitions

Despite common definitions in the EU Waste Framework Directive, and the introduction of the EU Waste Statistics Regulation to provide a common format for waste reporting, the interpretation of waste definitions varies within the UK and between EU member states. Recycling and composting targets and measurements differ across the four nations of the UK, with some being based on household waste and other on local authority collected waste. At the European level, member states can currently choose one of four methods to report their performance on recycling, meaning such measures are not directly comparable, although there is a move in Europe to adopt a harmonised definition of recycling based on municipal waste.

Looking forward, we need to be clear about the process for moving materials from being a waste to a secondary raw material. This raises the importance of end-of-waste criteria ie the point at which a material is no longer considered to be a waste and therefore not subject to waste management legislation and controls. There are EU End of Waste Regulations that define when certain waste-derived products are no longer considered to be a waste, but these currently apply only to iron, steel and aluminium scrap; glass cullet (the industry term for furnace-ready recycled glass); and copper scrap. If these regulations do not apply to a waste-derived product, an end-of-waste assessment is needed, to determine whether:

- the waste has been converted into a distinct and marketable product
- the processed substance can be used in exactly the same way as a non-waste
- the processed substance can be stored and used with no worse environmental effects when compared to the material it is intended to replace.

Table 2: *Key waste management data sources*

Data source	Coverage	Limitations
WasteDataFlow (WDF)	Types and quantities of all waste collected by local authorities. Reported quarterly by local authorities, except in Scotland where reporting is annual.	Data extraction can be complex, particularly since the introduction of more detailed treatment and disposal questions. There can be inconsistencies in reporting by local authorities but data validation can reduce inconsistency.
Environment Agency (EA): Waste Data Interrogator and Hazardous Waste Interrogator	Produced annually. Includes details of waste deposited based on returns from permitted facilities, along with some movement data including exports. It can be interrogated by waste type, facility type and by origin.	Excludes exempt facilities and energy-from-waste (EfW) facilities Does not link to the producing sector, other than by waste codes, raising the risk of double counting. The Waste Data Interrogator no longer includes Wales.
EA: Waste data tables	Produced annually. Based on EA Interrogator, but includes incineration. Allows comparison by region and historically. Inputs provided by named facility.	Does not differentiate between waste collected by local authorities, and commercial and industrial waste. Does not give waste type of input material.
EA: Exemptions Database	Contains details of all registered exempt facilities. Allows interrogation by exemption category and location.	Does not include tonnage data or waste types covered by each exemption. Data quality is poor, and is not published.
Scotland's Environment Waste Discover Data Tool and Household Waste Discover Data Tool	Presents waste from all sources (households, construction and demolition, commerce and industry). Based on waste returned from permitted facilities and some exempt activities, as well as WDF.	Includes 'complex' (but not all) exempt activities. Assumptions are needed when operators fail to provide origin information.
Scottish Waste Sites and Capacity Tool	Provides information about waste sites permitted by the Scottish Environment Protection Agency (SEPA), including: waste inputs, waste treated/recovered, waste outputs, and annual permitted capacity.	
StatsWales	Data on the types and quantities of waste collected by local authorities, and recycling destinations extracted from WDF.	Not a primary data source, so relies on the inputs to WDF and their associated shortcomings.
Natural Resources Wales: Waste data information and data tables	Produced annually - built up from data from permitted waste management facilities. Allows comparison by region and historically.	Does not differentiate between sources of waste. Excludes exempt facilities and EfW facilities. Does not link to the producing sector.
Natural Resources Wales: Surveys	Surveys of waste in Wales in 2012, covering the construction and demolition, and commercial and industrial, sectors.	As with all periodic surveys, this is a snapshot in time that becomes dated.
edoc (Electronic Duty of Care)	A free online portal designed to give businesses an alternative to the paper-based Waste Transfer Note required under the duty of care (see case study on p29).	Not mandatory, and limited uptake to date. Businesses are not required to input actual tonnages.

Others

- EA: National Packaging Waste Database provides data on reprocessed volumes, and imports and exports for specific recyclates for packaging
- EA: Import/export data reported by LoW code and includes refuse derived fuel (RDF) and solid recovered fuel (SRF) export data
- HMRC: Comprehensive list of waste material exports by Standard International Trade Classification code
- HMRC: Landfill tax returns at the national level
- Waste & Resources Action Programme (WRAP): Local authority waste collection systems
- WRAP: Material Recovery Facilities quality-monitoring data.

Waste Discover Data

Nigel Naisbitt, Naisbitt Resource Management Ltd

Waste Discover Data is an online service developed by the Scottish Environment Protection Agency (SEPA)[8]. It aims to make waste management data more accessible and to improve the quality of information available, and offers interactive tools that allow the data to be manipulated by type, sector and management method, for 2011 to 2014. One of the Waste Discover Data tools covers waste from all sources; another covers waste from household sources only.

The data are derived from similar sources to those used in other parts of the UK to estimate waste generation. The big difference is that the Discover Data Tools allows users to filter the information in a variety of ways, and to a higher level of granularity. This means that specific waste types can be identified, and trends in generation by sector can be considered. These are the first steps in understanding the potential for recovering a waste type.

While there are some limitations and gaps in the data sources, the information gathered has been collated into a format that allows it to be accessed by people with a detailed understanding of the waste management sector.

This can be achieved by demonstrating compliance with a quality protocol. However, if there is no applicable quality protocol, achieving end-of-waste status needs to be done on a case-by-case basis. End-of-waste status should be agreed with the appropriate regulatory body (ie the Environment Agency, Natural Resources Wales, Scottish Environment Protection Agency or Northern Ireland Environment Agency) but this can typically take 3 months or longer, which could be a barrier to recovering some waste streams.

Accessibility and usability of waste management data

Waste data are more accessible than ever before, but work is still needed to increase its usability. The local authority waste management data reporting system, WasteDataFlow (WDF), contains a wealth of valuable data and downloadable reports. But these reports have changed little in the past ten years, which means that more complex analysis requires the ability to extract information from the raw data downloads, which are not particularly easy to use. This has been compounded by the introduction of more detailed treatment and disposal questions, which require the local authorities to report treatment activities from the point of collection to end destination.

For commercial and industrial waste in England, the current methodology provides estimates based on data from a range of sources. But there are gaps in the data, and these limitations impact the reliability of the estimates. In addition, the complexity of the method means it would be difficult for non-waste practitioners to apply.

The commercial and industrial waste stream is potentially the area where resource productivity and recovery through to effective waste management could have the greatest impact. But the incomplete and complex dataset lacks granularity at the regional level, and relies on historical estimates to identify the producing sector.

Table 3: Summary of data gaps by sector

Data type / Waste type	Local authority collected	Commercial & industrial	Construction & demolition
Total waste generation	Detailed data set collected through WDF	Gaps resulting from the lack of reporting associated with exempt activities	Significant quantities managed at facilities that are exempt from permitting
Waste generation by region	Broken down to local authority level	Not straightforward, due to the need for multiple and incomplete data sets, and the lack of sound data on origin of waste	The extent of material handled through exempt activities leads to a higher level of uncertainty
Waste generation by sub-sectors	Not applicable	Difficult to allocate waste accurately to all sectors due to structure of LoW and lack of use of Standard Industrial Classification of Economic Activities (SIC) codes on waste transfer notes and site reporting	Relatively easily identified from Waste Interrogators due to LoW codes specific to the industry
Overall recycling / recovery	WDF provides the data needed to calculate recycling and recovery rates	Limited accuracy due to material moving through exempt recycling operations	Waste is often handled at site of production, which can limit data capture
Material- and industry-specific recycling / recovery	WDF requires material-specific data to be provided	Increased granularity compounds the problems associated with assessing overall recycling rates	Increased granularity compounds the problems associated with assessing overall recycling rates
Treatment / disposal routes	WDF now requires more detailed reporting of treatment / disposal activities, which means waste flows will be better understood	Most treatment / disposal routes require permits, enabling data capture, but some materials are managed through exempt activities	Large proportion of waste is handled through facilities exempt from permitting
Waste composition	Individual local authorities' compositional analyses now limited due to the cost (the most recent English data dates to 2007, for example)	No national data on waste composition available	No national data on waste composition available, but limited range of waste types means composition is less critical

Information on waste management facilities is also needed to **understand the capacity** available to manage waste

Case Study

Defra's Reconcile project

Nigel Naisbitt, Naisbitt Resource Management Ltd

In late 2013, Defra commissioned a project called Reconcile to develop a new methodology to estimate commercial and industrial waste generation in England[5]. Historically, estimates of this waste had been produced by extensive surveys of the sector, but Defra wanted a new and repeatable method, using existing data sources, in order to report commercial and industrial waste generation more accurately.

The method calculates the total amount of commercial and industrial waste by adding up:

- inputs to specified, permitted facilities
- incineration inputs
- inputs to exemption facilities
- direct exports

And subtracting:

- household waste
- construction, demolition and excavation waste
- imports.

Commercial and industrial waste goes through a complex management chain that can channel it through various treatment processes or transfer stations, ultimately ending up at destinations that include reprocessing facilities, exempt facilities, anaerobic digestion and landfill. Consequently, although the basic calculation outlined above appears straightforward, we need multiple data sources with signification data manipulation and a series of assumptions in order to generate the different figures in the calculation. The key datasets are outlined in Table 4, along with the manipulation and assumptions needed to feed the data into the calculation. This highlights the difficulties in producing reliable estimates for commercial and industrial waste.

Table 4: *Data sources needed by the Reconcile project*

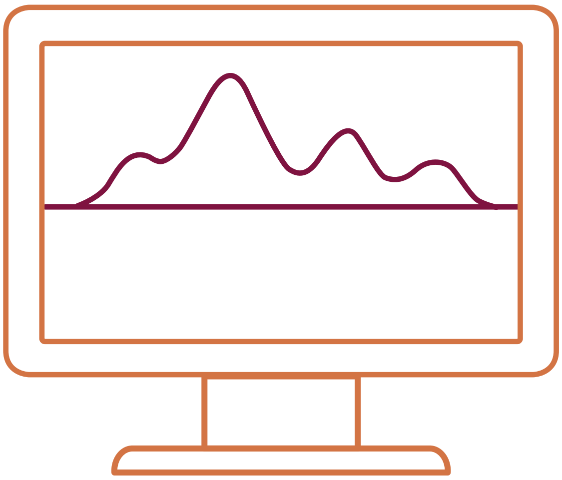
Dataset	Availability	Manipulation / Assumptions
Environment Agency Waste Interrogator data for permitted waste facilities (landfill, treatment, transfer and use on land)	Online, free of charge	Waste management from transfer stations needs to be excluded from the calculation to prevent double counting. The tonnage of household waste needs to be subtracted from the tonnages handled at waste facilities
EA-held Waste Incineration records identify the quantity of waste that is received at incineration facilities by LoW code	Provided by the EA from internal records. Not publicly available, although incinerator inputs – which are not broken down by LoW code – are available as open data	The tonnage of household waste needs to be subtracted from the tonnages handled at incineration facilities
EA-held Environmental Permit exemption records	Publicly available, on request from the Environment Agency	The data needs to be cleansed to remove duplicate entries. Assumptions about the material handled based on potential throughput capacity need to be made
EA-held import/export data (reported under the Basel convention) is not listed by LoW code. Refuse-derived fuel and solid recovered fuel (RDF/SRF) data is included in these returns	Publicly available, on request from the Environment Agency	Need to estimate direct exports, and separate tonnage handled at waste management facilities to prevent double counting Also rely on assumptions to map Commodity Codes to LoW codes
HM Revenue & Customs (HMRC) held import/export trade data, reported by Commodity Codes	Provided by HMRC, publicly available	
Jacobs C&I Waste Survey 2009 (Jacobs Survey) dataset to cross-check the proportion of waste by each LoW code assumed to be generated by different sectors	Provided by Defra, not publicly available	2009 survey data is used to map waste, in order to derive assumption about the producing sectors
EA-held and combined information on hazardous waste generated, listed by LoW and the producer registration system by Standard Industrial Classification of Economic Activities (SIC)	Publicly available, on request from the Environment Agency	The combined datasets provided breakdown of hazardous waste by sector. However, the producer registration system is now abolished, so this is no longer repeatable
EA-held reprocessor records from the National Packaging Waste Database	Publicly available	Used to cross-check waste handled through exempt facilities
WasteDataFlow to identify household proportion	Publicly available	Use to identify the household waste fraction that needs to be separated from municipal waste LoW codes

This document is not a statement of government policy

Similar issues apply to data in Scotland, but measures such as requiring operators of complex exemptions to report data have started to remove some of the data gaps. What is most notable in Scotland, though, is the availability of the collated data in an accessible format through the Waste Discover Data Tools provided by Scotland's Environment. The tools are online and interactive, with tables and charts that can be filtered to select specific information; one tool covers all wastes and the other is limited to household wastes (see case study on p32). Alongside the Waste Discover Data Tools, data on waste management facilities covered by Waste Management Licences and Pollution Prevention Control permits are available both online and downloadable in spreadsheet format.

Resource use in the UK

Beyond specific waste management, data are also available to help understand resource productivity, through sources such as the Office for National Statistics' (ONS) UK Environmental Accounts. The accounts provide statistics on the environmental impact of UK economic activity and include:



- natural asset accounts (eg oil and gas reserves, forestry, land)
- physical flow accounts (eg greenhouse gas emissions, air pollutants, energy consumption, consumption of raw materials)
- monetary accounts (eg environmental taxes, environmental protection expenditure)

The ONS material flows account tracks the consumption of raw materials, which is the key dataset related to increasing the flow of material back into the economy from the waste management sector. The reported data are at the UK level, which allows overall resource productivity to be assessed. However, they offer only a high-level breakdown of materials, which means it is not possible to align resource demand with potential secondary raw materials.

As highlighted earlier, the datasets used to monitor national progress and the impact of policy measures on resource productivity are often different from the information needed to identify materials in waste that can be fed back in to the economy. Assessing the success of resource productivity requires different data sets that those needed to facilitate the recovery of waste and deliver resource productivity on the ground.

Conclusions

To maximise the flow of waste back into the economy, and to identify the highest-value opportunities to increase our resource productivity, we need to understand the type, nature and quantity of waste generated. The benefits include:

- greater security of supply for critical raw materials
- boosting global competitiveness
- sustainable economic growth and job creation
- more cost-effective waste management

These benefits are being held back by gaps in our knowledge, particularly with regards to commercial and industrial wastes, and construction and demolition wastes. We also need to differentiate between the data needed to monitor national progress and the impact of policy measures, and those needed to move waste materials back into beneficial use. While we should improve definitions, metrics, data availability and accessibility etc, we also need to ensure that we have the fundamental building blocks about the amount of waste, the type of waste and where it is generated, if we are to have the greatest impact in supporting resource efficiency and productivity.

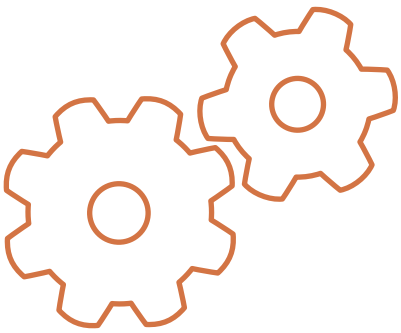
It is also important to ensure that the costs of data collection and collation are accounted for. Any initiatives to fill data gaps need to maximise data capture while limiting the burden of reporting, so that administrative requirements do not become a barrier to material recovery.

There are several ways to fill the key data gaps in our current knowledge.

1. The waste management industry has a detailed understanding of the wastes generated by their customers, but this information is often viewed as commercially confidential by the waste management industry. Therefore, greater liaison and increased data sharing between the waste management industry and government, particular in relation to the waste generated by different sectors, could improve the understanding of the wastes generated by different sectors. This was a recommendation within the Defra 'Reconcile' project[5]. However, in increasing the access to such data, the waste management industry would need assurances over data security, the granularity of publicly available information, and commercial confidentiality.
2. Measures could be implemented to ensure that all the necessary data is captured. This can be achieved at the point of generation, by making the use of the online Electronic Duty of Care (edoc) system mandatory; or at the point of deposit, by requiring the operators of waste management-exempt activities to report on the types and quantities of waste they handle. Either of these could significantly improve the data gaps in material- and industry-specific recycling and recovery.

Both approaches have a number of advantages and disadvantages. By identifying waste at the point of origin, a mandatory edoc would help to reduce double counting, and allow resource flows to be mapped. The edoc system already exists, and could replace the paper-based Waste Transfer Note that is already a legal requirement. However, a mandatory edoc would force all waste producers to use the electronic system, and bespoke waste industry IT systems

More **complex analysis** requires the ability to extract information from the raw data downloads



would need to be adapted. It may also raise issues around data security and commercial confidentiality.

Alternatively, reporting details about waste management-exempt activities would impose the obligation on a smaller number of businesses, and could be introduced as part of the existing regulatory framework. It would also accurately record the mass of waste handled. However, it would also demand new reporting requirements for certain waste management facilities. This could be perceived as a barrier to reuse and recycling activities, such as the baling, sorting, shredding, crushing or compacting of certain recyclable materials, or small scale composting, which are considered to be low risk in terms of harm to human health and protection of the environment. It would also not assist in identifying waste producing sectors, which would make it harder to target sectors that produce specific waste streams.

If we are to properly understand how much waste we generate, and the true opportunities to maximise the flow of waste back into the economy, one of these options should be adopted. Overall, a mandatory edoc system would provide better data, as it would yield information on the sectors producing waste, and also how that waste is managed.

The author wishes to acknowledge the input of Terry Coleman, Resource and Waste Solutions Partnership, to ideas presented in this chapter.

CHAPTER 3: Science and innovation

Novel technologies, processes and business models have the opportunity to transform systems of production, distribution and consumption. In a series of extended case studies, expert authors consider the potential impacts of developments ranging from 3D printing to the 'sharing economy' enabled by online platforms. In each area, policymakers can help stimulate these developments to create more sustainable waste solutions.

Mike Edbury, Head of Risk and Regulation, Government Office for Science; Felix Preston, Senior Research Fellow and Deputy Research Director for Energy, Environment and Resources, Chatham House; Kirk T. Semple, Alfonso Lag Brotons and Rachel Marshall, Lancaster Environment Centre; Lois Hurst and Ben Herbert, Stopford Energy and Environment; Dr Andrew Clifton and Alex Dulewicz, Rolls-Royce; Walter R. Stahel, Founder-Director, The Product-Life Institute, Geneva; Conrad Mohr, Business Development Executive, A2C Services, Portsmouth; Ellie Gummer, Director, Sharing Economy UK.

Science and innovation enable us to improve both our economy and the environment, in ways that previous generations could not. To respond to the problem of waste, we must use solutions from the natural and social sciences, technology and engineering to achieve sustainable growth without over-exploiting resources. We also need to look at how disruptive developments, such as the Internet of Things, can transform systems of production, distribution and consumption.

Science, innovation and social change bring new risks, as well as opportunities. Easier and cheaper methods of creating a product can raise demand for that product, which may generate additional waste. Moreover, the challenges of handling waste from emerging technologies like nanotechnology or synthetic biology will be very different from those needed to handle, say, plastics, which are themselves a constantly evolving set of materials. Policymakers have a key role to play in helping to ensure that science and innovation can navigate these opportunities and risks successfully, because the regulatory and policy framework shapes innovation: it can either provide incentives, or place barriers in its way.

This chapter examines the role of science, engineering and innovation through a series of extended case studies:

- **Technological advances.** Felix Preston explores how plastics technologies have affected waste in the past, and how the emerging technology of 3D printing might increase resource productivity in the future. In a different field, Kirk Semple and colleagues set out how the recovery of energy and nutrients from waste offers opportunities to tackle the global challenges of achieving food and energy security in a sustainable way.
- **Business models.** Understanding ownership and production chains are both critical to reducing waste. Andy Clifton explains how the Rolls-Royce TotalCare® scheme aims to provide ongoing management of the engines they make. This reduces repair and maintenance demands, encourages improved product design, and provides data that feed back into design and innovation to improve future products and services. Walter Stahel and Conrad Mohr pick up the theme of product ownership, illustrating how end-of lease remanufacturing of information and communications technology (ICT) can be profitable and at the same time reduce greenhouse gas emissions, build national resource security, and contribute to 'intelligent decentralisation' (using radically different models of manufacture and service such as 3D printing, repair cafes and energy-autonomous buildings).
- **Societal change.** Ellie Gummer explains how the sharing economy enables individuals to exploit the potential of assets they already own or possess (be it their homes, vehicles or skills). She demonstrates through practical models how the sharing economy can unlock time, skills and assets and bring flexibility to the market and, in doing so, contribute to the reduction in waste.

Opportunities and risks of past and future technologies for resource productivity

Felix Preston, Senior Research Fellow and Deputy Research Director for Energy, Environment and Resources, Chatham House

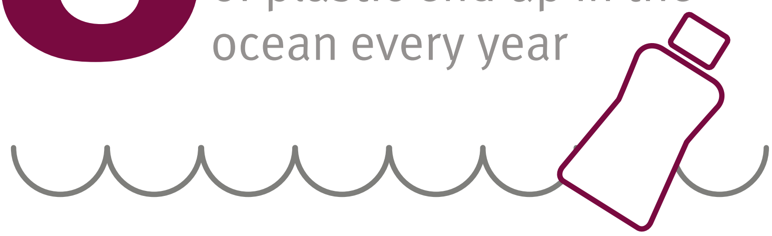
Despite considerable resource efficiency savings in recent years, global resource extraction is projected to reach 183 billion tonnes by 2050 under 'business-as-usual' scenarios, a rise of almost 100 billion tonnes[1]. Finding new ways to enhance resource productivity will, therefore, play a critical role in achieving the UN Sustainable Development Goals agreed in 2015.

A combination of innovations – advances in materials science, information technology, product design and business models – have raised hopes of decoupling resource consumption from economic growth. For policymakers, this presents both new opportunities and challenges. While such innovations may enhance growth and productivity, there will inevitably be winners and losers from such disruptions. Moreover, there are possible side effects: a rise in consumption that exceeds any efficiency gains, or the use of new materials that are harder to reuse. In light of these dynamics, we need policies and regulatory models that both accelerate innovation and avoid locking in unsustainable resource pathways.

There is also a risk that focusing on these disruptive shifts and 'moon shot' innovations will reduce policymakers' attention on well-known (but difficult to implement) waste management and efficiency technologies, where huge gains are still available. Deploying existing technologies at scale to capture these efficiency gains could play a crucial role in meeting key sustainability objectives. The UN Environment Programme (UNEP) International Resource Panel report, for instance, found that resource efficiency policies and initiatives could reduce global resource extraction by 17% by 2050, compared to a baseline scenario[2].

A balanced approach is needed to accelerate the shift towards a more resource productive economy. It must promote the uptake of existing mainstream technologies and best practices, but also harness and guide the resource saving potential of disruptive innovations. These two dimensions are illustrated below by considering the role of innovation in the plastics sector and in additive manufacturing. It highlights in particular a few areas where collaboration between governments and the private sectors may be needed to unlock the technical and political barriers to progress.

8 million tonnes of plastic end up in the ocean every year



Plastics

The plastics sector has huge resource implications. Around 300 million tonnes of plastics are produced each year globally, of which roughly 120 million tonnes end up in landfills and 8 million tonnes end up in the ocean[3]. Plastics vary considerably, not only in material composition but also in their end uses and waste management options. Although this a policy arena with decades of experience, there are still many opportunities to reduce both the volume of new plastics produced, and to reduce the impacts of plastic on the environment. The EU estimates that employing all available measures would avoid 16 million tonnes of plastic heading to landfill each year[4].

When it comes to capturing plastics at a higher stage of the 'waste hierarchy' (eg for reuse and remanufacturing), one challenge is how to encourage shared facilities and common infrastructure, avoiding a duplication of infrastructure by individual firms that could escalate costs and energy use. There may be lessons from other sectors with complex supply chains: in Scotland, for instance, small food suppliers reduced distribution costs by 20% by sharing logistics via a collaborative distribution initiative, according to Defra-funded research[5].

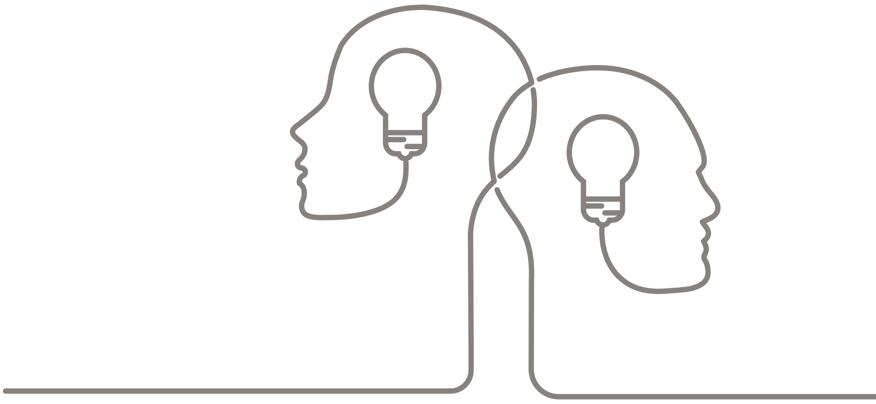
There are opportunities for collaboration between companies and policymakers in different countries, to make further progress on plastics waste. The New Plastics Economy initiative, launched this year at the World Economic Forum annual meeting, is developing industrial partnerships to target various goals, such as using a significantly smaller set of material or additive combinations in plastics packaging[6]. The impact of China's introduction of Operation Green Fence, limiting waste plastics imports especially from US companies (see Chapter 14), highlighted the often-overlooked importance of trade policies around scrap and waste[7]. The European Union's Circular Economy Package includes a raft of measures intended to align waste regulations, encourage regional hubs for remanufacture and reuse, and also set design standards that increase the durability of products[8]. This could provide a model for other regions (see Chapter 4).

In terms of technology cooperation, one area well suited to enhanced international collaboration is carbon capture and utilisation (CCU), which aims to create profitable uses for waste greenhouse gases. The US has invested $100 million in CCU research including in CO_2-based plastic manufacturing. Germany, China and Australia are also conducting significant research in this area[9].

3D Printing

The potential benefits of 3D printing as an alternative to mass manufacturing have been widely discussed[10]. These benefits could include reduced energy and raw materials use in production, emissions savings, and shorter supply chains. But these sustainability gains are not guaranteed. The growing array of 3D printing materials and processes vary considerably in their environmental implications. A lack of standardisation and limited transparency over the content of printing materials complicate any assessment of the impact. It is also possible that 3D printing could lead to increased material consumption overall by reducing the costs of production, just as inkjet printers led to overall increases in paper consumption in the 1980s.

At this early stage in the technology pathway,



Progress will inevitably require **collaborations** involving the private sector, universities and policymakers

there is a window of opportunity to encourage sustainable 3D printing production and consumption patterns through a combination of industry collaborations and policy action, ideally aligned across major markets. For companies, agreeing to industry-wide standards for printing hardware and software protocols could unlock more rapid innovation. This could be aided by the fact that in 2016, a number of key patents for liquid, powder and metal-based 3D printing are due to expire[11], and by the culture of open innovation fostered in parts of the sector.

For policymakers, the challenge is how to incentivise greener materials, recyclability and biodegradable prints over less sustainable options, without being overly prescriptive. Countries could work together to align standards on 3D printing that help scale up markets for the technology while promoting greener approaches. Governments could also support dialogues that aim to share lessons on consumer engagement in sectors that developed in recent decades. Ultimately, frameworks will be needed that encourage smaller firms, and that adapt to local industrial characteristics.

Conclusions

Today, resource productivity policies remain a largely national concern, but there are important areas where international collaboration is needed – not only to scale up and manage new disruptive approaches, but also to roll out best-practice approaches in more mature sectors, capturing efficiency gains in heavy industry and waste sectors. Given the complexity of these challenges, progress will inevitably require collaborations involving the private sector, universities and policymakers, and often the solutions will require cross-border cooperation.

In the run up to the international climate change negotiations in Paris in November 2015, a group of governments launched Mission Innovation, committing to increase the share of GDP spent on low-carbon technology. Meanwhile, industry and investors forged a complementary Energy Breakthrough Coalition. Both underscored the need to develop and scale up next-generation technological solutions to tackle energy and climate change.

Progress on resource-related innovation has seen comparatively little advance at the international level. This is despite the potential for resource efficiency measures to cut greenhouse gas emissions by 60% by 2050, relative to 2015 levels, a pathway consistent with the Paris Agreement[2]. Germany's presidency of the G20 in 2017 is a window of opportunity to foster action on this area, building on the work of Germany's and Japan's G7 presidencies in 2015 and 2016, and on collaborations between G20 countries such as the China-Korea-Japan Circular Economy Initiative and the proposed UK-China Circular Economy Zones.

There is therefore scope to establish a parallel 'Resources Breakthrough Coalition', also in partnership with Mission Innovation and perhaps under the G20, but focused on the intersection of resource savings, emissions reductions and green growth. Given the nature of resource challenges, companies in such a coalition could represent the transformative opportunities for enhanced resource productivity along supply chains and at different geographic scales. It could include action on today's large-scale challenges, such as those posed by plastics, food waste and critical raw materials, as well as helping risky and uncertain technologies with the potential to disrupt resource consumption pathways.

Resource recovery: linking renewable energy, waste management and sustainable agriculture

Kirk Semple, Alfonso Lag Brotons and Rachel Marshall, Lancaster Environment Centre, Lancaster University; Lois Hurst and Ben Herbert, Stopford Energy and Environment, Ellesmere Port

Achieving food and energy security in a sustainable way poses some of the largest challenges facing society worldwide. The recovery of energy and nutrients from waste offers opportunities to tackle these issues while simultaneously improving waste management – a key concept within 'circular

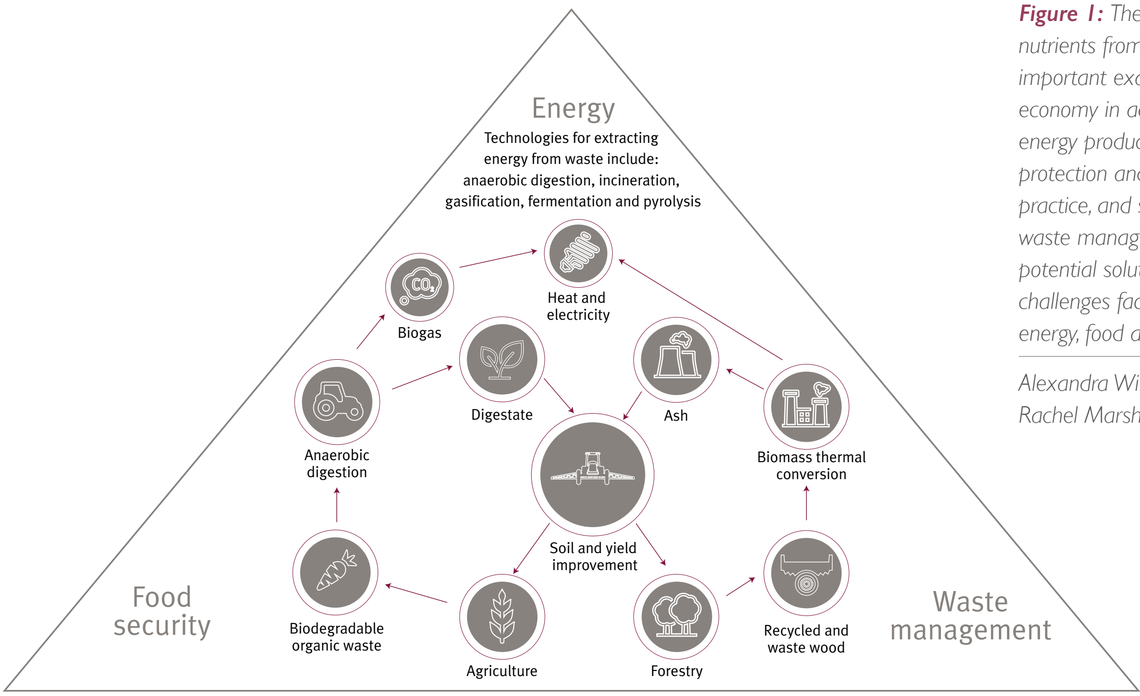


Figure 1: *The recovery of energy and nutrients from waste materials is an important example of the circular economy in action. It enables sustainable energy production, provides soil protection and benefits for agricultural practice, and simultaneously improves waste management, thus offering potential solutions for three major challenges facing the global community: energy, food and waste.*

Alexandra Wilkinson and Rachel Marshall

This document is not a statement of government policy

120
million tonnes
Annual plastic to landfill

economy' thinking (see Fig. 1). UNEP suggests that waste disposal is unsustainable as a management strategy[12]. In contrast, resource recovery from waste offers a chance to ameliorate detrimental effects on the environment while simultaneously providing societal and economic benefits.

The sustainable management of energy, waste and resources in the EU is governed by a number of high-level policy directives that establish a compliance framework (for example, the Waste Directive[13]) or stipulate time-bound targets to member states (such as the Renewable Energy Directive target and Landfill Directive[14]). Although such overarching directives govern the management of waste resources at an EU level, their interpretation and implementation at a national level presents a significant opportunity to develop innovative solutions for sustainable resource management.

In the UK, the Renewables Obligation Order (ROO)[15] and the Electric Market Reform (EMR)[16], as well as Defra's Waste Management Plan[17], are policy instruments that seek to reflect the requirements of their respective overarching EU directives. They do so by providing fiscal incentives for sustainable energy generation (eg Renewables Obligation Certificates) and resource management (eg the Landfill Tax). These policy mechanisms, which aim to promote low-carbon energy generation and sustainable waste management, have therefore created a commercial opportunity to develop energy-from-biomass and energy-from-waste (EfW) schemes in the UK.

The dominant technologies incentivised under ROO and EMR to convert biomass and waste into energy are combustion, gasification, pyrolysis and anaerobic digestion. The principal products from EfW schemes are heat, power and liquid or gaseous fuels. But the by-products – ash (rich in phosphorus and potassium) from thermal processes, and digestate (rich in nitrogen) from anaerobic digestion – have an inherent nutritional value. The nutritional value of these by-products can be exploited to offset demand for finite and energy-intensive fertiliser sources.

Resource recovery from waste

Focused research is required to tackle the complex reality of waste management and the potential technologies and pathways that facilitate resource recovery. To address this, the Natural Environment Research Council (NERC) has funded a £7.2 million Resource Recovery from Waste (RRfW) programme[18], which aims to deliver the science needed to accomplish a paradigm shift in the recovery of resources from waste. This initiative funded 6 projects in 2014: 5 of them are examining resource recovery from a range of different waste streams, and the sixth is developing a methodology for assessing the value of different waste recovery interventions.

As part of this programme, researchers from Lancaster University's Environment Centre, the consultancy Stopford Energy and Environment, and the James Hutton Institute, are developing a novel approach to maximise the nutritional value of anaerobic digestate and wood ash, both by-products of bioenergy generation. Through the formulation and testing of a suite of low-carbon land conditioners and fertilisers, the Adding Value to Ash and Digestate (AVAnD) project seeks to:

- Improve crop health and crop productivity
- Enhance the maintenance of soil function and quality
- Improve the sustainability of agricultural practice through the application of low-carbon technology
- Provide an alternative to energy intensive inorganic fertilisers produced from finite natural resources
- Monetise the waste streams from bioenergy generation to provide an additional revenue stream to the operator, thus reducing reliance on government's fiscal incentives for renewable energy generation

The challenges of handling waste from **emerging technologies**... will be very different from those needed to handle, say, plastics

- Divert bioenergy residues from landfill or low-value applications, presenting a cost saving to the plant operator.

The AVAnD project studies how the chemical composition and physical properties of different sources of bioenergy residues can be utilised to produce a fertiliser product to an exacting specification. The typical composition of ashes and digestates from bioenergy generation is well characterised. However, their application is limited due to variations in chemical and nutritional content, as well as the quality of the waste material, which are determined by the nature of the feedstocks and bioenergy processes from which they are produced. For the first time, this project aims to:

- formulate a standard blend of waste stream mixtures to optimise nutrient delivery for agricultural practice and/or soil conditioning
- work out the best way to combine waste streams, which are otherwise handled separately, for additive or synergistic benefits to soil health and fertility
- mitigate problems associated with utilising each waste stream separately, thereby enhancing predictability of product and adding value to materials derived from the bioenergy industry.

The project will create additional value in the bioenergy sector by transforming materials of low worth into high-value products for use in agriculture. In turn, this will enhance the long-term viability of a heavily subsidised industry. Both ash and digestate, in their unprocessed forms, have limited economic value, and this has put many plant operators under commercial pressure.

These innovations will also provide farmers with an alternative source of nutrients that will be resistant to the price volatility exhibited by existing synthetic products. The price of manufactured fertilisers has swung by 300% over the past 10 years, due to the supply and demand for finite phosphorus resources and the impact of fluctuating oil prices on energy-intensive ammonia synthesis. Formulating fertiliser products from bioenergy residues, using this innovative business model, presents a significant commercial opportunity for the bioenergy and farming sectors alike.

Policy barriers

Waste legislation controls the use of materials considered to be waste – even those with inherent value – in a 'risk conservative' approach. These mechanisms include Environmental Permitting Regulations[19], the reuse of specific materials, or ultimately granting end-of-waste status to a material (a long process, with risk mitigation as its principle driver – see Chapter 2).

Further technical advances are needed to mitigate the risks of mixed wastes that originate from their heterogeneity and possible contamination. If renewable energy policies promoted quality waste outputs (ie reduced contamination through improved waste management, and improved homogeneity through contract security), then by-products would present a lower risk and could be more easily valued. Additionally, integrated risk assessments should consider hazards associated with the production of materials that the waste resources are likely to replace (for example, the environmental damage caused by phosphorus mining).

A more holistic policy approach is required to maximise the value of biomass-to-energy and EfW schemes. At present, only the renewable energy generation potential of a scheme is incentivised, while the potential carbon savings attributable to by-product reuse is overlooked. Policies should aim to acknowledge not just renewable energy, but also renewable resources, in order to fully realise the financial and societal benefits of the UK bioenergy industry.

The TotalCare® business model

Dr Andrew Clifton and Alex Dulewicz, Rolls-Royce

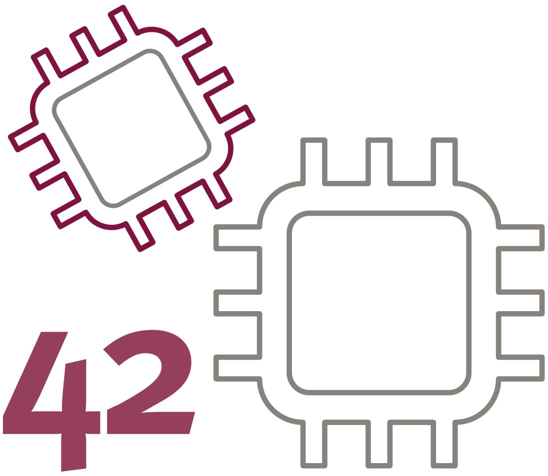
Rolls-Royce has always offered its customers a choice in the way they can manage the maintenance of their aircraft engines. These include traditional Maintenance, Repair and Overhaul (MRO) services; through to a more comprehensive offering called TotalCare®. The TotalCare option aims to alleviate the burden of engine maintenance and transfer the management of the associated risks to Rolls-Royce. Whilst an advantage to this approach to business is the positive effect it has on waste reduction and resource efficiency, it is the derived value to the customer in terms of allowing them to focus on their key business deliverables that makes it a success.

The concept of TotalCare originated as a mechanism to address a conflict in the traditional MRO aftermarket business model. Under the MRO model, if an engine requires unscheduled maintenance resulting from an operational event, then the original equipment manufacturer (OEM) of the engine would carry out the repair for a fee. This means that the OEM is effectively rewarded for the failure of its product, even if the customer's aircraft is grounded as a result. In contrast, TotalCare incentivises Rolls-Royce to actively manage an engine through its lifecycle to achieve maximum availability, ensuring that Rolls-Royce's business model aligns with the airlines' goal of keeping aircraft flying and maximising their revenue. At the heart of the TotalCare philosophy is its business structure: TotalCare is charged on a fixed dollar per flying hour basis, so Rolls-Royce is rewarded only for engines that perform. Fundamentally, TotalCare is designed to reward reliability, a factor valued most highly by customers.

The basic features of TotalCare are:

- Truly aligning business models
- Predictable cost of ownership
- Focus on minimising operational disruption.

Since the launch of TotalCare in the late 1990s, more and more customers have moved from traditional MRO services to 'power-by-the-hour' long-term service agreements like TotalCare. Customers state a variety of reasons for the shift, but the main driving factors are all related to cost and performance. Engines are critical to customers' operations, and their complexity and safety-critical nature makes maintenance and repair a costly and time consuming job. As such, when an engine becomes unserviceable, it can have a significant impact on the customer in terms of the disruption to flights and the resulting lost revenue and damage to reputation. In these situations, customers value the OEM's expertise and knowledge to manage these risks. It is also attractive from the OEM's perspective: Rolls-Royce can use its knowledge from designing, manufacturing and servicing a wide variety of engines to bring these risks down to much lower levels, and use the additional data they collect to help improve their products, both current and future. It is important to recognise that it is the distinctive benefits that TotalCare provides to the customers and the OEM through alignment of their business models that makes it work. The additional benefits of increased resource efficiency and reduced waste that are naturally provided by a more servitised business model are not enough to make it a success on their own.



The number of elements in a microchip

A business model that retains product service responsibility with the OEM provides an increased drive to **reduce repair** and **maintenance costs**

Product stewardship

Engines are highly valuable assets, and they require significant upfront R&D investment to certify and bring to market. In order to get a satisfactory return on investment, providing revenue to reinvest into developing new or improved engine products, engines need to be in service for a long time. Consequently, a business model that retains product service responsibility with the OEM provides an increased drive to extend product service life, and reduce repair and maintenance costs – all of which reduce wastes and increase resource efficiency. Rolls-Royce is able to deploy its expertise and product knowledge to ensure engines under TotalCare stay on-wing for longer, making TotalCare an attractive proposition for customers.

Rolls-Royce's business depends on ensuring that its engines are available for use, which requires a very good understanding of how the product is going to perform in service. The company needs to know what servicing will be needed, and when; how many spares it should manufacture; and where they should be kept to best serve the customer. Rolls-Royce has access to very large datasets, including historical data from MRO contracts and current data gathered in real time through proactive maintenance services such as Engine Health Monitoring (EHM) and Proactive Engine Life Management systems. This information, combined with advanced analytics, enables the company to proactively plan any maintenance or repair activity to minimise disruption. It also provides information that Rolls-Royce can feed back to its design teams to improve future products and services.

Retaining access to products and components has also provided opportunities to change the business in other beneficial ways. One such change is the Revert programme, a collaborative recycling programme between Rolls-Royce and its material suppliers. As part of the programme, metal removed during the manufacture of components and from certain unserviceable engine parts is collected, segregated by specific alloy type, cleaned of all coatings and contaminants, and returned to the material supplier for recycling. The extra levels of material stewardship provided by a TotalCare contract enables Rolls-Royce to produce very high quality recyclate, with the necessary chain of custody and certification for the material supplier to be able to reprocess it back into aerospace-grade alloys for reuse by Rolls-Royce – creating a closed loop material system, which retains the value of material that would otherwise have been deemed as waste.

TotalCare contracts have seen a significant uptake by customers. While the principles of TotalCare will remain unchanged, developments in digital technology – particularly in the areas of sensors, data, and analytics – will help Rolls-Royce to broaden the scope of the support offered to customers, to include route optimisation, asset management and end-of-life management.

By listening to customers, Rolls-Royce recognised that TotalCare could be optimised to meet the requirements of customers with engines approaching the end of their service life. In this phase of the product lifecycle, the customer's requirements are focused more on extracting as much of the engine's useful remaining life over a shorter timescale. In response, Rolls-Royce launched TotalCare Flex®, a version of the TotalCare model that enables Rolls-Royce to efficiently manage the fleet of in-service engines through the increased use of Serviceable Used Material (SUM) or engine exchanges. Basically, TotalCare Flex provides much more flexibility to use serviceable engine parts to support customer engines – increasing part and material utilisation and again reducing waste.

Rolls-Royce recently announced that it is collaborating with industry experts like Microsoft to pioneer next-generation, digitally-enabled services for a future 'Smart Engine' system. Aeroplanes produce terabytes of data during long-haul flights, and the collaboration with Microsoft seeks to develop tools and systems that use this data to help customers operate more efficiently, increasing the availability of aircraft and ensuring passengers get to their destination on time, every time. While the focus of the Smart Engine system will be on operational efficiency, the data can also be used to track components and materials across the large fleet of Rolls-Royce engine operators. This data can then be used to maximise utilisation of parts and material, further minimising wastes in the form of inefficient logistics, and ensure that Rolls-Royce extracts the maximum value from the resources available. These future enhancements should increase the resource efficiency potential provided by TotalCare contracts.

Remanufacturing ICT equipment

Walter Stahel, Founder-Director, The Product-Life Institute, Geneva; and Conrad Mohr, Business Development Executive, A2C Services, Portsmouth

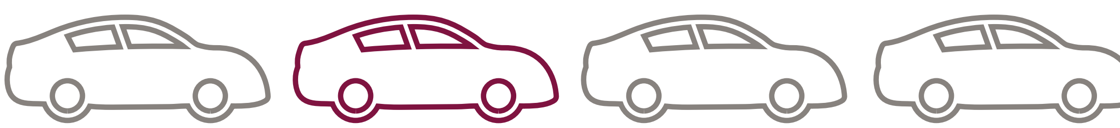
ICT hardware is an ideal candidate for remanufacturing, a process that rebuilds, repairs and restores equipment to meet or exceed its original performance specifications. It enables yesterday's technology to deliver the same performance as today's new technology, and can be applied to equipment that has been sold or leased to corporate clients, public bodies, or individuals. ICT remanufacturing offers a range of environmental and societal benefits, and is also profitable.

The 2008 EU Waste Directive lists waste prevention as its first priority, and reusing products – or extending their lifespan through remanufacturing – are the best tools to achieve this goal (managed under the EU Waste Electrical and Electronic Equipment (WEEE) Directive). Remanufacturing supports 11 of the UN's 17 Sustainable Development Goals[20] to end poverty, fight inequality and injustice, and tackle climate change by 2030. It is also the most economically- and environmentally-profitable business model of the circular economy[21] (see Chapter 1, box on p12).

A typical microchip incorporates 42 elements of the periodic table, and recycling these separately is an almost impossible task. Instead, remanufacturing can bypass bottlenecks in recycling and turn imported goods into a national resource. This helps to preserve metallic and mineral resources (including rare earth elements), prevents the loss of these resources in recycling processes, and reduces the global trade in electronic waste. Carrying out safe, low-carbon processes here in the UK can replace mining operations and ICT production processes abroad that may have a larger environmental footprint. As a consequence, it also offers a way to help tackle the health, safety and environmental hazards of mining and the global waste management industry.

Remanufacturing businesses in the UK can

40%



Reduction in congestion if half of drivers used ride-sharing apps instead

The **way we work in the UK is changing** and, for many, the prospect of traditional employment is outdated, rigid and unattractive

increase skilled local employment and taxable revenue, potentially playing an important role in the 'intelligent decentralisation' of high-tech industries and contributing to regional re-industrialisation. A2C Services in Portsmouth, for example, is a leading ICT remanufacturing company that employs 100 skilled people who processed 700,000 desktops and laptops from 2013 to 2015.

A2C Services has developed a process to remanufacture 99% of compliant end-of-lease ICT, upgrading it to meet customer specifications. This typically extends the useful life of 3- to 5-year-old PCs by at least another 9 years, providing another 3 lifecycles of operation. The lower sales price of remanufactured ICT also helps to bridge the 'digital divide', by making the equipment more affordable for a wider range of customers. A2C is developing additional services, such as geolocation tracking software to create a transparent chain of custody for used ICT, and social inclusion programmes that donate equipment to charities.

Future outlook

The potential for remanufacturing is set to grow, as manufacturers and consumers shift their focus from simply buying the latest hardware to ensuring that they have the software (or apps) that they need. Reprogrammable microchips can extend the service life of ICT equipment by remotely upgrading key functions, thus removing one of the main reasons for periodic replacement of hardware. This all makes renting or leasing hardware more attractive, potentially increasing the demand for local ICT repairs and remanufacturing.

National and local governments potentially have a key role to play in this sector. Using remanufactured ICT equipment could help them to make better use of their budgets, providing 'more IT for less money'. The UK government is one of the country's largest users of ICT equipment, and has advocated ICT reuse. The US government has already adopted and accepted ICT reuse in public procurement policy, and has a stated preference for buying services instead of hardware.

Policymakers could also substantially increase national competitiveness by promoting remanufacturing as part of the circular economy as a whole[22], through a number of measures:

- Much of the economic and technical knowledge of the circular economy is currently in the hands of SMEs such as A2C Services; and fleet managers such as Xerox, Rolls-Royce, the armed forces, and Caterpillar. Bringing this knowledge into universities and vocational training will help the economic transition to a circular economy
- Stimulating basic research into technologies to de-polymerise, de-alloy, de-laminate, de-vulcanise materials, and de-coat surfaces could improve and extend remanufacturing, and its associated recycling processes
- Policymakers can help to close 'liability loops' by clarifying the ownership of waste ICT equipment, through schemes such as Extended Producer Responsibility (see Chapters 4, 13 and 14). If there is no available loop option (eg remanufacturing or environment-friendly recycling) at the end of a product's service life, the manufacturer or importer should be liable to take the product back and develop such a method or process at their expense.

The Sharing Economy

Ellie Gummer, Director, Sharing Economy UK

There is no single definition of the sharing economy, but a recent report from the financial services company UBS defined[23] it as:

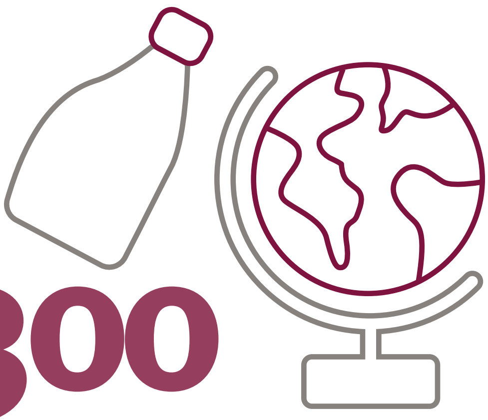
"A socio-economic movement which allows consumers to get products or services from each other or shared platforms via use of the web or mobile interfaces. Buyers and sellers are brought together by a peer-to-peer sharing of goods and services where underutilised assets can be monetized."

In essence, the sharing economy enables people to make money from their time, or assets they already own for example by renting out a spare room or a driveway.

In addition to making money, the sharing economy enables people to save money by offering goods and services at more competitive rates than traditional business. The financial crisis of 2007 to 2008, and the economic hardship which followed, has driven growth in the sector as consumers spend more cautiously and seek out the best deals.

Consequently, the sharing economy offers benefits to both supplier and user. For example, a parent may have an empty room when a child is away, so they use companies like Airbnb to top up their income. Their guest is able to stay at a more affordable price than traditional accommodation and also 'live like a local', enjoying a more authentic trip.

Due to these benefits, the uncertain economic situation and the flexibility of the industry, the UK has seen the sharing economy expand rapidly. According to a recent report from the professional services firm PwC, the sharing economy in the UK was valued at £7.4 billion in 2015, up from £2.1 billion in 2012 – a 252% increase[24].



300
million tonnes
Annual global plastics production

Reducing waste, increasing productivity

These new platforms allow users to use otherwise idle assets in a number of different ways to reduce waste. Accommodation is the sector which has seen the most significant growth of this kind, as it enables people to make money from their most valuable asset – their home. Sharing economy platforms mean that your home doesn't need to be empty while you are on holiday: it can be rented out and used to contribute to your household income.

The transport sector is also expanding rapidly, a trend likely to continue. For example, it used to be that when you were using your car, your driveway would be empty. Now, with platforms like JustPark, you can allow other people to 'rent' it on a temporary basis. This allows the driveway's owner to earn money from their unused drive, and relieves pressure on city car parks.

Indeed, you no longer need to own your own car: a platform such as Zipcar allows you to rent one when and where you need. There is also evidence that ride-sharing apps like Uber and BlaBlaCar have had co-benefits, such as in reducing traffic fatalities[25]. If 50% of drivers adopted ridesharing, there could be a 20% reduction in the number of vehicles on the road, and a 40% reduction in the amount of time drivers spend in congested traffic[26], with commensurate savings in fuel use.

The sharing economy also enables people to value their time by providing micro-entrepreneurs with greater control over their time, rates and where they work. The way we work in the UK is changing and, for many, the prospect of traditional employment is outdated, rigid and unattractive. There has been a real shift in employee expectations. The PwC report 'Millennials at Work: Reshaping the Workplace'[27] illustrated that after training and development, flexible working is the biggest issue for millennials. In addition, 44% of working age women are economically inactive, often due to caring responsibilities such as being a mother[28].

For these women the sharing economy can offer ad hoc work and a route back to work.

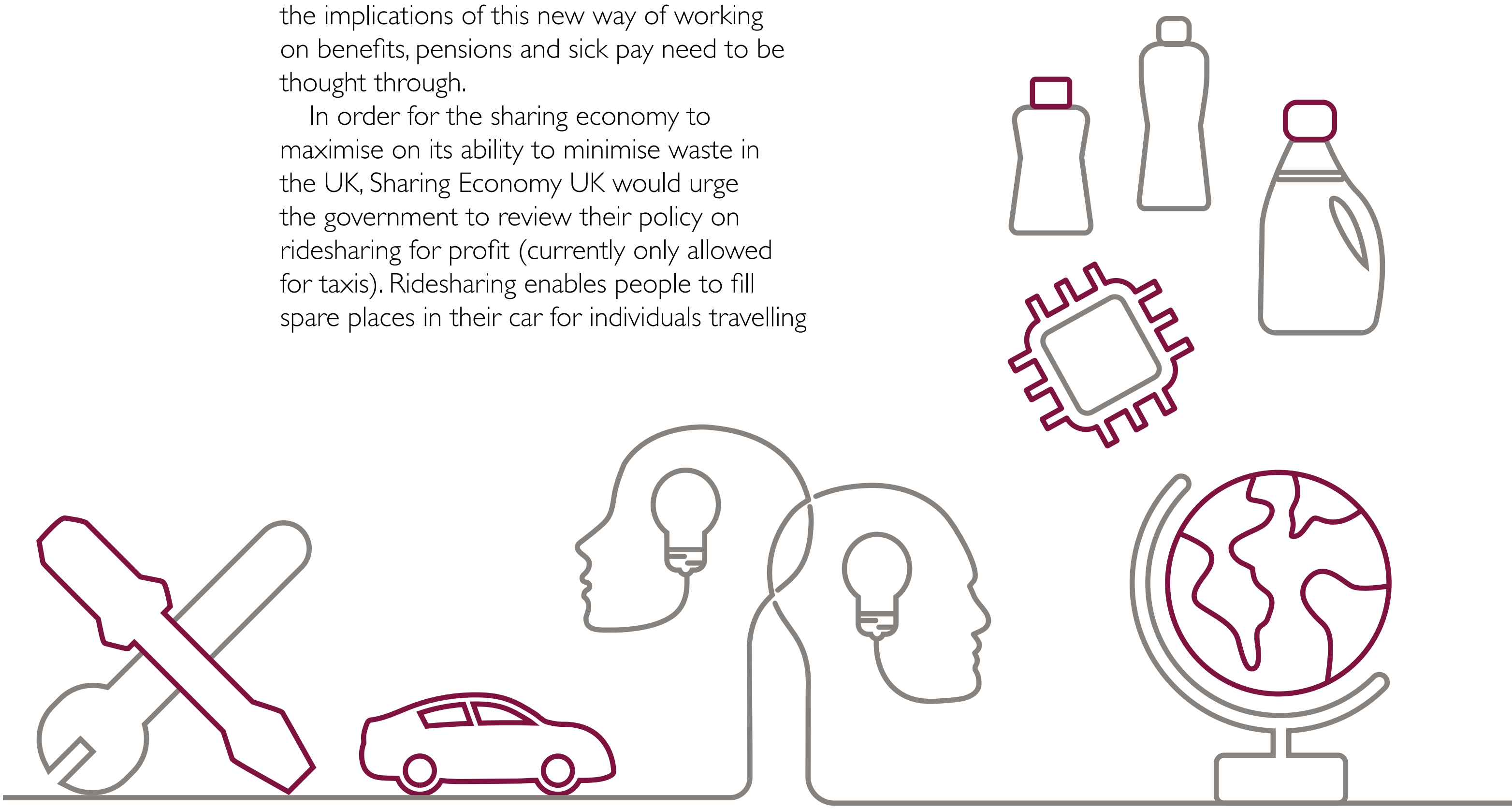
The economist Diane Coyle wrote in her 2016 report, 'The Sharing Economy in the UK', that it "leads to win-win efficiency gains not included in GDP"[29]. The report also highlighted that "in the case of the sharing economy, the eliminated waste can take the form of search time spent looking for, say, a specific service such as the ideal holiday rental, or for someone with specific skills; or it can be under-used assets".

Conclusions

Alongside the substantial opportunities, the sharing economy also brings a number of challenges – not least in terms of the need to protect the working conditions and other rights of those who operate in the field. Rules around self-employment need to take account of the growth of the sharing economy and the implications of this new way of working on benefits, pensions and sick pay need to be thought through.

In order for the sharing economy to maximise on its ability to minimise waste in the UK, Sharing Economy UK would urge the government to review their policy on ridesharing for profit (currently only allowed for taxis). Ridesharing enables people to fill spare places in their car for individuals travelling on similar journeys. There are a number of successful ridesharing companies in the UK, but due to the fact that a driver is unable to ride share for profit, it has not reached the same levels as in the US.

While we know that the sharing economy has a positive impact on productivity, there is currently a 'measurement gap', so it is not yet clear exactly how significant this impact is. This is in part because GDP figures do not take into account of economic benefits such as time saved, increased choice and lower cost of products – all of which are key consumer benefits of the sharing economy. Coyle recommended that the Office for National Statistics (ONS) should look at how productivity is measured in the UK, and this would be an extremely positive step.



SECTION: 2

Sectors

Businesses operate, and engage with citizens, across many economic sectors, each generating very different quantities and types of waste. In every sector there are a range of substantial opportunities to increase resource efficiency. While the technical solutions to these problems are diverse, some important common themes emerge when we think about waste through the perspectives of different sectors. This section examines how the objectives of businesses operating within each sector could be successfully aligned with resource productivity objectives.

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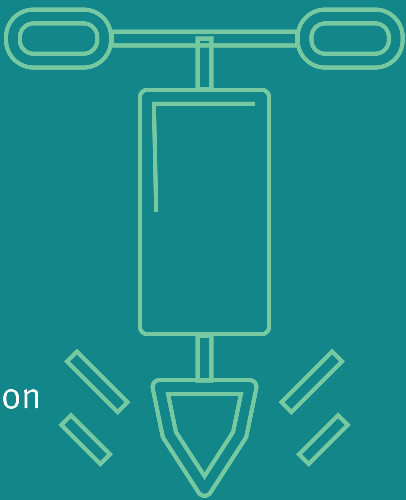
In Brief



50%

Proportion of waste produced by construction and excavation

8,000

Number of people employed in scrap recovery in the UK

27

million tonnes per year

Waste from households

$1-2 trillion

Cost of global food sector inefficiency per year

1,000

Unique inventions around 3D printing were seen in 2015 alone

CHAPTER 4:

Household waste

In the UK, recycling of municipal solid waste has increased from 11% to 45% over the past 15 years, making the country one of the fastest improvers in Europe. But global economic conditions, the changing landscape of local government, and wider social and behavioural factors could act as a barrier to further progress. Greater attention to market forces, the allocation of responsibility and cost, and a broader set of policy levers could all help to overcome these hurdles.

Steve Lee, Chief Executive Officer; and Pat Jennings, Head of Policy & Communications, Chartered Institution of Wastes Management

In the context of resource productivity and environmental behaviour change, municipal solid waste (MSW) – essentially waste from households – is something of an oddity. It amounts to roughly 27 million tonnes per year, representing just 14% of total waste arisings in the UK[1], and yet it has been the primary focus of most waste and resource policy and legislation to date. This reflects the important role that municipal waste management plays in protecting public health and the environment, imperatives that have shaped waste collection services across the UK since local authorities were given responsibility for the regular removal and disposal of refuse in the 1875 Public Health Act[2a] (see Chapter 12). Other reasons for its prominence in policymaking include its visibility as the main frontline council service that residents engage with on their doorstep; the cost to the public purse (waste collection and disposal is the fourth largest area of council spend, at £7 billion per year[2b]); and its changing composition and complexity (see Fig. 1).

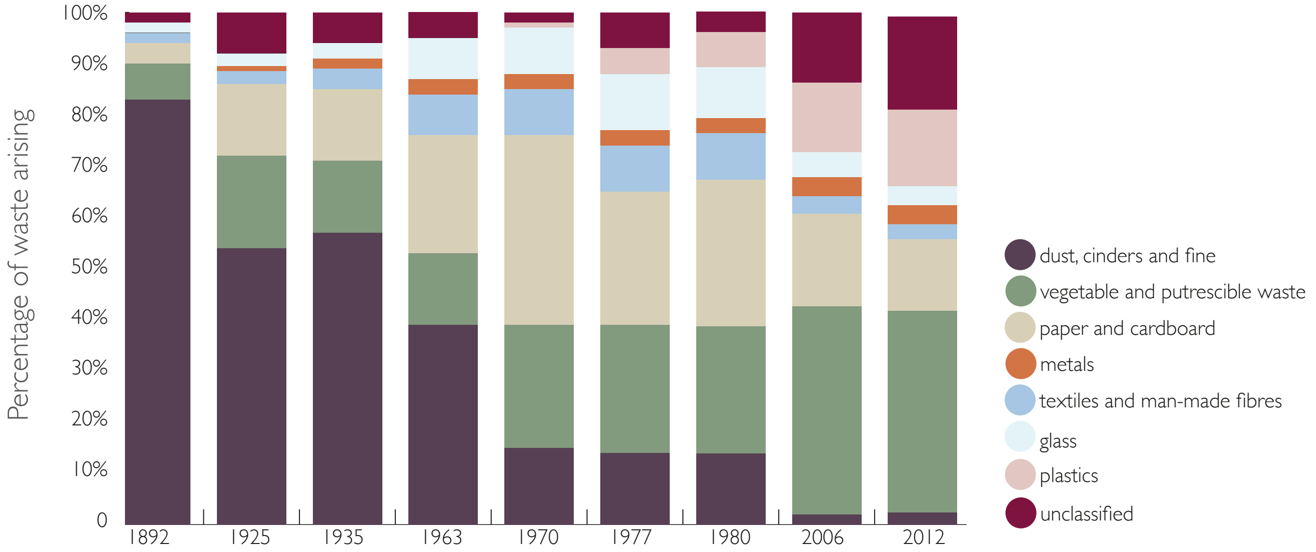


Figure 1: *The composition of waste from households 1892 to 2012*

David Greenfield and Ryan Woodard: adapted from Royal Commission on Environment Protection (1985), Coggins (2003), Resource Futures (2009), and Resource Futures (2012).

As recycling and resource recovery have emerged as desirable outcomes, the system for managing MSW has successfully adapted to meet these goals. As a result, the UK's recycling rate (based on the amount of recyclable material collected by local authorities, less any contamination removed in the first sorting process) has quadrupled over the past 15 years[2c]; in 2015 it recycled almost 12 million tonnes of valuable materials. If resource productivity and optimising the volume and value of the secondary materials it makes available to the market had been the primary aim at the outset, however, the system might have looked very different. That is the challenge facing the sector today: how to deliver the necessary health and environmental protection, while simultaneously supporting the drive for resource productivity and optimising the volume and value of the secondary materials it makes available to the market. These imperatives are not always easy to align, and this chapter discusses the complex range of factors that influence waste management and recycling performance in the UK. It shows that recovering value from MSW can be achieved if the right drivers are in place: clear and co-ordinated policies, targeted funding to support the roll-out of necessary services and infrastructure, and economic mechanisms (such as the Landfill Tax) to change behaviour, for example. However, it also suggests that if higher levels of recycling are desirable to support greater resource productivity in the future, there are a number of barriers that now need to be addressed.

Policy and performance in modern waste management

Notwithstanding the UK's pioneering work in sanitation and public health engineering during the 19th century, the EU has played a pivotal role in driving the shift from 'waste' to 'resource' management in the UK. A number of EU directives have shaped modern waste policy in the last 20 years, including:

- the Waste Framework Directive[3]
- the Landfill Directive[4]
- Producer Responsibility legislation
  - the End-of-Life Vehicles (ELVs) Directive[5a]
  - the Waste Electrical and Electronic Equipment (WEEE) Directive[5b]
  - the Directive on Packaging and Packaging Waste[5c]
  - the Waste Batteries and Accumulators Directive[5d]
- the Waste Incineration Directive (now part of the Industrial Emissions Directive)[6a, 6b]

- the Ozone Depleting Substances Regulations[7]
- the Waste Shipments Regulations[8]
- Integrated Pollution Prevention and Control Directive (now part of the Industrial Emissions Directive)[9]

Although all of these are relevant to MSW, the first three have been particularly important. In line with the EU Waste Hierarchy[10], which categorises landfill as the least preferable waste management option, the Landfill Directive (1999) introduced measures to reduce the amount of MSW disposed of in this way, particularly biodegradable waste due to the environmental impact of the leachate and methane emissions; and set stringent technical requirements to prevent or reduce any negative effects on the environment from landfilling. The Waste Framework Directive (progressively developed between 1975 and its latest iteration in 2008) went on to provide a much more holistic legal framework for treating waste, with the aim of protecting the environment and human health by emphasising the importance of proper waste management, and promoting recovery and recycling techniques to reduce pressure on resources and improve their use. It enshrined in legislation some of the fundamental concepts that now shape modern waste management: the 'waste hierarchy'; the 'polluter pays principle'[11]; 'producer responsibility'; and the point at which waste ceases to be a waste and can be considered a product[12]. In its 2008 iteration, it also introduced recycling and recovery targets for MSW (50%) and construction and demolition waste (70%) to be achieved by 2020.

The four Producer Responsibility Directives, of which packaging was the first in 1985 and batteries the most recent in 2006, are designed to make producers more responsible for their products at end-of-life by setting out recovery and recycling targets.

Against the backdrop of this overarching EU legislative framework, and with clear policy and funding support from UK governments, UK landfill diversion and recycling progressed rapidly between 2000 and 2010. UK MSW recycling has increased from around 11% in 2000 to hover around 45% for the past couple of years[2c, 13a] (although Wales has significantly bettered the UK average by reaching 61% according to the latest statistics[13b]) and both the 2010 and 2013 Landfill Directive biodegradable municipal waste diversion targets were met. This step change has marked the UK as one of the fastest improvers in Europe, and puts the country within the group of higher performers.

Additional interventions were needed to deliver this success. Market development and other initiatives[13c] undertaken by the government-funded delivery body WRAP (Waste and Resources Action Programme), for example, increased the amount of UK-based reprocessing capacity, with major investments in a number of facilities including paper mills and plastics reprocessors. It also developed and rolled out the national Recycle Now consumer campaign, created a body of knowledge and best practice for waste collection and recycling, and provided funding to local authorities for local communications campaigns[13d].

The clear policy direction on waste and renewable energy, along with central government support and funding (including Defra's Waste Infrastructure Development Programme and the introduction of the Landfill Tax in 1996) and a period of relative stability and/or growth in secondary raw materials prices[13e] stimulated investment in a range of alternative treatment and processing infrastructure to manage and derive value from the waste streams diverted from landfill. A 2014 report commissioned by HM Revenue & Customs[13f] identified Landfill Tax as a strong driver, noting that: "Investment had been observed right across the supply chain, from improvements in collections, sorting and segregation, through to investments in infrastructure including the construction of new energy recovery facilities and facilities that produce refuse-derived fuel." It also identified a positive impact on research and development in the sector, for example "research into ways to recycle traditionally 'hard-to-treat' materials such as carpet and particular types of plastic".

Technology developments spanned the full spectrum from thermal treatment through to mechanical and biological processes, although with varying degrees of uptake and success.

More sophisticated emissions control technology was developed for conventional thermal treatment (incineration) and advanced thermal treatments, such as pyrolysis and gasification, emerged to derive value from a range of waste streams, producing fuel products such as syngas, chars, and oils. Increasingly, these technologies are being further developed and refined to deliver secondary raw materials to the chemical industry and wider bioeconomy sector and to recover materials from challenging waste streams (see case study on p59).

Advanced composting techniques and anaerobic digestion (AD), meanwhile, have been deployed to convert biowaste into biogas and soil conditioning/fertiliser products (see Chapter 6). This has been one of the most significant areas of growth in tonnage terms: with the rise in household and business food waste collections, coupled with government support and renewable energy incentives, capacity in the food waste AD industry increased from 250,000 tonnes per year in 2009 to over 2 million tonnes by the end of 2015, according to the Anaerobic Digestion and Bioresources Association.

Combined mechanical biological treatment (MBT) and heat treatment solutions also emerged, many focused on pre-treating residual MSW (as required by the Landfill Directive) and usually involving a sorting process followed by either a biological or heat treatment process to deal with the organic content. These technologies aimed both to reduce the biodegradable content of waste sent to landfill and recover recyclables that have not been separated at source.

Higher up the waste hierarchy, developments in materials recycling have primarily been focused on improving the quality of sorting and separation of recovered materials. Some of the most modern materials recovery facilities (MRFs) use a range of technologies including optical and infra-red sorting, with a particular emphasis on plastics and the need to separate the different plastic polymer types to optimise end market value. Advances have also been made in other areas, such as colour separation technology for recovered glass (see case study on p63). These innovations aimed to improve both sorting capacity and quality of recyclables at the output stage.

Diverging policy and performance across the UK

While recycling performance improved across the board for a decade, the policy landscape for waste has changed as a result of the devolution of waste policy. Today, there is a growing divergence across the four UK countries in relation to policy, performance and the drive for 'quality' recycling (articulated in the Waste Framework Directive) to meet end market needs (see Chapter 12). Wales and Scotland have developed ambitious waste and resource strategies[14,15], aligned with wider climate change and economic strategies, that in some cases go beyond the targets and requirements set out in EU legislation. Both governments have continued to invest directly in recycling, most notably in separate household food waste collections. They have also given their local authorities a strong policy steer on the separate collection of recyclables from households (which is mandatory for businesses in Scotland, and includes food waste) in an attempt to both harmonise and improve the quality of the output from household waste and recycling collection services[16,17].

England, on the other hand, has chosen not to be as prescriptive about how recycling is achieved and what collection methods (source separated or co-mingled) should be used, allowing English authorities to tailor collection to suit local needs, but with the overarching 2020 EU targets as the end goal. The Review of Waste Policy in England in 2011 (ref. 18), which superseded the Waste Strategy for England 2007 (ref. 19), is the current policy framework on waste and while it sets out a number of actions and commitments to move towards a 'zero waste' economy, it also effectively removed statutory recycling targets for individual English local authorities.

In October 2013, Northern Ireland published its new waste strategy entitled 'Delivering Resource Efficiency'[20]. While the position is broadly again one of compliance with EU legislation (a 60% recycling target for 2020 was mooted but not adopted), the strategy did set out a number of future policy and legislative proposals, particularly on food waste. These have materialised in the form of the Food Waste Regulations (Northern Ireland) 2015 (ref. 21), which require the separate collection of business food waste where the mass exceeds 50kg per

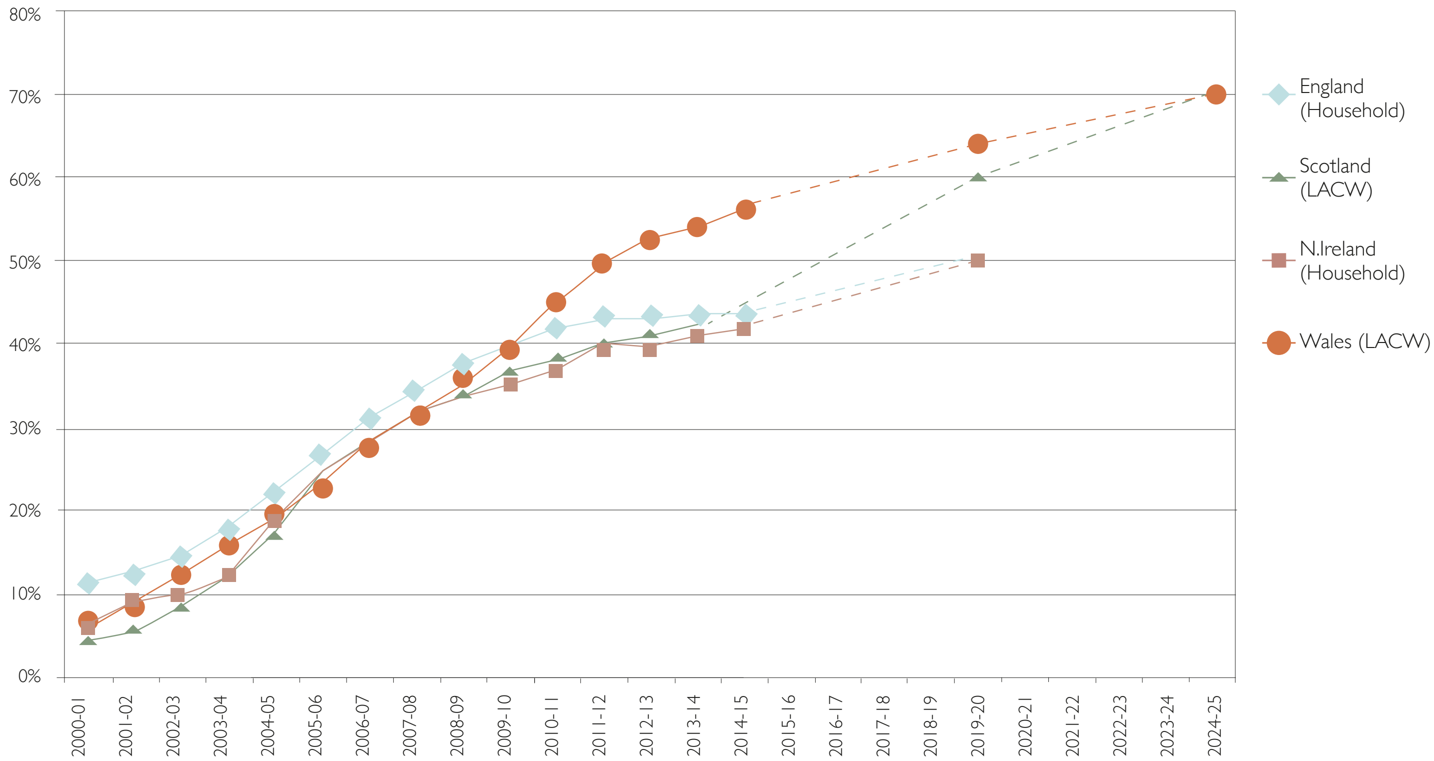


Figure 2: Recycling and composting rates of household or local authority collected waste (LACW) in England, Wales, Scotland and Northern Ireland 2000 to 2014, with projections to 2025.

Nigel Naisbitt / Defra; Statistics for Wales; Scottish Environment Protection Agency; Northern Ireland Department of Agriculture, Environment and Rural Affairs

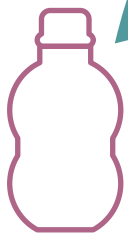
week. From 1 April 2017, this requirement will be extended to food businesses producing more than 5kg of food waste per week.

Figure 2 shows the strong and continuous progress on recycling between 2000 and 2012, with the rates then starting to slow in Scotland and Northern Ireland and plateau in England. Wales, in contrast, has maintained an upward trajectory (although it should be noted that, unlike the rest of the UK, Wales counts metals recovered from incinerator bottom ash towards its national recycling figure, which is estimated to have boosted the 2015/16 recycling rate by 3.6%[22]).

Direct comparison of recycling rates across the four UK countries belies the more complex picture that sits behind the 'headline' performance figures. There are, for example, differences in both scale (England has 53 million people and 353 local authorities; Scotland, by comparison, has 32 local authorities serving 5.3 million people), and in policy approach, thanks to waste being a fully devolved matter. However, the higher performance in Wales deserves a closer look in terms of potential lessons for the UK as a whole.

Wales has set out the strongest and most prescriptive policy framework for household waste of all the UK governments so far and, while accurate comparisons of local and central government recycling expenditure and funding across the UK are challenging, it has invested more per capita in recycling than the rest of the UK, according to Green Alliance[23].

17,000



tonnes per year

Aluminium used in laminate packaging

It also has one of the clearest breakdowns available of expenditure relative to recycling rate (see Fig. 3). Given that other policy and economic drivers (EU-derived legislation and targets, Landfill Tax, etc.) apply equally across the UK, and trends in total waste arisings are broadly similar[24], the Welsh approach does suggest that targeted supportive funding provided in the 'transition' years has acted as a long-term 'invest to save' strategy. The funding has been primarily directed at developing consistent and comprehensive collections services including country-wide household food waste collection and supporting infrastructure and since 2012, the costs of waste/recycling have plateaued and then decreased in Wales, while recycling rates have continued to increase.

For the reasons already mentioned, there are, of

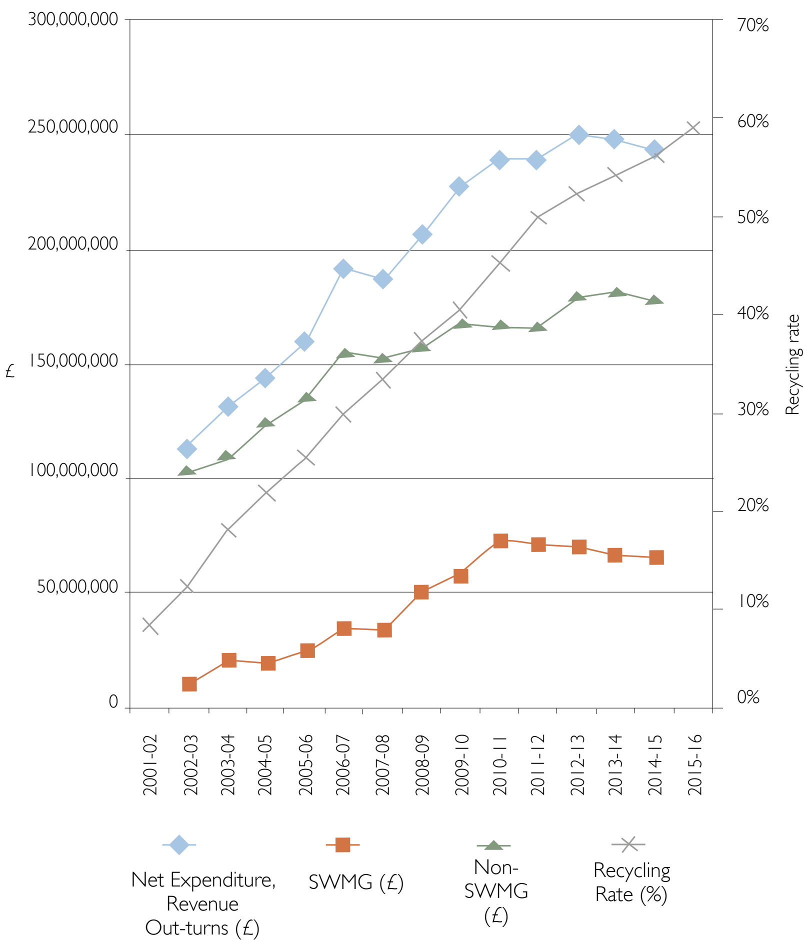


Figure 3: Net expenditure, Sustainable Waste Management Grant and recycling rates in Wales, 2001 to 2016.

Department for Natural Resources, Welsh Government

course, caveats to any comparison or conclusions, and the availability of granular and comparable data is one of the challenges in the waste and resource management sector. As noted above, different local government funding mechanisms and expenditure on waste and recycling are complicated by the varying levels of central funding from the four UK governments, delivered over the course of the last 15 years or so through a range of different grants and funding initiatives. In addition, waste data is also often expressed in terms of the totality of waste collection; specific recycling data cannot easily be disaggregated to reach a true cost per tonne, or cost per household figure.

If recycling and its contribution to resource productivity are seen as strategic future priorities for the UK, a more holistic understanding of the relationship between policy and investment and recycling performance will be needed, complemented by a more accurate quantification of the wider benefits of recycling. This might be a robust and shared method of assigning a value to reduced CO_2 emissions, for example, or avoided primary extraction impacts (see Chapters 10 and 14). These data gaps will need to be addressed to allow accurate cost-benefit assessment of further public investment in recycling and to support evidence-based policymaking in the future. At a wider level, a more rigorous articulation of the wider economic costs and benefits of recycling and resource productivity could help to better engage everyone responsible for creating and using the products that ultimately become waste.

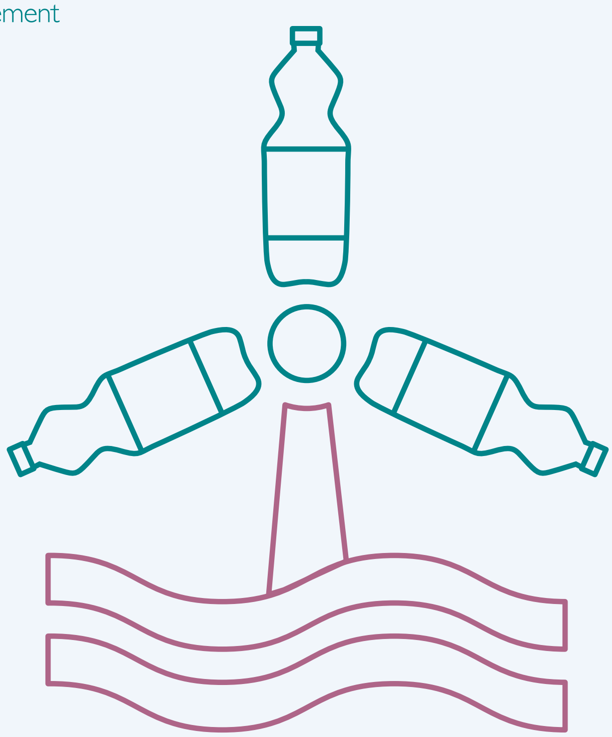
Another consideration in any discussion about policy approaches to, and levels of investment in, recycling is the law of diminishing returns. The rapid progress made to date on recycling has been based on recovering the easily identifiable, high volume materials that have a market value; further progress beyond the rates being achieved by local authorities to date in Wales means accessing smaller, more challenging waste streams for which there may be little demand and which are likely to cost more per tonne to capture than the main recyclables currently collected. Having picked the low hanging fruit, therefore, further gains are likely to require more effort. There are practical issues too: inner-city urban areas with high density housing, for example, face particular challenges in providing accessible recycling services and engaging residents (see

This document is not a statement of government policy

Case Study

From waste plastics to marine power

Pat Jennings, Chartered Institution of Wastes Management



The world's annual plastics production continues to increase and now stands at well over 300 million tonnes[44]. Some of this plastic can be economically recycled into new products using mechanical processes, but a significant proportion currently has to be disposed of because it is unsuitable for this type of processing: the plastic may be contaminated with other forms of waste, co-mingled with other types of plastic, laminated with other materials, or mixed with inherent dyes, fillers and other additives. In 2014, for example, 25.8 million tonnes of plastic waste were generated in the EU. Of this, only 7.6 million tonnes were recycled, with the remaining 18.2 million tonnes of residual plastic waste (RPW) sent to landfill or energy-from-waste (EfW) plants[i].

In response to this problem, Recycling Technologies (RT) in Swindon has developed a process that uses a depolymerisation process to convert this challenging plastic waste stream into a waxy solid called Plaxx™. The soft wax melts to a low viscosity liquid at 70°C, similar to a clean, low-sulphur crude oil. In its raw state, the material is a direct replacement for waxes, heavy fuel oils and, being ultra-low in sulphur, particularly lends itself to marine applications because it meets the new International Maritime Organization marine fuel regulations. Plaxx™ also contains naphtha, and the proportion of this component could be increased with further processing. Naphtha can be used as a chemical feedstock to produce virgin quality plastic, which would help to propel plastic fully into the circular economy as an input to plastics manufacturing. A lifecycle assessment commissioned by Zero Waste Scotland estimates that each tonne of plastic waste diverted from EfW and processed into Plaxx would contribute a net emissions saving of 1.7 tonnes of CO_2 equivalent[45].

A pilot plant able to process 100kg of RPW per hour has been built and is undergoing performance trials at Swindon Borough Council's Recycling Centre. The first full scale unit – the RT7000, capable of processing 1 tonne per hour – is expected to be in operation by mid-2017. Given the modular design of the technology, RT anticipates a rapid roll-out across other sites. RT will design, build, own and operate RT7000s on existing waste sites where feedstock is available, with waste operators agreeing a gate fee per tonne of material processed. RT will market Plaxx™ under a separate commercial agreement to an offtaker, and with payback times currently estimated to be less than three years, the company expects to have 45 machines in operation by 2024, generating revenue of £71 million.

RT is now collaborating with Bristol Robotics Laboratory – a partnership between the University of the West of England and the University of Bristol – to determine if Plaxx™ can be used efficiently in marine diesel engines, which currently use heavy fuel oil, without increasing engine wear. Funded by Innovate UK and the Engineering and Physical Sciences Research Council, the research aims to test engine performance, exhaust emissions and engine wear on different engines over a broad range of test conditions. It is also expected to develop software tools that will monitor these three aspects to enable engine users to achieve optimum performance using this alternative fuel.

The challenge facing the sector today: how to deliver the **necessary health** and environmental protection, while simultaneously supporting the drive for **resource productivity**

Chapter 11). The drive to capture more recyclables from the waste stream has also brought the issue of recycling contamination to the fore [25a].

All these factors, coupled with the growing divergence in policy and performance across the UK, suggest that where recycling rates are plateauing, it would be unwise to assume that they will resume an upward momentum without further interventions.

Waste prevention

The same conclusion could be applied to the UK's success further up the waste hierarchy. In spite of fulfilling the requirements of the Waste Framework Directive to prepare national waste prevention plans, it is difficult to gauge how much progress has been made on waste prevention and reuse in the UK, both of which deliver greater resource productivity than recycling. This is partly due to the more complex nature of the interventions necessary to deliver waste prevention, many of which need to be targeted higher up the supply chain at the point of design and manufacture of products (see Chapter 10). It is also challenging to accurately measure waste that has been avoided and genuine levels of reuse, given the multiple channels through which reuse activities occur (charities, social enterprises, commercial platforms such as eBay, etc).

WRAP has, however, delivered some tangible results on this agenda since 2005, bringing retailers and brands together to deliver waste prevention objectives through four voluntary initiatives known as the Courtauld Commitment[25b] (see Chapter 1, case study on p20). The third phase of the commitment, Courtauld 3, concluded at the end of 2015 and was successful in reducing food and packaging waste in manufacturing and retail by 3%, and improving packaging design and recyclability in the grocery supply chain without increasing the carbon impact, although the household food and drink waste reduction target was not met[25c] signalling the need for a stronger push through Courtauld 2025, the next phase of the programme.

Indeed, all four UK governments have prioritised food waste prevention, supporting Courtauld 2025 and the WRAP-designed Love Food, Hate Waste[26] campaign (see Chapter 9). Some have now gone further: in 2016, Scotland became one of the first areas within the EU to introduce a food waste reduction target to "reduce all food waste arising in Scotland by 33% by 2025 and work with industry to reduce on-farm losses of edible produce".

Wales and Scotland have also set wider prevention and reuse targets, with Scotland taking a particularly proactive stance on reuse, repair and remanufacturing, including its Making Things Last circular economy strategy[27a]; the establishment of the Scottish Institute for Remanufacture; and a mapping exercise to quantify the value resource and economic value of reuse.

Clearly some of the future interventions that could drive waste prevention and reuse are beyond the ability of a single government to put in place. For example, multinational product supply chains and international trade agreements and tariffs mean that embedding resource efficiency principles into product design legislation would need to be done at a European level at least. However, the opportunity to develop clear national policies in this area has been demonstrated by Scotland and unilateral action is possible too – a case in point being Defra's recent decision to reduce plastic waste and marine pollution by banning the sale and manufacture of cosmetics and personal care products containing microbeads[27b].

Policy and funding are not the only factors that affect recycling and resource efficiency, however. Consumer consumption behaviour, product supply-chain drivers, political considerations, and global commodity market trends all play their part, making for a complex dynamic. These factors are explored in more detail below.

Global economic and market conditions

The economic crisis that started in the US in late 2007 and spread across the globe has had a significant impact on the balance sheet for MSW collection and recycling. The ensuing recession in the UK resulted in austerity measures and ongoing public spending cuts. In its November 2014 report on the impact of funding reductions on local authorities, the NAO predicted that by 2015/16, central government funding to local authorities would have been reduced by 37% (excluding the Better Care Fund and public health grant), and whilst it found that statutory services such as waste had been largely protected to date, it said that "Ensuring that local authorities remain financially sustainable, in that they deliver their statutory services to a sufficient standard, is becoming more difficult."[28]

These pressures could have an impact on the ability of councils to adapt and tailor their services in the future to capitalise on the resource value of waste rather than simply fulfilling their statutory duty to collect it, especially if significant upfront costs in equipment or infrastructure are required. In an ideal world, the value derived from putting secondary raw materials back into productive use should provide its own source of revenue to fund collection services – but the 'return on investment' for recycling is dependent on global market forces and supply chain decisions well beyond the control of local authorities and their private sector waste contractors involved in the collection and sorting and waste.

This tension between desired policy outcomes and market forces has been evident in recent years as a result of commodity and secondary material market trends. The decade-long commodity boom from the mid-1990s was largely due to the rising demand from emerging markets such as the BRIC countries, particularly China. It was interrupted by a sharp downturn in prices during 2008 and early 2009 as a result of the credit crunch and sovereign debt crisis, but after this blip, commodity prices rose again and peaked in early 2011. The past 5 years, however, have been characterised by falling prices and a marked increase in volatility, with the slowdown in China's economic growth and the oil price crash exerting additional downward pressure since the beginning of 2015 (see Chapter 14).

These conditions undermine the value proposition for recycling, as market demand for secondary raw materials is inevitably price dependent and their uptake is often predicated on being cheaper than virgin materials. This price pressure has implications for the whole recycling supply chain. Reprocessors have been squeezed, particularly in the plastics sector, where the significant fall in oil price has left secondary plastics struggling to compete against virgin material, the price of which shadows the oil price. As a result, several UK plastics reprocessing facilities have closed down. Local authorities and private waste contractors have also felt the effects, not least because the revenue received from recycling has become far more significant in offsetting collection and sorting costs in the drive for higher recycling rates[29a]. As the value of a 'basket' of recyclables has fallen, there have been many industry discussions about the future net cost of services and the degree to which price risk is shared between authorities and their private sector partners. These market pressures have also sharpened the ongoing debate about the quality of the recovered materials and levels of contamination (see Chapter 9).

Investment in both recycling and residual waste infrastructure is reported to have slowed too. Managing and adding value to recyclable materials requires investment in both services and treatment infrastructure, but with revenues from secondary materials volatile and subject to a downward trend in recent years, the return on investment has become less favourable. In 2016, the Environmental Services Association estimated that around 15% of the UK's current recycling capacity would reach its end of life and could close in the period up to 2020, potentially reducing household recycling rates by 5% (ref. 29b). This is worrying in a wider context, as MSW has a disproportionately strong underpinning influence on the development of future waste infrastructure as a whole. The long-term reliability and high value of MSW management contracts, compared with a more 'spot market' scenario for industrial and commercial waste, lowers the perceived risk and helps to lever investment.

8x

Increase in capacity for anaerobic digestion 2009-2015

A degree of policy uncertainty has not helped the investment case; the Government Review of Waste Policy in 2011[29c], for example, did not set national targets beyond 2020 (unlike strategies set out in Scotland and Wales) and effectively removed statutory recycling targets for English local authorities. The withdrawal by Defra of private finance initiative (PFI) funding from a number of major residual waste infrastructure projects in the past few years, based on assumptions made regarding the UK's ability to meet relatively short-term (2020) objectives, coupled with a number of changes to renewable energy incentives that apply to technologies including anaerobic digestion of food waste, have sent shock waves through the sector.

As Defra notes in its 2015 'Resource Management: a catalyst for growth report'[29d]: "Decisions on investment in new infrastructure are made by market participants based on their assessment of future demand and supply and financial viability. Expectations about future Government policy, including in relation to waste and resource management, affects those assessments and therefore influence investment decisions."

A 2011 report on the financing of new waste infrastructure commissioned by Associate Parliamentary Sustainable Resource Group[29e], also identified 'regulatory and policy uncertainty" as one of the key barriers to private sector investment.

UK policy, which broadly favours a market-led approach, has taken a while to catch up with these issues and we are not alone. Back in 2007, a policy briefing[30] by the Organisation for Economic Co-operation and Development (OECD) summarised the key findings from its 2006 Improving Recycling Markets report, which analysed the non-environmental (ie economic and commercial) market failures for secondary materials. It states:

"Many OECD governments have introduced recycling targets for a wide variety of materials, as well as dedicated policies to encourage recycling. However, the efficiency of such measures depends not only upon their design, but also on the underlying characteristics of the markets in which they are introduced. Unfortunately, it would appear that markets for at least some recyclable materials are subject to significant failures and barriers."

There is now, however, growing recognition that further action is needed to support public policy objectives in the face of these challenges. A Defra supported project initiated in 2015 by the incumbent minister Rory Stewart[31a] and led by WRAP is exploring the opportunities and benefits that could be delivered through greater consistency in local authority collection systems. It is being supported by an advisory group of representatives from right across the sector[31b] and the premise is that a more consistent approach will result in improvements in the quality and quantity of recyclables collected from the household waste stream, better engaged and less confused householders, and financial benefits. Launched in September 2016, the 'Framework for Greater Consistency in Household Recycling for England' is still an ongoing programme of work and WRAP chief executive Marcus Gover acknowledged that "More consistent household recycling isn't going to be easy, it will require the collective action of brands, retailers, manufacturers, local authorities, waste management companies and reprocessors."[31c]

More recently, Defra pledged to spread best practice to boost recycling rates after the statistics confirmed the fall in UK and English recycling rates between 2014 and 2015 (ref. 12b) and the

proportion of total **waste households** are responsible for in UK

Case Study

Boosting circularity in Scotland

Pat Jennings, Chartered Institution of Wastes Management

A glass recycling centre that opened last year in Newhouse, North Lanarkshire, is helping to drive Scotland's circular economy, by reducing reliance on imported materials for whisky and beverage bottles. It has the capacity to ensure that 100% of recovered Scottish packaging glass is fit for use by the burgeoning Scotch whisky and drinks sectors.

The 70,000 square foot facility, the result of a £25 million investment by recycling company Viridor, is one of only three such facilities globally. It was developed to reflect the changing legislative landscape for glass recycling in Scotland, by aligning the recycling process to end-market requirements and ensuring that more high-quality recycled glass can be utilised. The plant has also created 30 full-time jobs while boosting the Scottish Government's Warmer Homes Scotland scheme through a partnership with insulation provider Superglass in Stirling.

In the past, the majority of recycled glass was collected at 'bring bank' facilities where members of the public separated the coloured glass streams at source. However, as recycling targets have increased, glass has become a key material in household kerbside recycling collections. Prior to Viridor's investment in advanced colour-sort technology, this had made recycling easier for residents, but restricted local authorities' ability to achieve colour separation.

A further driver for glass recycling has been the Waste (Scotland) Regulations 2012, which requires all businesses and organisations to separate key materials – plastic, glass, metals, paper and card – for recycling; most food businesses are also required to separate food waste for collection. Commercial operations are obligated to use dedicated recyclate collections, which has also shifted glass from colour-segregated to mixed-glass collections.

Until now, mixed-colour recovered glass was typically used in aggregate production, which historically had a lower market value and lower net environmental benefits than 'closed loop' recycling.

The Newhouse recycling centre is designed to process materials to meet these market needs, featuring advanced recycling technology from across the globe. That includes 15 'scientific eye' optical sorters; x-ray sorters; over 0.5km of conveyer belts; and 2.5km of electrical cabling across 3 floors of processing towers, which can process over 50 tonnes of glass per hour.

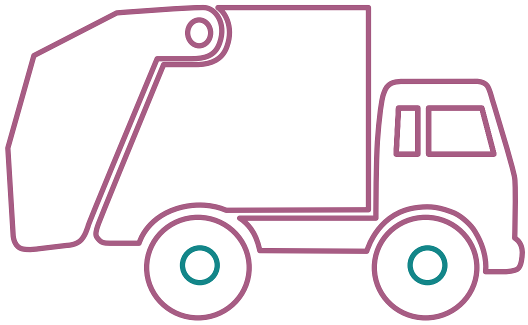
Waste glass entering the process goes through an initial pre-treatment to remove ferrous and non-ferrous metals using eddy current and magnetic machines, with larger contamination fractions removed using manual quality control. Before moving into the optical sorting process, a three-dimensional screener filters out any remaining contamination streams including bottle-cap waste from glass bottles. Finally, the infeed material is processed using optical sorting technology from Dutch company Mogensen, diverting clear ('flint'), green and amber glass streams into separate processing lines.

This is complemented by a quality-control hub, and finally an x-ray sorter to remove any Pyrex materials, with the glass then segmented into fines (0 to 5mm), 5mm to 10mm, 10mm to 15mm and 16mm to 50mm 'cullet' (glass scraps) for onward manufacture.

Recycling glass from across Scottish local authorities, the facility recovers up to 97% of input materials, achieving up to 99% product purity, according to Viridor. That exceeds the quality requirements for the manufacturing of new bottles for the Scotch Whisky industry, a sector focused on high-end product packaging.

£7 billion per year

Council spend on waste collection



Industrial Strategy Green Paper published by the Department for Business, Energy and Industrial Strategy (BEIS) has made explicit reference exploring opportunities to "promote well-functioning markets for secondary materials"[31d].

In addition, Scotland and Wales have been proactively exploring ways to support local authorities in securing better prices from the market. These include providing external expertise to ensure that local authorities have the skills to negotiate effectively with the market and, in Scotland, the establishment of the Scottish Materials Brokerage Service[31e]. It should be noted that efforts in this area are more relevant in Wales and Scotland where the majority of collection and recycling activities remain within the control of the local authorities rather than being contracted out to private waste management companies.

Producer Responsibility and local authorities

EU Producer Responsibility legislation has been implemented in a variety of ways by member states, with some applying the 'polluter pays' principle more fully than others. The UK has opted to introduce producer responsibility frameworks that are based on market competition and aim to meet the targets set by the EU at "least cost to business". In doing so, it has not wholly embraced the concept of full cost recovery from producers, and a proportion of the collection cost rests in some cases with local authorities, and is not always offset by the fee structure applied to producers (see Chapter 12).

This has been less of an issue with regard to batteries, WEEE and ELVs, although market conditions do dictate, to a certain extent, how well the system works for local authorities. In the case of ELVs, for example, when scrap prices have fallen and damaged the 'value proposition' for recovery and recycling, there have been periods when dealing with abandoned vehicles has placed a significant financial burden on local authorities.

In the case of WEEE, there are very clearly defined requirements for producers to bear the costs associated with the collection of WEEE, and measures in place to ensure local authorities can retain the commodity value in WEEE if they so choose. Overall, the system has been efficient in meeting the targets without placing a significant cost burden on local authorities, although there are currently some issues in the market. Factors such as lower material prices; current collection rates already delivering targets in some categories; and recent changes to the regulations reducing trading of evidence between compliance schemes have all led to a fall in demand for local authority WEEE. As a result, it appears that a number of local authorities may have to enact Regulation 34 of the WEEE Regulations (the London Borough of Bexley has already done so[32]), which places a legal requirement on WEEE compliance schemes to pick up Designated Collection Facility WEEE if an authority has been unable to secure a collection contract.

Packaging, however, functions differently to the other schemes, using a competitive, market-based system of tradable Packaging Recovery Notes and Packaging Export Recovery Notes (PRNs and PERNs). One PRN or PERN is generated for each tonne of material reprocessed. Businesses covered by the regulations do not have to recycle their own packaging, but they do have to ensure that an equivalent amount of packaging waste has been recovered and recycled to meet their obligation.

They prove this by securing evidence of

recycling or recovery in the form of a PRN or PERN from accredited reprocessors (or exporters for recycling overseas). This usually involves a financial transaction and PRN/PERN revenue is then meant to relieve any bottleneck in that particular material recovery chain (such as material collection, sorting, reprocessing or supporting end-use markets).

It is debatable how well this system supports local authority collection infrastructure, but it is widely recognised that it falls far short of meeting the full costs of recovery. As the government's Advisory Committee on Packaging states in its 2016 PRN System Guide[33a]: "The system does not finance the full cost of recycling or recovery but instead it provided a "top up" subsidy over and above market prices to incentivise reprocessors to process sufficient material". A report in Bio by Deloitte[33b] to the European Commission's DG Environment in 2014 notes that "In the UK, it is estimated that the fee covers only 10% of the total cost of the system, whereas in most other schemes, 100% of net costs are covered".

The PRN value is also intrinsically linked to commodity market trends, which means that the cost and revenue flows can be highly variable in a given period of time and extremely difficult to map. This results in a further lack of transparency when it comes to gauging the extent to which any funds are channelled back down to local authorities.

In a recent report on recycling and producer responsibility[33c], Green Alliance estimates that "dealing with packaging when it is thrown away costs English local authorities around a third of a billion pounds every year". Late last year, a research report commissioned by the Environmental Services Association[33d] observed: "It is also clear that local authority budget cuts are putting existing recycling schemes at risk and that a perceived lack of benefit from the PRN system is likely to lead to reductions in collected household packaging waste… This would suggest that while the PRN system could continue to bridge gaps, it will be increasingly difficult to meet rising targets without planning and investment, something the market-based PRN system does not readily lend itself to."

The issues discussed in the last two sections – the current fragile nature of the 'value proposition' for recycling because of market conditions and the level of revenue that flows back through the supply chain – raises important questions about the future. At present, the responsibility for waste collection, treatment and disposal falls to UK local authorities, who managed almost 27 million tonnes of waste in 2015 and recycled almost 12 million. The cost of this function (some £7 billion according to the LGA[2b]), is paid for through central government funding and Council Tax and offset by revenue streams from recycled materials, including PRN revenue. Both sides of the equation, however, are under strain, with public sector funding cuts, rising costs in key areas of council spend such as social care, and constraints on what additional money can be levied through Council Tax on the one hand, and variable income from recycled materials on the other due to the market volatility discussed earlier. In 2013, for example, the LGA estimated that English local authorities were only obtaining approximately 28 per cent of the total financial value of materials

Consumer consumption behaviour, product supply-chain drivers, political considerations, and global commodity market trends all play their part, making for a **complex dynamic**

Case Study

Recycling 'smart' packaging

Pat Jennings, Chartered Institution of Wastes Management

Companies that make fast-moving consumer goods – often perishable, low-cost items that are sold quickly, such as foods and toiletries – are increasingly using flexible packaging, including plastic-aluminium laminates. These laminates are typically made from layers of plastic and aluminium foil, which acts as a barrier to protect products from oxygen, moisture and light. It also reduces the weight of packaging, cuts transport costs and energy use, and reduces the environmental impact attributable to packaging. Common products packed in plastic-aluminium laminates include baby food, pet food, juices and toothpaste.

As a result, the use of laminates has grown considerably in recent years, with more than 160,000 tonnes of flexible laminate packaging entering the UK marketplace each year. This packaging contains more than 17,000 tonnes of aluminium, and its composite nature makes it challenging to recycle.

British company Enval has developed a microwave-induced pyrolysis process that can recycle laminates from both post-consumer and industrial waste. Pyrolysis is a process in which organic (ie carbon-based) material, such as paper or plastic, is heated and broken down in the absence of oxygen to produce products that can be used as chemical feedstock or to generate energy. In microwave-induced pyrolysis, that heat energy is provided in the form of microwaves. The process can be configured to operate under gentle mechanical conditions in order to extract fragile materials without damaging them. It is powered by electricity, eliminating the need for a chimneystack and providing the option to use a renewable source of energy.

In the patented Enval process, which has been proven at a commercial scale at the company's demonstration facility near Huntingdon, shredded plastic aluminium laminates are mixed with carbon. When carbon is exposed to microwaves, it reaches temperatures of up to 1,000°C and, in the case of the Enval process, this energy is then transferred to the plastic by heat conduction.

The fragile aluminium foil remains undamaged during this process and can be recovered in solid form, clean and ready for reprocessing. A typical Enval plant with a throughput of 2,000 tonnes/year produces 200 to 400 tonnes of aluminium a year, depending on the feedstock. With a purity exceeding 98% and a minimum metal yield of 80%, this recovered aluminium can be directly reintroduced to the re-smelting process.

The plastic component of the laminate packaging pyrolyses to form a mixture of hydrocarbons. This mixture is then cooled down and separated into gas and oil. The gas is used to generate the electricity required to power the process, while the pyrolytic oils from the process can be used as chemical feedstock or for energy generation. The Enval process can be configured to adjust the balance between the gases and oils that are produced according to operator and market requirements.

As a modular process, the plant is designed to be economically operated at a variety of scales, allowing for local treatment. The current demonstration plant operates on industrial waste feedstock; however Defra-funded research trials last year studied various methods of collecting post-consumer plastic aluminium laminate packaging through existing household recycling schemes. The collaborative trials project – involving Enval, consultants Anthesis LRS, French utility Suez Environnement, Nestlé UK & Ireland, and Coca-Cola Enterprises – has also explored how communication approaches, consumer behaviour and brands can influence collection models across different demographics and locations. Enval hopes that the trials will present a solid business case for this technology to be bolted on to existing materials facilities, and help increase levels of household recycling across the UK.

they collect as a result of how the supply chain works[33e], and PRN revenue directed back into collection is also highly variable year on year – ranging from around £3m in 2010 to £36m in 2013 according to the Advisory Committee on Packaging. The Committee also notes that "the system is designed to fund expansion of collection and reprocessing capacity, but because the system is not transparent, it is unclear if or how the funds are being invested in collection. In addition the total funding available through PRNs at around £50m to £100m per year is probably lower than many local authorities expected. This suggests that there is likely to be limited scope for the PRN system to directly fund increased collections or infrastructure."[33a]

Wider policy factors

Deregulation and localism are two other broad political agendas that are affecting MSW, particularly in England.

Local decision-making and accountability has always been an important aspect of the UK's approach to the management of MSW and, in this sense, the localism agenda is supportive. However, the removal of the regional planning tier through the Localism Act 2011 (ref. 34a) has caused some concern across the sector. In its 2011 report on the Abolition of Regional Spatial Strategies[34b], which included planning for minerals and waste, the Communities and Local Government Committee's conclusion on strategic planning reflected this concern saying: "The evidence that we received showed a widespread concern about the proposed absence of planning at a level between the national and the local. There is a real risk of local authorities, individually or in combination, failing to address important planning issues in an effective and co-ordinated manner. There needs to be a way of ensuring effective planning at a larger-than-local level."

Regional spatial strategies (RSSs) were intended to provide a framework for private investment, public sector planning, and "an evidence-driven, strategic focus for spatial planning decisions"[34c]. In the context of UK resource productivity, therefore, they could have been a useful tool for planning and delivering appropriate waste and recycling infrastructure capacity, realising optimum economies of scale, and providing a structure to help align the recovery of material and energy resources with local economic development strategies. RSSs have been replaced by a 'Duty to Co-operate', but it is not clear whether this will deliver the strategic approach needed by the sector. Ultimately, many believe that a planning and decision-making framework should also be articulated at a level beyond localism and the same Communities and Local Government Committee report noted that: "Although generally welcomed, there was considerable doubt amongst our witnesses as to whether the 'duty to cooperate' would be an effective means of securing robust strategic planning."

The government's broad deregulatory agenda, including the Deregulation Act 2015, has also had implications for the sector in its relationship with the householder. UK governments have, in the main, sought to avoid any measures to compel householders to recycle or penalise them for not using the services appropriately, preferring instead to promote the use of incentives. In a statement on the Deregulation Bill in July 2013, the Secretary of State for Communities and Local Government said: "New laws will ensure householders are no longer penalised by their council if they accidentally put their rubbish out early or put the wrong item in the wrong bin"[34d].

In addition, while it is only one of a number of measures that can be deployed to drive up recycling rates (Wales has reached 61% recycling without it), local authorities are now not allowed under UK law to implement pay-as-you-throw (PAYT) schemes (see Chapter 9), which are common in many other European countries and are credited with helping Europe's highest performers to reach recycling levels of 60% and beyond, and to progress towards decoupling waste from economic growth. A report to the European Commission by BIO Intelligence

The **science of behaviour change** will assume greater importance as resource productivity moves up the agenda

Service in 2012 (ref. 34e) identified PAYT as one of three economic instruments that in combination are likely to have a significant impact on waste.

Resolving these tensions between different policy areas requires a clearly articulated set of shared objectives around waste and resources but the formal policy framework for these in England has fallen out of date. England's most recent articulation of government policy on waste and resources is the Government Review of Waste Policy in England 2011 (ref. 29c), which superseded the 2007 Waste Strategy and set out a number of actions and commitments, and the 2012 BIS/ Defra Resource Security Action Plan[35], but a lot has changed across the sector in the last five years.

There are positive signs of more joined up thinking and cross-department collaboration on the horizon, however. Defra's commitment to developing a 25 Year Environment Plan[36], the framework for which will undergo a wide consultation exercise, will see the department put forward long-term objectives on waste and resource management, and the sector is also one of the six priority sectors in the National Infrastructure Commission's current National Infrastructure Assessment[37a] process. In addition, as already noted, the Industrial Strategy Green Paper from BEIS also acknowledges the need for a strategic approach to waste and resource management, stating: "The Government will work with stakeholders to explore opportunities to reduce raw material demand and waste in our energy and resource systems, and to promote well-functioning markets for secondary materials, and new disruptive business models that challenge inefficient practice. This work will be supported by the Government's 25 Year Environment Plan which will set out a long term vision for delivering a more resource efficient and resilient economy."

The development of these various national plans and strategies will need to draw in all the government departments with an interest in or influence on waste and resource productivity, including Communities and Local Government and the Treasury, to ensure that future policies are effectively aligned to deliver the desired outcomes.

> Recalibrating the system to deliver **enhanced resource productivity** is not a straightforward task

Wider social and behavioural factors

The changing composition and fluctuating volumes of waste adds a further layer of complexity when planning for better resource productivity. A diverse range of manufacturing, retail and consumer behaviour trends – including the growth of online shopping, stronger corporate sustainability agendas, and rapid product update cycles – all play a role, alongside the ongoing push from consumers for greater convenience and lower cost.

At the most basic level, while household recycling behaviour is now fairly well established, communications and awareness-raising are still needed to refresh and reinforce the messages if higher recycling rates are to be achieved. Behaviour research by WRAP reports a strong relationship between the amount of information received on the kerbside collection by the householder and levels of effective recycling[37b]. Evidence suggests, however, that communications activities are being reduced as a result of public spending cuts. Survey-based research carried out for CIWM by Ricardo-AEA[37c] on the impacts of austerity across local authority waste, recycling and street cleansing services found that for service activities "almost half of the respondents stated that there had been a reduction in their communications budget".

Beyond recycling, a bigger challenge is the continued link between waste and economic indicators such as GDP and disposable income, the decoupling of which is seen as key in achieving improved resource productivity. The latest Defra statistics[38] on total UK household waste arisings between 2010 and 2015 provide little evidence to indicate this decoupling is yet underway in the UK. The complexity of the interactions between policy mechanisms, service provision, communications and recycling behaviour discussed in this chapter suggest that the science of behaviour change will, therefore, assume greater importance as resource productivity moves up the agenda.

In terms of waste prevention and resource productivity, one of the critical questions will be the extent to which we can expect behaviour change from consumers and producers without providing stronger drivers. Should the onus be on producers to embed waste prevention in their business models and supply chains or should consumers be encouraged or incentivised to make purchasing decisions based on the efficiency and recyclability of the item or to consider sharing or leasing rather than ownership? Who is best placed to change consumer attitudes? The big brands and retailers are certainly well positioned to be influencers. One can imagine the impact if some of the iconic global household brands put their full weight behind environmentally-responsible consumption and pushed more circular business models into the mainstream.

Technology and innovation

The current rate of technological change is often difficult to measure, for several reasons: there is a lag time between development and wholescale adoption; some innovation delivers a change in quality rather than quantity; and the latest gadget can make us forget how radical the product was that it replaced. What has clearly speeded up, however, is the design cycle for many products, which not only brings innovation to the market more quickly, but is also one of the factors behind the relentless pressure to keep upgrading consumer goods, particularly high-tech products that are resource intensive.

Market adoption rates are also speeding up. It took 40 years for the telephone to achieve 40% market penetration, for example, while smart phones achieved the same in just 10 years[39a]. This means that new products and materials are not only reaching the market more quickly, they are also entering the waste stream more quickly. The problems arise when current systems for managing waste are not geared up to handle new waste streams. It has taken some time to develop sustainable recovery routes for Tetra Pak-style packaging, for example, let alone for the range of new materials on the horizon such as nanocellulose, graphene and carbon fibre. Recyclability and reliable lifecycle analysis needs to be part of the upfront discussion about the materials used in products if we are to have any chance of reducing the lag time between product launch and the development of suitable recycling or remanufacturing infrastructure.

Packaging, in particular, highlights the competing pressures at work in this area. While often held up as an environmental villain, one of the key roles of packaging is to protect goods from damage or degradation – thereby reducing product wastage – and it is a highly innovative sector. Efforts to improve the environmental footprint of packaging have seen a range of initiatives from packaging producers, brands and retailers, including 'lightweighting'; smart packaging that keeps food fresher for longer; and multi-functional packaging that both protects products and acts as a shelf display unit.

The net environmental gain, however, is more difficult to measure. Some of this innovation has introduced new materials or composite packaging designs that cannot easily be recycled, occur in volumes too small to make household collection and treatment cost effective, or end up as contaminants in existing collection and recycling systems. The growing number of 'bioplastics' coming onto the market[39b], for example, continues to present challenges. While these plastics, derived from renewable biomass or microbial sources, clearly offer some environmental benefits at the production stage, correct treatment at the point of disposal can be challenging. They can also be difficult for householders and current sorting technology to identify and separate correctly, potentially contaminating conventional plastic waste recycling. Varying degrees of biodegradability can also mean that they are not suited to current biowaste treatment options.

Volume and value play a big part in shaping the sector's response to these materials. In the case of laminated pouches, for instance, rapid growth in their use, and the value of the aluminium content, has stimulated innovation in recycling technology (see case study on p66).

Conclusions

With all these competing forces acting on the management and recovery of resources from MSW, recalibrating the system to deliver enhanced resource productivity is not a straightforward task and, drawing on the evidence in this chapter, is likely to require further policy intervention.

The fundamental issues that must be addressed are:

- how can we improve the economic rationale for recycling across the supply chain and mitigate market risks and uncertainties?
- how can we ensure that responsibility and cost of waste management and recycling is shared differently with a wider group of stakeholders?
- what other policy and financial mechanisms could be deployed across the whole product supply chain?

In addressing these questions, policymakers can be guided by the framework set out in the EU Circular Economy package, and aided by a range of research and development activities in this sector.

1. Improving the economic rationale and market confidence, and mitigating risk

Put simply, the economic conditions for recovering resources from MSW in recent years have not been fully aligned with the public policy objective to increase recycling, and while different approaches in some parts of the UK have been successful in maintaining progress, the fact remains that the UK's overall recycling performance fell back in 2015 for the first time in well over a decade. Investment in recycling infrastructure has slowed, domestic reprocessing capacity has been lost, and the availability of public funding to continue to support recycling is now, and is likely to remain, constrained.

While conditions created by global economic trends and commodity markets cannot be easily mitigated, and direct market interventions may not be politically attractive, UK governments can act to improve confidence and encourage investment through integrated policies that more fully recognise and seek to capture the economic benefits of improved resource efficiency and productivity.

These are documented and increasingly well quantified. Defra's 2015 'Resource Management: a catalyst for growth report' [29d], estimates that the UK waste sector generated an estimated £6.8 billion in gross value added (GVA) and supported 103,000 jobs in 2013; research by Green Alliance and WRAP[39c] in the same year concluded that "a more extensive expansion of circular economic activities" could create around half a million jobs.

Currently, there is a unique opportunity for the UK government to create a reinvigorated policy framework through the development of a set of shared objectives on resource productivity in Defra's 25 Year Environment Plan, BEIS' Industrial Strategy and the National Infrastructure Assessment. If adequately aligned, these three strands of government policy could provide longer term certainty and improve the landscape for strategic planning and investment in services and infrastructure that convert the resources recovered from waste (both MSW and the far larger amount of commercial and industrial waste) into valuable feedstocks, create jobs and help to improve the competitiveness and resilience of the UK's manufacturing base as we leave the EU.

2. Allocation of responsibility and cost

Currently, the public sector bears most of the cost for MSW recycling but with far less control over the factors that impact on the 'value' of the recyclables or their share of the revenue. Ongoing pressure on public sector budgets coupled with concern over the UK's progress towards the 2020 50% recycling target and the ambition for higher recycling articulated in the EU's Circular Economy Package[39d], have brought the role of 'producer responsibility' under the spotlight. At a UK level, evidence presented earlier in this chapter indicates growing concern that the framework for dealing with the packaging component of MSW, which represents a significant proportion of the arisings, may not be sufficient to support the cost of collection and recycling in the future, particularly if further increases in recycling are expected.

At the same time, this re-evaluation of how responsibility, cost and revenue is shared is bringing about a wider discussion on Extended Producer Responsibility (EPR) – a wider application of product stewardship concept. The UK has not followed the example of some other European countries in adopting national Extended Producer Responsibility schemes for waste streams such as furniture and textiles to better distribute the cost burden (although Scotland is currently exploring the opportunities for EPR schemes as part of its circular economy strategy).

It has also highlighted the need for further work to assess how best to engage and incentivise households both to reduce the waste they generate in the first place and how much they recycle. There is currently no direct incentive for householders to reduce waste, which is why industry debate about PAYT has not been shelved, and while there are some incentive schemes designed to reward recycling behaviour, interim findings of research carried out by Brook Lyndhurst for Defra in 2013 (ref. 40) concluded that "Reward and recognition schemes cannot be seen as a 'quick fix'. They require careful consideration, time and investment, especially if they are not only meant to be successful, but also to demonstrate their success and impact."

The remaining choices include stimulating greater participation through changes to service provision and communications, both of which require funding, and sharing local authority best practice. Specific issues related to demographics are also likely to require attention. Commenting on the dip in England's recycling rate in 2015, a Defra spokesperson acknowledged that "The slight dip in the household recycling rates clearly shows more needs to be done... Compared with the devolved administrations, a much higher proportion of the population in England lives in urban areas where there are unique challenges to recycling."[41].

Ultimately, genuine progress towards resource productivity in the context of MSW is likely to require a reshaping of the relationship between householders, local authorities, private sector waste companies and reprocessors, and the product supply chain.

3. A broader set of policy levers

To date, the policy framework for MSW has primarily focused on 'push' mechanisms, with targets and taxes focused on discouraging disposal to landfill in favour of some form of value recovery, whether as energy or the recovery of materials through recycling. In the main, these 'end-of-pipe' policy levers have applied mainly to MSW, with only the Landfill Tax impacting on commercial and industrial waste in the UK, along with producer responsibility legislation in some sectors.

Progress further up the waste hierarchy, where resource productivity sits, is unlikely to be achieved without additional 'pull' measures further up the product supply chain. These are needed to create stronger and more stable market demand for secondary raw materials by incentivising their use (and thereby improving the value proposition for recycling), to support the wider business case for more resource efficient product design and supply chains, and to support consumption models that integrate sharing, reuse and remanufacturing opportunities into the product lifecycle.

In the same way that the UK governments developed an incentives framework for renewable energy, the move towards resource productivity and more circular material loops for all waste streams, not just MSW, is likely to require priming, either through economic instruments and incentives, regulation, or a shift in the focus of taxation.

In considering what approaches and policy levers will be needed in the future, the UK government and the sector must consider some important questions:

- Are basic weight-based targets the best option for the future, or should we develop smarter, material-specific recycling and re-use targets based around resource value or carbon?
- What are the wider implications of a stronger focus on producer responsibility, resource-efficient design and waste prevention during the whole product lifecycle? These interventions might yield less material for recycling, and increasingly leave local authorities to deal with residual waste that has energy rather than material value. This, in turn, would affect how targets are set, and may also require further development of domestic energy-from-waste capacity (see Chapter 1, case study on p18).
- Given the budget pressures they are facing, should local authorities continue to play an integral role in collecting and recovering materials from MSW? Should waste management become a utility in the same way as energy and water services? Or are there options in between?.

4. EU Circular Economy package

The challenges and imperatives outlined above are not unique to the UK – they are replicated and recognised across Europe and beyond. In its EU Circular Economy package, the European Commission has sought both to address some of the barriers to progress and provide a road map through to 2030. Despite the UK's impending exit from the EU, the latest indications from Defra officials and Resources Minister Dr Thérèse Coffey MP[42,43] suggest that the package may become law under the Great Repeal Act. At the very least, it is a useful blueprint to inform the development of UK policy going forward. It articulates some of the key principles and measures that will be needed to drive circular thinking and greater resource productivity, including: producer responsibility; curbing planned obsolescence; improving repair and remanufacturing activities; and incentivising eco-design. It also encourages EU member states to deploy economic instruments to stabilise and improve market demand for secondary raw materials, incentivise resource efficient product and service supply chains both on the supply and demand side, and change consumer behaviour most notably through the introduction of PAYT.

5. Science and technology

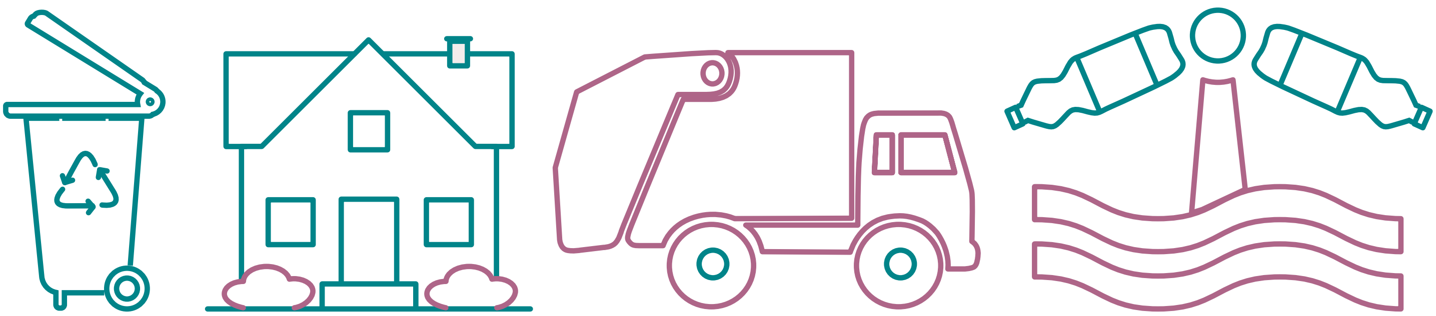
Policy and legislation alone will not deliver the necessary innovations to make resource productivity a reality. The EU Circular Economy package included a commitment to significant funding support for research and development, and in light of the exit from the EU, the UK will need to make a similar commitment to achieve those goals.

Design and product modelling, lifecycle analysis, material sciences and remanufacturing will all be critical to improve the design, use and recovery of products from a full lifecycle perspective, and to ensure that the embedded resource value – energy, water and land use as well as materials – is not lost or downgraded at the point of discard. Technological advancements such as bioplastics, nanomaterials, carbon fibre and additive manufacturing will all pose new recycling and recovery challenges.

Environmental economics, resource flow modelling and data capture, and behavioural science will also play important roles in building the case for resource productivity and shifting business and consumer attitudes. Accurate modelling of the impact of changing consumption behaviours such as online shopping on waste arisings will also be required to inform the planning of future services and infrastructure.

Given that MSW is inherently the most complex and cross-contaminated waste flow, future recycling rates will also depend upon presenting high quality materials to the market. Further improvements in materials separation technology will be required to deliver high quality recyclate streams and remove contamination, especially if significant volumes of recyclables continue to be collected using co-mingled approaches. Industrial biotechnology is another area where there are significant opportunities to be explored (see Chapter 6, case studies on p89 and 91).

Ultimately, shifting our behaviour and infrastructure to embrace resource productivity will be a challenge. It links into almost every aspect of our social and business structures and attitudes and will require robust and integrated policy frameworks that are capable of delivering the optimum outcomes for both the environment and the economy. In the context of MSW, it means re-evaluating the relationship and distribution of financial and behavioural responsibility between householders, local authorities, private sector waste companies and reprocessors, and waste producers. In light of the new era heralded by the UK's exit from the EU, it is also an unmissable opportunity to develop a more resilient and sustainable UK economy.



CHAPTER 5: Commercial and industrial waste

Transitioning to a circular economy requires a fundamental transformation in how products are designed, made, owned and consumed. The commercial and industrial sector is the second-largest waste-producing sector, and it has many opportunities to reduce waste and increase resource productivity. Policymakers should consider the factors that motivate innovation in relation to waste, the health and safety risks that might arise, and how new technologies can be used to mitigate them.

Mike Edbury, Head of Risk and Regulation, Government Office for Science; Felix Preston, Senior Research Fellow and Deputy Research Director for Energy, Environment and Resources, Chatham House; Stephen Kinghorn-Perry, Head of the Foresight Centre, and Jo Bowen, Knowledge Sharing and Futures Lead in the Foresight Centre, Health and Safety Laboratory, Buxton; Richard Leese, Director of Industrial Policy, Energy and Climate Change, Mineral Products Association

Two concepts are central to the debate about how to reduce waste: the circular economy, and resource efficiency. At the heart of the circular economy idea is the general principle that economic activity can be reworked on ecological lines by closing 'material loops', so that wastes are seen as resources for other processes. Remanufacturing, reuse and recycling ensure that materials and products continue to circulate in the economy. These activities also promote resource productivity by maximising the value extracted from resources.

However, transitioning to a circular economy is not straightforward. For the idea of the circular economy to become reality, a fundamental transformation in how products are designed, made, owned and consumed is needed. That transformation usually begins with resource efficiency, where industry works to minimise currently generated waste, then progresses to improving the value returned from those wastes, so building the knowledge and capacity to become circular and resource productive.

The commercial and industrial sector is the second-largest waste-producing sector (behind construction – see Chapter 2), and the majority of its waste comes from manufacturing and service industries. From returns made under the EU Waste Statistics regulation, waste generated from commercial and industrial activities in the UK was estimated to be 48 million tonnes in 2012, with some 39 million tonnes of this coming from England.

A key priority for government is to boost growth in the economy while continuing to protect and improve the environment and human health. Between 2009 and 2012, there was an increase in both the gross value added (GVA) per unit of waste arisings, and waste arisings for commercial and industrial sectors as a whole. Initially, GVA increased at a faster rate than waste arisings, but by 2012 waste arisings had caught up, resulting in no net change in waste per unit of GVA between 2009 and 2012. This means that historically it has been possible to achieve greater resource efficiency, in terms of the amount of waste generated compared to GVA, but that maintaining this positive relationship is challenging.

Innovation and risk are critical issues for the commercial and industrial sector in attempting to reduce waste and increase resource productivity. These issues encompass the drivers for initiating and adopting innovative business practices and technologies (see case study on p77); the means by which the sector manages the risk of that innovation; and, more generally, how it manages the risks of the waste that it does create. This chapter considers the factors that motivate innovation in relation to waste; then the health and safety risks that arise, and how new technologies can be used to mitigate them. Finally, it looks through the prism of the cement industry at the extensive environmental challenges that industry gives rise to, how it has sought to manage those and, in doing so, make the most of waste throughout that process.

Mapping the innovation landscape for the circular economy

Felix Preston, Senior Research Fellow and Deputy Research Director for Energy, Environment and Resources, Chatham House

Safety and **health** issues have a significant **impact** on the waste industry

It is notoriously difficult to assess and track innovation[1], but a clear picture of the innovation landscape could help decision makers to identify opportunities for addressing resource productivity. It could also help to inform the design of policy responses, and help to measure progress under key strategic frameworks for the circular economy, in the countries of the Organisation for Economic Co-operation and Development (OECD) and emerging economies, not least China.

A Chatham House collaboration with the consultancy CambridgeIP is exploring innovation in the circular economy using a patent landscaping approach. It aims to shed light on where innovation is happening; the types of organisations making breakthroughs; which sectors are experiencing rapid growth; and on networks and clusters of innovators[2].

An interesting contrast is provided by plastics use and waste, which has benefited from decades of technological and process improvements but remains a key sustainability challenge[3]; and by 3D printing, which today is relatively limited in application[4] but potentially offers the promise of disruptive shifts in resource use[5] (see Chapter 3).

For plastics, preliminary data is consistent with OECD research, which identified several spikes in patenting activity around plastics recycling since the 1960s, due in part to policies introduced in the late 1980s in the US, Japan and in Europe[6]. For new plastics materials, there was a sharp rise in the number of patent filings on bioplastics in recent years, rising 30% in 2013 to 2014 alone, while biodegradable plastics has seen steady growth since the 1980s. The overall activity in both these areas, however, is relatively limited. Fossil fuel prices appear to have had limited impacts on these trends.

Patent filings on 3D printing go back to the 1980s, but there has been a surge in activity in the past five years. 2015 alone saw more than 1,000 unique inventions around 3D printing globally, with China and the US accounting for roughly one-half and one-fifth of total patent filings respectively. Large multinationals are responsible for much of this activity, but the last three years has seen an increase in activity by smaller firms and universities.

Drawing on these and other areas of innovation in the circular economy, participants at an expert roundtable at Chatham House in July 2016 identified three insights that could inform policy developments[7].

1. **Trade-Offs**. Circular economy approaches are not guaranteed to be the most sustainable, and there is a role for policy in guiding the technology pathway. For example, there are significant challenges associated with water use in bioplastics and the emissions implications of plastics-to-energy processes. For 3D printing, there is an opportunity to create a market 'pull' for more sustainable materials before the technology is scaled up.
2. **Digital enablers**. Digital technologies play a crucial role in enabling and accelerating resource productivity[8]. For plastic waste management, for instance, cities have been piloting the use of smart bins to reduce the costs of door-to-door collection[9]. Information technology plays a different but equally vital role in 3D printing: online platforms[10] allow users to access printers and collect data to inform future innovations.

3. **Collaboration**. Progress on resource productivity often depends on systemic changes, collaborative arrangements and business models. Technological innovations need to be seen in this broader context[11]. The role of academic-business partnerships is visible, for example, in the clusters of innovation for 3D printing among universities and small firms in China. Our previous assessment of innovation in low-carbon energy technology found few instances of innovations involving organisations in different countries, suggesting an important role for international policy coordination[12].

The preliminary research points to the value of combining data with frameworks that allow decision makers to identify, evaluate and compare innovative approaches in the circular economy, and ultimately use these to help determine priorities and manage sustainability trade-offs. Chatham House is in the process of developing such a prototype framework, and hopes to pilot this with stakeholders in the coming months.

Health and safety in the waste industry

Stephen Kinghorn-Perry, Head of the Foresight Centre, Health and Safety Laboratory, Buxton, and Jo Bowen, Knowledge Sharing and Futures Lead in the Foresight Centre, Health and Safety Laboratory, Buxton.

Maximising the opportunities to move from waste processing to resource productivity presents challenges for the UK's health and safety system, not least because of the sheer diversity of the waste and recycling industry – ranging from large international businesses to small local firms – as well as the large amount of waste produced.

A further complication is that the spectrum of activities undertaken within the waste industry is also very diverse, encompassing the handling and processing of industrial, commercial and household waste. Specific activities include: collection; reception; transfer/sorting and processing, which itself includes reuse, recycling and recovery of materials; biological treatment of organic material; thermal treatment; and ultimately disposal activities. As a result, there is a broad range of safety and health risks to consider and address, including risks to the public through domestic collection activities that account for over 26 million tonnes of municipal waste handled each year.

It is unlikely that the drivers for waste and recycling will diminish anytime soon, with economic and political pressures for a circular economy increasing. Such pressures have already driven significant changes. Current patterns of industry development include expansion in activities other than landfill: there is increased demand for separation and segregation of waste as the result of legislative demands and environmental targets, and increasing opportunities for value-added activities arising from the creation of new markets for waste. There is much scope for innovation in the sector, along with the opportunities and challenges that come with trends such as the use of drones to move waste; economic pressures that are increasing the viability of thermal treatment of asbestos; and the recycling of new products such as hybrid cars.

1,000

unique inventions around 3D printing were seen in 2015 alone

Health and safety performance

It is important to recognise that although there has been a gradual improvement in health and safety performance across the waste industry, overall performance remains poor, both in terms of fatal injury rates, major injuries and ill health. When looking at a cross-industry comparison over a 5-year period between 2010 and 2015, fatal injuries in the waste industry averaged 5.59 deaths per 100,000 workers. This is more than 10 times the all-industry rate of 0.52, approaching 3 times the fatal injury rate in construction of 2.04, and second only to the rate of 9.40 in agriculture.

In addition, figures from the Office for National Statistics' Labour Force Survey show that each year around 5,000 workers in the waste sector suffer non-fatal workplace injuries, and a further 6,000 workers suffer an illness they believe to be work-related. These numbers are significant and show that workers in the industry are being exposed to risk that converts to injury and ill health rates in the thousands per 100,000 workers.

For incidents that have to be reported under the Reporting of Injuries Diseases and Dangerous Occurrence (RIDDOR 2013) Regulations, the main causes of death are: being struck by moving vehicles; contact with moving machinery; and being trapped by something collapsing. For non-fatal injuries reported by employers, the main causes are lifting and handling injuries; slips, trips and falls; being struck by an object; and a fall from height. The causes of death and injury are not new: the precautions necessary are typically well known, and the main focus for improving the industry's safety performance is likely to lie in improving health and safety management, monitoring and supervision and a focus on behavioural safety.

The ill-health problems represent a different sort of challenge when compared with safety performance. The diverse range of collection and sorting activities, and the absence of data on some of the health risks, mean that a broader evidence base is needed to tackle these issues. There is the potential for significant ill-health risks arising from some of the newer and emerging processing and recycling activities (eg bioaerosols and composting; and exposure to lead or mercury during recycling of cathode ray tubes, fluorescent tubes and electrical equipment).

Given the industry's role in providing a service to the public, accident and ill-health performance is likely to have an unseen economic impact on customers, as part of the broader business performance. Safety and health issues do have a significant impact on the industry and the economy, and there is undoubtedly a societal benefit and an economic impact from improving performance in this sector.

In considering the opportunities of transitioning from waste to resource productivity (see case study on p82), it is also important to recognise the possibility for tensions between health and safety and environmental pressures. For instance, the pressures to improve the quality of recyclate can lead to a requirement to 'sort at source', requiring the person disposing of the waste to separate materials (such as glass from plastics). Conversely, health and safety considerations for reducing noise in glass collections can lead to co-mingling of waste as a way of managing that risk. In such cases it can be challenging to satisfy different regulators, requiring a good degree of understanding and cooperation. Similarly, the solution to managing risk may involve transferring the risk to customers, for example a local authority imposing requirements for handling bins on residents to avoid their operatives having to do so.

Plastics use and **waste**... remains a key sustainability challenge

Case Study

Orangebox

Gareth Banks, Senior Designer, Orangebox

With the effects of climate change and biodiversity loss becoming ever more visible and significant, finding a workable alternative to our current 'take-make-waste' system of resource use is becoming an increasingly pressing issue.

The circular economy describes an alternative to our existing wasteful linear system that helps us to keep resources in use for as long as possible, while supporting a more resilient global economy. Ultimately, the circular economy aims to eliminate the idea of waste all together.

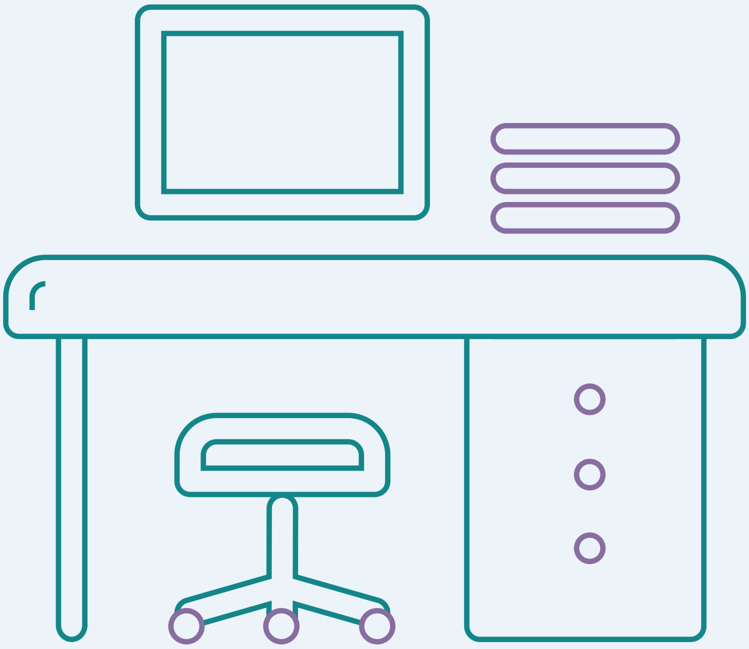
This involves taking a new perspective on both product and process, re-organising how we do business and re-thinking how we design materials, water and energy into the products we all use every day.

For example, Cardiff-based furniture business Orangebox has always taken an environmentally-led approach to product development. But it is now going further to demonstrate its belief in the circular economy. In September, the company launched Orangebox Remade, which supports the remanufacturing of products that would otherwise be heading for end-of-life waste disposal. Remade products have been restored to a 'good as new' condition, and are sold with a warranty to match that of new furniture.

The first product to be offered under the Orangebox Remade banner is the G64, one of the company's most enduring and successful office chairs within the European market. The remade version, called G64-R, offers the same precision engineering and ergonomic benefits of a new G64 but with extensive environmental and cost savings built in. With a recycled content of around 80% (by weight), each remanufactured chair delivers a 60% reduction in CO_2 emissions and saves 75% of water consumption compared to a new chair. Moreover, 98% of its parts are recyclable, with removed components either kept for reuse or returned for material reprocessing.

To help deliver this offer, Orangebox has partnered with Premier Sustain, a UK company leading in remanufacturing office furniture. It remanufactures all products to an exacting Orangebox-approved specification at its Renew Centre in North London, which was recognised earlier this year with the Queen's Award for Enterprise in Sustainable Development, the UK's highest accolade for environmental business success.

By optimising new furniture designs for remanufacturing in the future, and by offering the very best reuse solution for end-of-life products today, Orangebox aims to offer its customers a truly 'closed loop' approach. Orangebox Remade sets down an important marker for the future of manufacturing in the circular economy.



Future developments

Health and safety is not a barrier to the development of alternative novel waste treatment and recycling technologies. It is just a matter of ensuring that the hazards and associated risks of operating new plants and processes are identified and understood. Armed with this information, it is easier to understand how to put control and management practices in place. It is also possible that many of the new approaches to waste and recycling may remove the need for direct human intervention, thus further reducing health and safety risks.

The rapid evolution of the working world, and the impact that scientific and technological change is having on our personal and professional lives, should not be understated. This is certainly the case where innovation in business models and advances in technology could be used to either minimise waste production, or allow valuable materials to be extracted from previously unrecyclable material. To identify and explore potential risks, threats, emerging issues and opportunities that could affect the workplace in the future, the Health and Safety Laboratory (HSL) has implemented a systematic and structured system of searching for, detecting, analysing and storing information on drivers and trends of change. HSL's horizon scanning includes science and technology developments that fall in any of the following categories: basic science through to applied technology; areas where principles fall between speculative and well-defined; research undertaken in the fringe through to mainstream communities; and science and technology developments exploited by commercial or academic organisations. The approach covers both scientific literature and 'grey' literature, and covers the full range of technical, economic, environmental, political, societal and ethical trends and drivers.

Some examples of the opportunities and challenges identified through HSL's current horizon scanning include:

- **Autonomous undersea 'hoover' for plastic clean-up.** This involves using drones to detect and clean up litter from beaches, and undersea litter. Industrial designers from the French International School of Design, among others, have conceived an autonomous submarine vehicle to address the need to clean up the 'Great Pacific Garbage Patch'.
- **A bird's eye view on safety.** In the future, drones could be used more routinely to supply risk assessment and monitoring data, and to avoid needing humans to set foot on potentially hazardous sites. For example, the University of Manchester and the Environment Agency have teamed up to deploy an experimental drone to detect biogenic methane levels generated from 200 landfill sites. This could lead to real time, round the clock monitoring of landfill methane, which is a potent greenhouse gas but can also be captured and turned into electricity (see case study on p80).
- **Wasting no time to collect your bin.** The emergence of the 'Internet of Things' and 'Smart Cities' means that rubbish collections will become automated and more efficient. A robot refuse truck guided by an autonomous drone has been developed by students from three universities working in collaboration with the Volvo Group and the waste firm Renova. It automatically collects and empties waste and recycling bins. A sensor in the refuse bin will send out a signal to indicate it is full and ready for collection.
- **Come fly away, come fly away with WEEE.** US, New Jersey company E-Cycle is investing in drones to collect small items of Waste Electrical and Electronic Equipment (WEEE).
- **Constructing a zero-waste future.** In Cardiff, Constructing Excellence in Wales (CEW) is conducting flying drone trials to monitor and survey construction projects, with the aim of achieving zero-waste construction. The data obtained are fed into modern Building Information Modelling (BIM) systems with the aim of making construction more efficient (see Chapter 8).
- **Waste not, want not.** A more widely-adopted circular economy may lead to reuse and recycling of hi-tech devices such as mobile phones, with recycling planned into the design and sales processes. The Ellen MacArthur Foundation is spearheading the call for a less wasteful and more sustainable future by encouraging global businesses to

Case Study

The long view on landfill

Sam Bradley, Government Office for Science

Redhill landfill is run by Biffa Waste Services Ltd at a former quarry that covers 0.51 km^2 and takes waste from Surrey, Kent, West Sussex, Hampshire, and London. In the financial year 2015 to 2016, it accepted 395,000 tonnes of municipal, construction, and asbestos waste; 162,000 tonnes of soil; and treated 62,000 tonnes of hazardous soils. This case study highlights how landfill management has had to constantly change, despite its nature as a long-term investment.

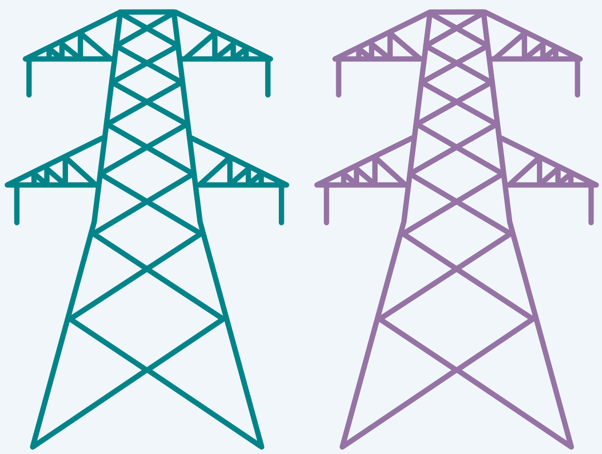
Redhill can recover landfill gas to produce electricity, reducing its reliance on the National Grid. The changing nature of waste has caused operational and maintenance challenges, and will cause declining power output over time. Redhill's landfill gas facility generates 6 megawatts, producing over 45,000 megawatt-hours (MWh) per annum of electricity at its peak. This energy is used to power onsite facilities and local businesses.

The chemistry of the gas has changed significantly over time, driven by changes in legislation and practice. During the mid-1990s, the gas included significant amounts of compounds that contained halogens (chlorine and fluorine). Halogens form corrosive gases when burned, and are managed by using lubricating oils that protect the generator. In the 2000s, more silicon-based compounds were introduced into cosmetics and cleaning products. When the gas is burned, this silicon forms sand that erodes the metal surfaces of the generator. Recently, with reducing gas production and increased metals and materials recovery and recycling, the proportion of hydrogen sulphide in the gas has increased. Hydrogen sulphide also forms an acidic gas when burned, and in combination with the erosion caused by silicon it can be particularly damaging.

Biffa estimates that between 1995 and 2013, biodegradable waste disposed in landfills declined from 36 million tonnes to 9 million tonnes. Forecast generation from gas production across all Biffa sites is expected to decline from around 700,000MWh in 2017 (enough to provide electricity to about 200,000 homes) to around 50,000MWh (serving roughly 16,000 homes) in 2050. This is because biodegradable waste is now diverted from landfill to other energy recovery methods such as anaerobic digestion.

Leachate (landfill-contaminated water) is contained within the landfill by the basal engineering, which comprises clay and high-density polyethylene lining that is used to create cells across the site. Leachate is pumped from the site, treated with bacteria to remove ammonia and organic compounds, and then disposed of in the sewer. Redhill will close in 2030, but Biffa will still be responsible for the land and any contamination arising from it for approximately 60 years afterwards, until the waste has stabilised. Leachate management is a long-term cost that many older sites do not deal with.

Biffa is committed to maintaining and monitoring the site until it is stable. There is a bond of £8 million in place so that if the company goes out of business, the site can still be maintained. Landfill operators require a regulatory landscape that is explicit and stable to allow them to make better long-term investment decisions.



Case Study

Opportunities for waste in the Yorkshire bioeconomy

Fay Kenworthy, Science Policy Adviser, Risk and Regulation, Government Office for Science

The definition of the bioeconomy is very broad, taking in the production of food, feed, energy, chemicals and other materials from renewable biological resources. Within this there are many opportunities to use waste, particularly in the industrial biotechnology and bioenergy sectors. This includes using waste as a feedstock, which can drive growth in the sector while bringing under-utilised wastes and by-products back into the manufacturing chain, thus reducing reliance on virgin resources.

Across the UK, the transformational bioeconomy comprises agriculture and fishing, forestry and logging, water and remediation activities, food products and beverages, and industrial biotechnology and bioenergy.

Recent research published by the Biotechnology and Biological Sciences Research Council (BBSRC) shows that the UK leads the way in research underpinning the bioeconomy. In field-weighted citation impact, a measure of the 'quality' of research, the UK is ranked number one globally[12]. However, a key challenge remains in translating our world-class science-base into industrial applications.

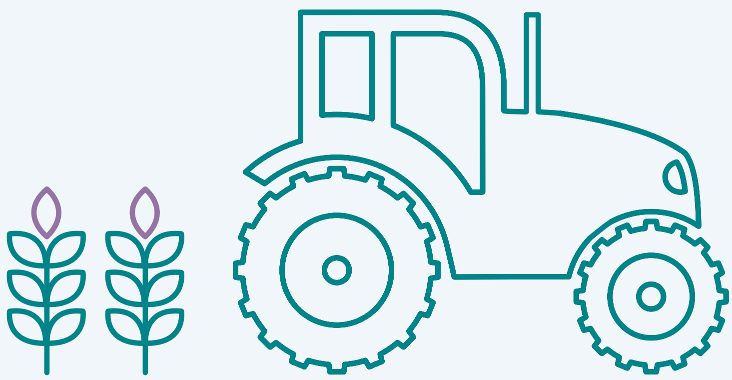
The Yorkshire bioeconomy

In 2012, the University of York founded the Biorenewables Development Centre (BDC) to support the commercialisation of new bio-based technologies and products. Alongside this, BioVale was established to develop the region as a hub for the bioeconomy. Together with other regional organisations, they are accelerating the growth of the bioeconomy in Yorkshire. Since its launch, the BDC has worked with more than 200 clients, including SMEs and multinationals, on over 350 bio-based projects. BioVale connects some 500 stakeholders through focused communication and networking activities.

For example, the local business Wilson Bio-Chemical is working with the BDC to turn municipal solid waste – one of the most abundant raw materials in the UK – into a unique bio-based fibre. The company has built a pilot autoclave in BDC's warehouse facility, and will be adding a demonstration plant later this year. These facilities aim to establish the potential of the fibre as a coal substitute, and its value in the production of fuel and chemicals. If successful, this will both divert waste from landfill and displace fossil fuels.

The BDC is also working with Veolia and GSK (GlaxoSmithKline) on using food waste to make glucose, a feedstock for producing antibiotics. Food-grade glucose has been subject to highly volatile pricing, and its production has a considerable environmental impact through substantial carbon, water and land-use footprints, leading GSK to search for a more sustainable supply. BDC was able to connect GSK with Veolia to identify potential sources of feedstock from the food manufacturing supply chain. The BDC has completed two successful pilot-scale fermentation trials to assess the potential of using food waste, and is now starting a year-long project with GSK to explore converting this into glucose at a commercial scale.

These examples demonstrate some of the opportunities for waste in the bioeconomy, and that bioeconomy businesses are

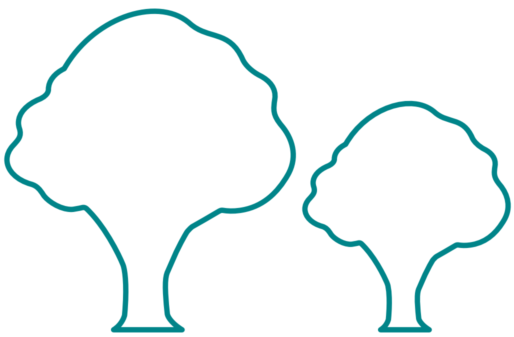


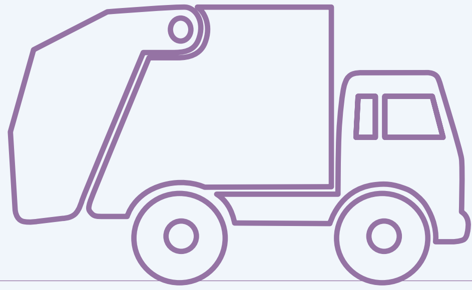
continuing to research, invest and develop new approaches to using waste. However, regulatory frameworks and sustainability of supply both pose continuing challenges to the wider use of waste in the bioeconomy. For example, in developing a more sustainable glucose source, GSK will face challenges in having by-product-derived glucose pass the stringent regulatory thresholds necessary for use as a raw material in pharmaceutical drug production. In addition, the long-term viability of using sustainable feedstocks has to be ensured in order to justify the significant capital investment required for such an ambition. Security of supply and environmental assurance are essential components for feedstock consideration.

The BDC and Biovale in Yorkshire are strong examples of how an innovative cluster of related businesses and organisations can build local, national and international biotechnology collaborations. Their role in developing technologies that utilise waste highlight the value that bio-based businesses can have in re-using and revaluing waste and other by-products.

sign up to the cause. In 2016, construction firm Arup joined the ranks of strategic global partners in this effort, which also includes Google, Cisco, Nike and Unilever.

- **Revolutionary farming methods to reduce waste.** There is the potential for a food-waste revolution if factory farming can improve resource efficiency and reduce waste (see case study on p80). A Japanese company called Spread is opening the world's first 'robot farm' to produce lettuce at its Kameoka farm. The use of robotics and automation will improve efficiency, reduce energy costs and recycle 98% of the water needed to grow the crop.
- **Good bacteria, the power cells of the future.** Factories of the future could deploy colonies of genetically-engineered bacteria, such as the common bacterium Escherichia coli, to create valuable chemical commodities in an environmentally friendly way. A form of E. coli, which has been created in the laboratory, feeds on sugar and produces an oil by-product that can be readily used to fuel conventional diesel engines. A large-scale process could produce a viable synthetic alternative to fossil fuels. Meanwhile, novel microbial fuel cells may hold the key to reducing the huge power consumption of conventional waste treatment. Boston-based Cambrian Innovation is just one team that has commenced field-testing a self-powered sewage treatment plant. These novel plants use bacterial cells, graphene and nanoparticles in an innovative way to produce usable electricity from wastewater. Other beneficial features are being engineered into pilot treatment plants, such as the removal of pharmaceuticals from the processed waste.





Integrated waste management

Laurel Morris, Government Office for Science

The Veolia Waste Management Facility (WMF) in the London Borough of Southwark is the product of a £34.5 million, 25-year private finance initiative (PFI) contract for the integrated collection and treatment of waste, which was agreed with the Department for Environment, Food and Rural Affairs (Defra) in 2008. The contract was driven primarily by Southwark Council's desire to encourage recycling (from its relatively low recycling rate of 17% in 2008) and divert waste from landfill. This case study highlights how a modern waste management facility can coexist with and benefit a dense local community, while remaining resilient to future change.

End-to-end processing

Unlike other UK WMFs, the Southwark site is a single facility in which drop-off, sorting, materials recovery and processing are all carried out in a single setting. Materials are first sorted based on physical properties and optical imaging, so that distinct stores of papers and plastics can be recovered and passed onto reprocessors. Critically, the mechanical equipment used for this sorting and recovery is reprogrammable. This means that as waste compositions and market values for secondary materials change, the facility can adapt and maintain resilience in resource management.

General black bag waste that would usually go to landfill is processed in the facility's mechanical biological treatment (MBT) plant. The mechanical element comprises an automatic segregation system to separate some recyclable materials from the mixed waste, such as metals or glass. The biological element seeks to remove moisture from the waste before breaking down the organic, biodegradable components by way of a composting-like process. These materials are therefore upgraded in value: they are entered into an energy recovery plant or sold to other users (eg cement plants).

The outputs from the MBT plant at Southwark are largely sent to South East London Combined Heat and Power (SELCHP) plant, which, through waste incineration, can generate 35 megawatts of electricity. Residual heat produced by this process provides heating and hot water to 2,500 local homes. This end-to-end processing presents an efficient and robust business model for waste management with beneficial implications for the local community.

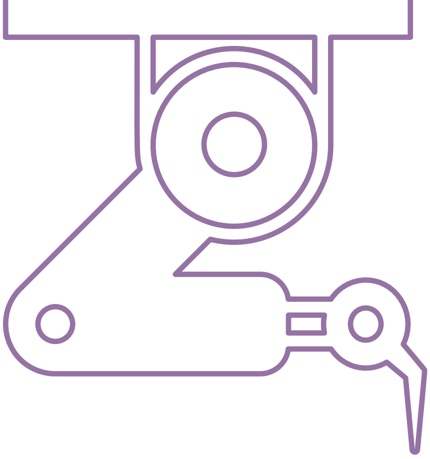
An inner city environment

The Borough of Southwark is socially and economically diverse. Around 25% of the 250,000 residents are transient, and 107 different languages are spoken. There is also a mix of single homes with individual waste disposal streams and dense, high-rise housing with communal waste streams. This presents a number of waste challenges, including the trade-off between collecting large amounts of mixed waste that is easier for the consumer to provide, versus collecting sorted and separated materials that is easier for the WMF to process.

Veolia and Southwark Council have been working with the local community and property managers to increase awareness of the importance of recycling. As a result, the recycling rate is up to 35%. A more systematic rules-based system of bin provision, collection requirements and clear recycling procedures would make it easier for consumers to navigate waste as they move between boroughs.

Being a large facility in a highly urban environment, it is important that all dust and odour generated onsite is successfully contained and managed with an air filtration system. That Southwark Council and Veolia share the site is an important step forward in relations between public and environmental sectors.

Veolia at Southwark presents a strong example of a public-private sector relationship that benefits the local community: producing hot water, reducing costs in the council and supporting a more circular economy. The scale of the facility in a dense urban environment is unique and highlights how resilient resource management can be achieved in a unitary, environmentally-conscious setting.



How many robot arms does it take to dismantle an iPhone?

- **How many robot arms does it take to dismantle an iPhone?** The answer, according to Apple, is 29. The company has developed a 29-armed robot that can take apart iPhones to recover spare parts that can be recycled and reused. It also yields valuable components from the iPhone such as gold, copper and cobalt. The robot is capable of undertaking a complete disassembly process every 11 seconds and also demonstrates how human workers can be removed from the health and safety risks of the disassembly operation. The approach contributes to a new recycling program called Apple Renew.

The above list is by no means exhaustive – there is a host of other innovative processes and approaches being explored and developed. Rapid progress is likely to be made in the application of waste-to-resource technology as companies begin to turn their attention to the global need for reduced carbon emissions. Ensuring that the right needs are met, by the best waste and recycling approaches, demands effective collaboration between the waste and recycling sector and technical developers. To avoid the preventable health and safety issues that may arise with new technology, it is vitally important to ensure the potential risks to workers are considered and addressed very early on in the design process.

Making productive use of wastes from cement manufacturing

Richard Leese, Director of Industrial Policy, Energy and Climate Change, Mineral Products Association

Cement is a manmade powder that is mixed with water and aggregates to produce concrete. The cement-making process can be divided into two basic steps:

- Making cement clinker in kilns at temperatures of 1,450°C from (typically) quarried rock raw materials containing calcium, silica, iron and alumina.
- Grinding clinker with other minerals, including gypsum, to produce the powder known as cement.

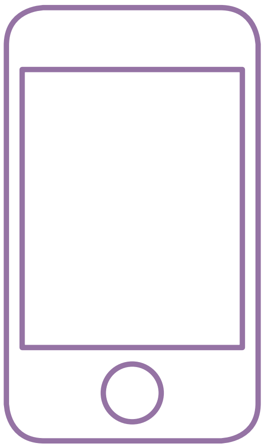
The high-temperature process and carbonates present in the raw materials make the cement industry a major global emitter of carbon dioxide, but the industry recognises the need to reduce its environmental footprint. Historically, for example, cement manufacturing used only natural raw materials. But today it uses natural and waste mineral raw materials, along with heat from fossil and waste-derived fuels, to produce cement clinker. Grinding the clinker into cement provides another recycling opportunity, and interground materials often include waste and by-product mineral raw materials.

Unlike other combustion processes – such as power generation, incineration and biomass boilers – the ash from fossil and waste-derived fuels forms part of the mineral content of the cement, and is not a waste residue. Thus, cement manufacturing recycles the mineral content of wastes with energy recovery as a co-benefit of that recycling, known as 'co-processing' ie recycling with simultaneous energy recovery.

In 2015, 11% of raw material and fuel inputs

The answer, according to Apple, is

29



to the UK cement industry came from waste and by-product sources, amounting to over 1.8 million tonnes of material. If the recycling, harvesting and reuse of wastewater is included, the recovery levels rise to 25%. Cement manufacturing produces almost no process waste, and since 2012 manufacturers have avoided landfill by recovering all process wastes for beneficial uses such as construction products or as a soil improver and fertiliser.

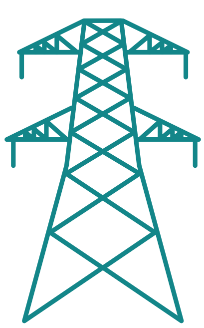
Waste-derived raw materials can include: granulated ground blast furnace slag; pulverised fuel ash; quarry washings; waste sands; and plasterboard and other waste gypsum. Waste-derived fuels are similarly diverse in nature and commonly include: packaging and refuse-derived fuel; tyres; waste solvents; meat and bone meal; and paper sludges.

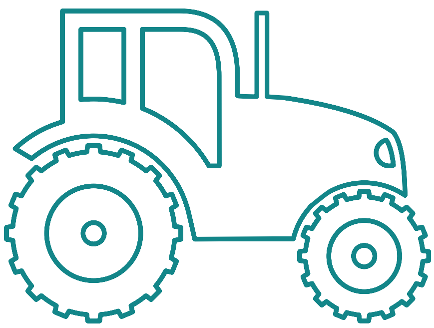
Manufacturers carefully select fuels and raw materials so that the mineral content is correct for the final high-quality cement product, and so that the calorific value is beneficial to the process. Waste consumed in the cement industry comes from a range of sectors including steel, chemicals, ceramics, foundries, automotive, power generation, and also commercial and domestic waste. In 2015, fuels from alternative sources made up 42% of the thermal input for cement kilns, equivalent to leaving about half a million tonnes of coal unused every year. As part of this effort, the use of biomass from waste-derived sources reduced carbon emissions by around 500,000 tonnes of CO_2. Furthermore, if the waste fuels used in cement production had been disposed via incineration, an increasingly common option, overall CO_2 emissions would increase by nearly 590,000 tonnes if the cement plants switched back to their traditional coal fuel source.

The total recycled content of all cement manufactured in the UK, through the recycling of waste materials and the use of by-products, was 13% in 2014. Almost 2% of this was ash recycled from the fossil and waste-derived fuels. As such, the cement sector provides local, high added-value opportunities for waste materials that have reached the end of the value chain, and cement manufacturing contributes significantly to the circular economy through resource efficiency in the production processes. Having a healthy domestic cement industry therefore reduces the UK's need for landfills and incinerators.

UK cement manufacturers continue to invest in recycling waste-derived fuel and raw materials to ensure that they meet their strict specifications. Each new fuel requires multi-million pound investments in storage, handling and delivery systems, along with their accompanying health, safety and environmental controls. Long term and secure supplies of waste materials are necessary to justify such significant investments, so the industry works very closely with local authorities and waste companies to maximise the synergies.

To achieve the greatest environmental, social and economic benefits of co-processing waste materials, the Mineral Products Association (MPA – the UK's minerals industry body) produced a 'Code of Practice for the Use of Waste Materials in Cement and Dolomitic Lime Manufacture', which has been adopted by all UK regulators. The code sets out the minimum standards to which MPA members will adhere when using waste materials and goes beyond statutory legal requirements, aiming to ensure that employees and the public are aware of the strict conditions under which waste is transformed into useful products. Regulators have embodied the code's requirements in manufacturer's environmental permits.





CHAPTER 6:
Agri-food

The agri-food sector is at the centre of the challenges associated with population growth, food security, climate change and resource scarcity. Although waste prevention is a key priority for the sector, unavoidable wastes can be valuable resources that yield fuels and feedstocks for the bioeconomy. Policymakers can support these efforts through policies that incentivise the utilisation of unavoidable agri-food waste, alongside a clear industrial strategy for the UK bioeconomy.

Shane Ward, UK AgroCycle Hub, Harper Adams University; Nicholas Holden, Eoin White, and Thomas Oldfield, University College Dublin, Ireland.

Agriculture is a critical sector of the UK economy, providing the food, feed, and biofuels that help sustain society. The UK agriculture and food (agri-food) chain, which includes primary agricultural production, processing, retailing and catering, employs roughly 3.9 million people, is worth about £109 billion per year to the economy, and contributes to 12% of UK greenhouse gas (GHG) emissions[1a].

The agri-food sector is at the centre of the challenges associated with population growth, food security, climate change and resource scarcity. In the past 50 years, agriculture has become resource intensive, relying heavily on the availability of fossil-based inputs in the form of synthetic nitrogen fertilisers, petroleum-based agrochemicals and fuels. About 10 megajoules of fossil energy are required to produce 1 megajoule of food energy[1b]. Inefficiencies in the agri-food chain mean reduced productivity, wasted energy and natural resources, as well as significant costs attributed to agri-food wastes. The UN Food and Agricultural Organisation (FAO) estimates that inefficiencies in the global food economy cost $1 trillion to $2 trillion per year[2]. Ultimately, when analysing the entire agri-food chain, up to one-third of the food produced for human consumption every year is wasted[2]. This waste equates to lost money, but also lost material resources that were invested in its production.

The definition of agri-food waste is subjective and stakeholder dependent. The EU Waste Framework Directive provides a definition of waste as "items that people no longer have any use for, which they either intend to get rid of or have already discarded"[3]. Many material flows are perceived as waste in the subjective opinion of the relevant observer, but may be valuable resources in the agri-food system. To overcome this ambiguity, it has become important to categorise the 100 million tonnes of biogenic agri-food wastes that are generated each year[4] into 'avoidable' and 'unavoidable' wastes. Avoidable agri-food wastes are material streams that have been mismanaged and disposed of, and are typically a mixture of different components (heterogeneous). These include wasted foods generated in processing, retail, catering and households. Avoidable agri-food waste occurs when foods are discarded because they are regarded as 'suboptimal', or when they pass their 'best-before' date, or due to product flaws. Unavoidable agri-food wastes, on the other hand, are materials arising from food production systems that are not consumable, typically described as by-products, co-products, or residues (eg manures, crop residues, leaves, peels). Unavoidable agri-food wastes cannot be prevented and are typically homogeneous streams.

The UK annually produces approximately 80 million tonnes of agricultural manure[5] and 7 million to 15 million tonnes of crop residues[6]; processing and logistic stages generate an additional 2.4 million tonnes; retailers produce around 240,000 tonnes of wasted food (representing 0.7% of sales)[7]; while UK consumers generate ca. 7 million tonnes of wasted food and food residue per annum, representing about 20% of the food

In the past 50 years, agriculture has become **resource intensive**

they purchase each year[8]. A great deal of the post-harvest agri-food waste is avoidable, with estimates of manufacturing and retailing wastes being 56% avoidable (ie it could have been eaten, with or without further processing) as well as 60% to 80% of household food waste being avoidable[7].

The generation of agri-food waste is a key indicator of inefficiency in agri-food systems. Post-harvest food wastes in the UK account for a lost value of over £17 billion per year. The majority of this value, £12.5 billion, is lost in the household on food that could have been consumed but is instead discarded[7]. These wastes are responsible for a significant amount of greenhouse gas emissions generated from producing food that is never eaten, with the Waste and Resources Action Programme (WRAP) estimating that avoidable household food waste alone accounts for 17 million tonnes of CO_2 per year[8] (equivalent to the emissions of 25% of the cars on UK roads).

Towards a zero waste agri-food sector

The classification of material streams as 'wastes' or 'resources' has influenced how they are treated: 'resource' highlights its potential value, while 'wastes' implies that it has little or no value. Some may view animal manure as a waste, but it is used locally as a fertiliser on agricultural land due to its value as a nutrient source and soil conditioner. Farmers sometimes utilise crop residues such as straw to maintain soil organic matter levels and improve soil structure. These examples highlight that reclassifying what may be considered 'wastes' as 'resources' – by recognising and valuing their characteristics – provides a template for policy to change how the UK recognises and manages agri-food waste. For example, yeast left over from brewing was once perceived as an agri-food waste, but when processed into an added-value product it became one of most recognisable brands in the UK: Marmite (see case study on p92).

Two key narratives are driving the management of agri-food wastes:

- The waste hierarchy, which enshrines the role of preventing and reducing the amount of waste generation as the top priority.
- The UK's bioeconomy vision, which focuses on "the high value opportunities that are available from using waste as a feedstock"[9]

The waste hierarchy was designed to prioritise pathways for waste, and was developed to look at waste management as a service; it was not developed to assess wastes' value as a resource. Unavoidable agri-food waste can be viewed as a resource, as it cannot be prevented, and thus its effective utilisation should be prioritised. Avoidable wastes, on the other hand, represent mismanagement and inefficient use, and the waste hierarchy should govern their management.

The source of the biomass being exploited as a resource is an important consideration. Several decades ago, biofuels started to be advocated as a kind of panacea for addressing the atmospheric impacts of fossil fuels, and this led to major mistakes regarding the use of land for fuel versus food. Some market instruments intended to support biofuels led to distortions in the market whereby, for example, tropical rainforests were chopped down to make up the shortfall in land required to meet global food requirements. This 'food vs fuel debate' highlights the social, economic and environmental damage that can be caused by poorly thought out policies, and illustrates the potential conflicts around the types and provenance of biological materials that are suitable for use in a bioeconomy.

Wastes may be considered very differently to biofuel crops and forestry, but their use as potential resources also involves several trade-offs. Resource productivity can be achieved through a myriad of pathways, and while it is not the government's role to dictate a pathway, it has an obligation to develop a policy framework in such a way that agri-food waste is directed to more sustainable pathways.

Broadly, there are four classes of agri-food waste, segregated by economic value and the amount and type of a waste stream (see Fig. 1). This valorisation of waste, which has resulted in it becoming a feedstock for a number of technologies, means that there is a strong relationship between its economic value and the amount that is available. Avoidable food wastes currently sit in class 2 (high mass, low value). Policies can incentivise the reduction of this waste (forcing it to class 1), which would represent an efficient production process. Policies could also promote the use of avoidable food waste as a feedstock for valorisation, shifting it to class 4 to make it a valuable and sought after resource. Food waste (avoidable and unavoidable) is a feedstock for anaerobic digestion (see case study on p91) and composting technologies in the UK, which may diminish the incentive to reduce the waste (extending the inefficient food system). Unavoidable agri-food wastes, such as by-products, co-products and residues, should be incentivised to either class 3 or 4, to maximise their recovery potential as a resource. The example of brewers' spent grain that may have been traditionally perceived as a waste by-product (class 2), has now become a valuable resource (pushed to class 4) through the exploitation of valuable compounds present within.

Determining sustainable pathways for agri-food waste requires both qualitative and quantitative assessments, from environmental, economic, and social perspectives. Lifecycle assessment (LCA) tools have been used extensively for assessing waste management

Figure 1: *This frames the relationship between economic value and the amount and type of a material stream.*

Thomas Oldfield[11]

as a service; to compare possible management routes such as AD, compost, incineration, and landfilling; and in some cases comparing against waste reduction efforts[10,11].

The upstream impacts (the resources invested in the products that eventually become waste) of potential feedstocks must also be included, rather than just comparing downstream technologies. The inclusion of the upstream impact in LCA enables the quantification of the embedded environmental impact of agri-food waste and potential environmental burdens of valorisation pathways. Following such an approach enables decisions to be made around waste minimisation/reduction versus its valorisation and potential promotion.

Using LCA, the 'embedded impacts' of various organic wastes have been quantified, as well as the various pathways they can be processed through. Avoidable food wastes have high embedded impacts (about 5kg CO_2 per kg waste) with other waste streams, such as green waste, having much lower impacts (<0.1kg CO_2 per kg waste)[11]. This embedded impact is very significant and can influence the potential suitability of a waste stream for valorisation. For example, the processing of green wastes (trees, bushes, grass, leaves) through composting technology, from an environmental perspective, is a good option for nutrient recovery and its environmental impact is comparable to mineral fertiliser per kg of nitrogen produced. But avoidable food waste is not a favourable option for fertiliser production due to its high embedded impact, which cannot be offset by its utilisation via composting[11]. Each waste stream needs to be assessed for the best valorisation options because one cannot assume that the impact of valorisation is always environmentally positive.

There are certain challenges in using LCA, especially in the case of agri-food waste, in terms of reasonable data, and clear and transparent system boundaries. LCA can be used to prioritise differing agri-food wastes through competing pathways, which includes valorisation and minimisation. The embedded impacts of any waste must be assessed to determine the ability of pathways to offset upstream investments. Quantitative analysis tools, such as LCA, allow policymakers to assess whether or not an incentive should be given to a particular pathway grounded on evidence-based assessments.

Resource productivity opportunities

The growing demands on the world's food supply chain make resource productivity crucial to its sustainability. Influenced by 'circular economy' thinking (see Chapter 1), resource productivity in agriculture centres on the production of agricultural commodities using a minimal amount of external inputs, closing nutrient loops and reducing negative discharges to the environment (in the form of wastes and emissions). Examining the entire agri-food system through the resource productivity lens reveals opportunities at all stages, from primary production using precision agricultural techniques, to utilisation of agri-food wastes in the bioeconomy.

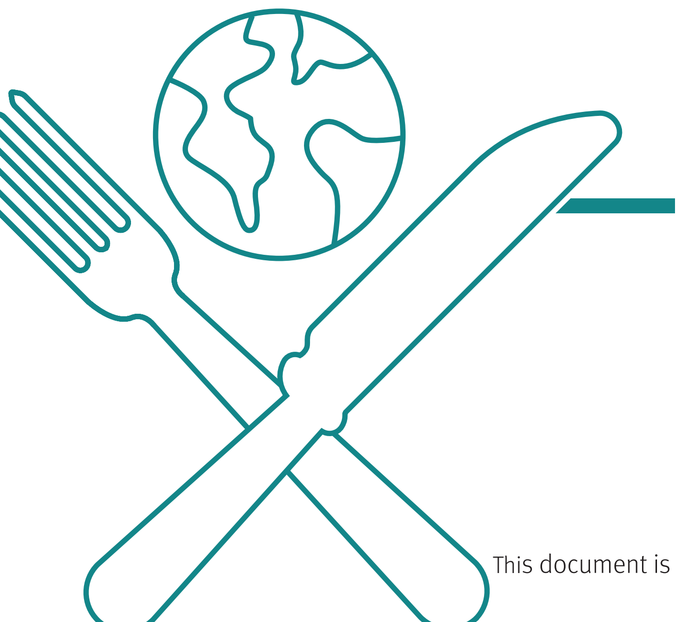
Resource productivity efforts must start with the resources invested in agriculture, which has a significant level of in-built wastefulness. Crops absorb just 30% to 50% of applied nutrients from fertilisers and absorb less than 35% of water applied to fields[12]. Critical materials such as phosphorus are also wastefully applied, with an estimated 57% of phosphorus fertiliser input to arable soil being lost to inland and coastal waters[13]. To address these inefficiencies, precision agriculture mechanisation systems use 'big data' provided by sensors and machine control systems, which enable an enhanced level of control over the application of inputs (fertilisers, agrochemicals) that reflect geospatial variability in soils, microclimate and other relevant

Cost of global food sector inefficiency per year

$1-2 trillion

husbandry parameters. Precision agriculture utilises the vast capabilities of information technology systems to optimise the application of agricultural inputs, delivering the 'right amount, at the right time, in the right place'. This ensures that the minimum resources needed are used at the production stage, in order to achieve optimum performance with minimal environmental impact.

Precision agriculture techniques are not new. The Department for Environment, Food and Rural Affairs (Defra) has estimated that 22% of farmers have GPS steering systems; 20% utilise soil-mapping software; 16% use variable rate fertiliser and spray application; and 11% have yield mapping[14]. Tractors can already drive themselves using GPS systems, but more advanced technologies such as drones are now starting to be used to sow seeds, monitor crops and ensure optimum applications of chemicals. The government's agri-tech strategy[15] outlines the vision and the financial support that will enable the UK to become a world leader in agricultural technology. In addition, government can create favourable regulatory and business environments to allow these agricultural technologies to flourish in the UK. They can play a more active role in facilitating greater participation and adoption of these technologies by UK farmers and agriculture organisations in order to embed skills and technology within UK agriculture. Harper Adams University is a good example of where world-class research is taking place on optimising precision agriculture systems. A consortium including Harper Adams



Case Study

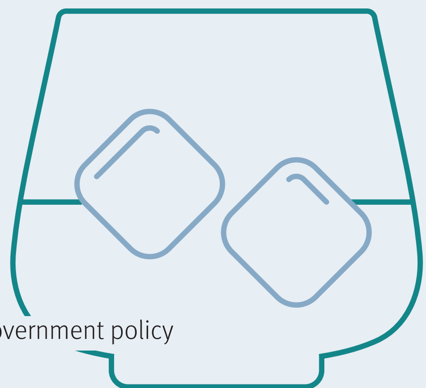
Scotch Whisky

Morag Garden, Head of Sustainability and Innovation, Scotch Whisky Association

Scotch Whisky has significant importance for the Scottish and UK economies, adding almost £5 billion to GDP each year, supporting more than 40,000 jobs, and generating almost £4 billion in exports.

The Scotch Whisky industry launched its Environmental Strategy in 2009 with a set of ambitious sustainability targets that includes greenhouse gas emission reduction, enhanced energy efficiency and renewable energy targets. Distillers have committed to sourcing 20% of their primary energy requirements from non-fossil fuels by 2020, and 80% by 2050. The industry has already made progress in meeting its targets, with the contribution of non-fossil fuels increasing from 3% to 17% between 2008 and 2014.

Since 2008, the Scotch Whisky industry has invested more than £160 million in renewable energy schemes across five major production sites. These include large-scale anaerobic digestion (AD), biomass and renewable combined heat and power (CHP). A specific example of waste valorisation is Horizon Proteins, a spin-out company from Heriot-Watt University in Edinburgh. By adapting techniques more usually applied to high-value pharmaceutical products, it has developed a process that uses 'pot ale' (a by-product from malt whisky distilleries) to produce a sustainable, nutritionally-suitable protein for salmon feed. The integrated by-product processing technology has been installed and tested at a Scotch Whisky distillery. This not only benefits the food chain, but also improves the quality of the remaining material for use in bioenergy processes such as AD.



240,000 tonnes

food wasted by retailers per year

University (HAU), Cranfield University and Scotland's Rural College (SRUC) has recently established the Agricultural Engineering Precision Innovation Centre (Agri EPI Centre) with £17.7 million investment under the government's Agri-tech Strategy. The centre, in collaboration with HAU's National Centre for Precision Farming (NCPF), provides a collaboration network for organisations across the agri-food supply chain, 76 companies and institutions in all, with the objective of embedding precision agriculture systems and practices within UK production agriculture.

Capturing lost value in the agri-food chain

The upstream investment in resources (eg fuel, phosphorus, soil) and natural capital impacts (eg land use, soil degradation) make agri-food waste reduction, where practicable, a priority in order to create a sustainable, secure agri-food supply system. Coordinated efforts in the UK have helped to reduce avoidable household food waste by 21% over five years (2007 to 2012). This represents a retail value of around £13 billion over that period; prevented 4.4 million tonnes of GHG emissions per year, the same as taking 1.8 million cars off UK roads; and saved one billion tonnes of water per year[8]. Reducing avoidable food waste continues to be the priority. In addition, the Courtauld Commitment 2025 – a voluntary agreement aimed at improving resource efficiency and reducing waste within the UK grocery sector, delivered by WRAP – has ambitious targets to cut the resources needed to provide food and drink by one-fifth in ten years (2015 to 2025), which would result in a cumulative saving of around £20 billion[16]. Significant economic value still remains untapped, such as the millions of pounds worth of potential nutrients or energy that is disposed of in UK landfills annually.

Prevention must remain the priority for all agri-food waste streams (whether avoidable or not). The costs of decreasing food waste are low, but the returns are very significant. Less waste means greater agri-food chain efficiency, and more competitive goods and services. UK policy should encourage efficiency and reduction of all avoidable wastes to make the sector more valuable to society and the economy.

Incentives are needed to encourage producers and retailers to redistribute food waste. In food processing, policies promoting industrial symbiosis can further reduce food waste, while exploiting more powerful data analytics can help retailers with demand forecasting and stock management.
In households, more education and awareness is needed for people to utilise food that is currently going to waste. In order to support consumers in making sustainable food choices, it is also necessary to educate them on labelling, and improve transparency regarding the degree to which these labels are controlled and trustworthy. Policies regarding food labelling (eg 'best before' dates) need harmonisation and clarification to send clear messages to consumers.

Examining the entire agri-food system through the **resource productivity** lens reveals opportunities at all stages

Case Study

Anaerobic digestion

Thomas Oldfield, Eoin White, Nicholas Holden and Shane Ward

A continuous supply of nitrogen (N), phosphorus (P) and potassium (K) is needed to sustain crop yields. These nutrients are typically provided by mineral fertiliser, but estimates suggest that global supplies of virgin mineral P will be exhausted in the next 50 to 100 years. Anaerobic digestion (AD) has emerged as an innovative method to recycle N, P and K within agricultural systems, part of an effort to 'close the loop' by returning agri-food waste back to agricultural soil.

More than 160 AD plants are already operating in the UK, spurred by factors that include nitrate vulnerable zone restrictions[21] (land areas designated as being at risk from agricultural nitrate pollution); the expansion of farm size[22]; and AD's stabilising influence on the volatility in milk prices[22]. Major challenges still exist, however, including a lack of familiarity with the technology, which can be a barrier in accessing funds[22]; finding a demand for the heat produced[2]; planning restrictions[22]; and limitations in electrical grid connectivity[22]. Installers have found that acquiring a food waste permit can be very expensive and not viable if a local company does not commit to delivering sufficient material each year[23]. And despite the UK's 2010 budget prediction that electricity prices would rise each year, the reality is that they have not – consequently, some installers are currently selling electricity at 80% of the price budgeted in 2014.

When AD is introduced to a farm, it necessitates changes to business practices. AD needs full time monitoring, even when operating smoothly, to achieve the best performance. By structuring the farm business around the AD plant, a farmer can ensure maximum returns from AD[22], but this requires education and training. A common lesson learnt from a number of installers was that future AD plants should be incentivised to co-locate the combined heat and power plant near a local school or business that has a substantial continued demand for heat and electricity[21, 22, 23.] This is critical in order to achieve environmental and economic savings from the AD process.

If these hurdles are overcome, the benefits for AD installers can be substantial. Some have become 90% to 95% self-sufficient in electricity, which enables a relatively remote farm with poor infrastructure to become an on-site power plant, making it more robust and providing a better platform for growth[24]. Other direct benefits are job creation in rural areas, delivering 'multiplier effects' in the local rural economy.

Feedstock selection is critical, and must consider multiple types, due to fluctuations in waste availability. Using on-farm wastes is logical, but transporting avoidable food waste from the surrounding community to the farm could undermine waste prevention strategies, especially when a farmer can generate more income from energy than the milk they produce.

The scale, robustness and costs of AD plants are also crucial issues, with 'plug and play' small-scale AD units offering greater options to the farmer, industry, public buildings and small businesses (eg restaurants, hospitals, or schools). The AgroCycle Hub at Harper Adams University is studying the development of such plug and play units, in collaboration with specific UK technology providers and end-users, such as the poultry industry. These small-scale units provide better control of the feedstock and digestion process, while also offering a relatively low cost self-contained system suitable for retrofitting into existing operations. On-farm AD units are hugely popular in Germany[25, 26], and there is a major opportunity for the UK to become a global leader in this technology, extending on-farm to downstream businesses in a cost-effective and technically efficient manner.

Coordinated efforts in the **UK** have helped to reduce avoidable household food waste by **21% over five years** (2007 to 2012)

Maximising value of agri-food waste as a resource in the UK

Many agri-food wastes are ideal raw materials for biological processes to create new products (or existing products by new processes), providing a major opportunity for UK agriculture and industry. The characteristics of agri-food wastes mean they can act as a source of renewable carbon for making valuable chemicals and fuels, replacing many common chemicals that rely on virgin fossil material. The annual value of the UK's growing bioeconomy is currently estimated to be worth £36 billion in direct contribution, and £150 billion in gross value added (GVA)[17], with a potential market size of around £100 billion per year, of which waste-based resources would make a significant contribution[4].

Novel processes are being developed that combine extraction of high-value products with subsequent fermentations (or green chemical conversions) for the production of chemicals, materials and fuels to minimise production costs. The UK has a substantial innovation ecosystem in the bioeconomy domain[9], including

Case Study

Marmite: transforming waste into a British institution

Thomas Oldfield, Eoin White, Nicholas Holden and Shane Ward.

Marmite was one of the first waste-to-resource products in the UK, and is perhaps the country's most successful to date. The product was developed in the 19th century by German chemist Justus von Liebig, and commercialised in the UK by the Marmite Food Company in Burton upon Trent in 1902, using leftover yeast from the nearby Bass brewery to create the protein-rich food.

Marmite now uses 50,000 tonnes of yeast per year from the Bass brewery to make 50 million jars of Marmite. Meanwhile, 18,000 tonnes per year of solid Marmite waste is converted into methane via anaerobic digestion, which is used to provide 30% of the factory's thermal energy. Unilever, which owns Marmite, is committed to developing other waste-to-resource systems, using lifecycle analysis (LCA) tools to better measure, manage and improve the performance of their products.

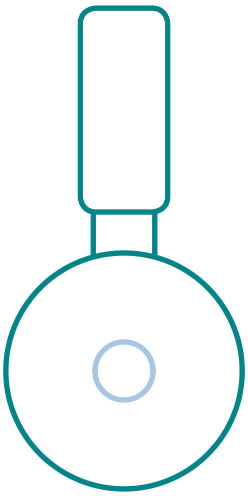
the government-funded Centre for Process Innovation, the Biorenewables Development Centre at the University of York, and the AgroCycle Hub at Harper Adams University, which is part of an EU Horizon 2020 agri-food waste valorisation project, Agrocycle[18]. In addition to the academic and research capabilities, many novel enterprises are transforming wastes into valuable products, such as innovative processors turning waste coffee grounds into biofuels, and dairy processors' conversion of whey wastes in cheese manufacturing into high-value whey protein products. Larger sector initiatives, such as the Scotch whisky and the British sugar industry, are now generating significant revenue from non-core sales by harnessing waste streams from their core production processes into useful and positive inputs to new product lines (see case study on p89)[19].

The waste-to-bioeconomy transition offers the UK significant potential to exploit its innovations. But this transition will also require important contributions from government: to help facilitate the industrial coordination that will be required, as well as putting in place policy measures and incentives to achieve optimal outcomes. Particular efforts should focus on:

- **Quality standards and raw material 'passports'.** It is important to know the provenance and quality of a given waste when using it as a feedstock. Existing quality standards for compost and AD are set out in standardisation documents called publicly available specifications (PSAs), issued by the BSI Group (British Standards Institution). It is now important to extend quality protocols for agri-food waste streams, thereby strengthening their economic potential by ensuring quality and sustainability of supply. The establishment of 'raw material passports' would be a major step in ensuring product provenance and quality, providing information on the origin of input nutrients to ensure that recycled and recovered nutrients can compete with fossil-based alternatives. Without this passport information, many valorisation pathways may be damaging the environment due to the use of inappropriate feedstock.
- **Industrial symbiosis.** Through its new focus on industrial strategy, the government can play a clear role as a facilitator in helping to coordinate the key stakeholders in the bioeconomy, including local government, relevant research and innovation ecosystems, and industry. A national stakeholders' platform could help the agricultural industry and collection/processing sectors come together with technology/process solutions and business customers (eg energy, chemical, or pharmaceutical sectors) to identify and develop the opportunities of the waste-to-bioeconomy transition, and complete the business case for development. The stakeholders' platform at the AgroCycle Hub demonstrates how this networking facilitates such industrial symbiosis.

10 **megajoules**

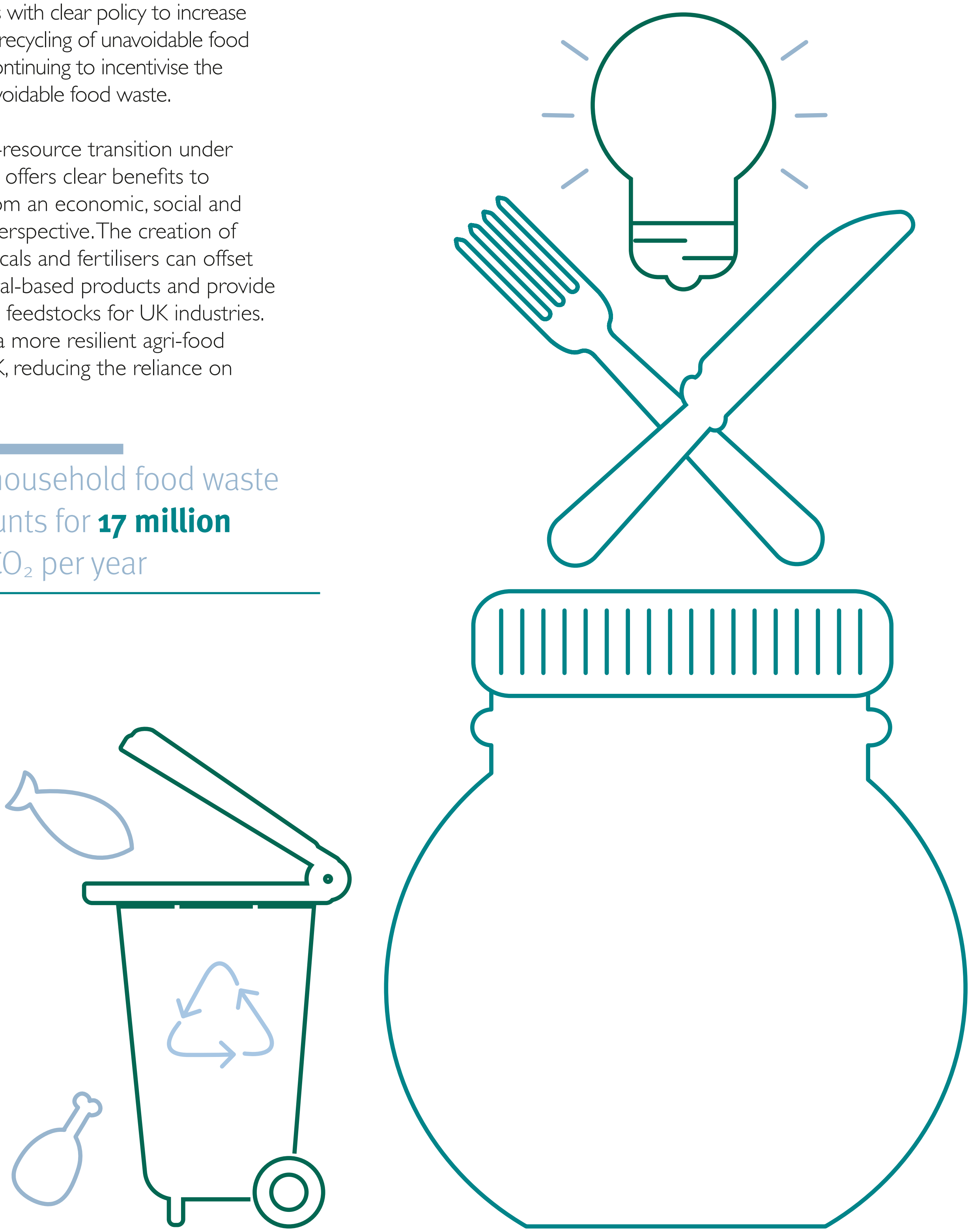
Amount of **fossil energy used** to create 1 megajoule of food energy



- **Waste reduction and collection.** Industry has taken the lead with WRAP's new Food Waste Recycling Action Plan[20], using collaboration across the supply chain to increase the collection of food waste. Government can complement these initiatives with clear policy to increase collection and recycling of unavoidable food waste, while continuing to incentivise the reduction of avoidable food waste.

The waste-to-resource transition under the bioeconomy offers clear benefits to UK industries from an economic, social and environmental perspective. The creation of bio-based chemicals and fertilisers can offset traditional mineral-based products and provide more renewable feedstocks for UK industries. This will enable a more resilient agri-food system in the UK, reducing the reliance on finite resources.

Avoidable household food waste alone accounts for **17 million tonnes** of CO_2 per year



CHAPTER 7:
Mining and resource recovery

Extracting metals and minerals from the Earth's crust is a major human activity that has substantial environmental impacts. Increasing the recovery of these resources from the human environment could help to mitigate those impacts and, in time, reduce pressure on primary resources. That could be achieved by collecting better data on the stocks and movement of secondary materials; and by supporting research and innovation in product design, remanufacture and metallurgy.

Andrew Bloodworth, Gus Gunn and Evi Petavratzi, British Geological Survey

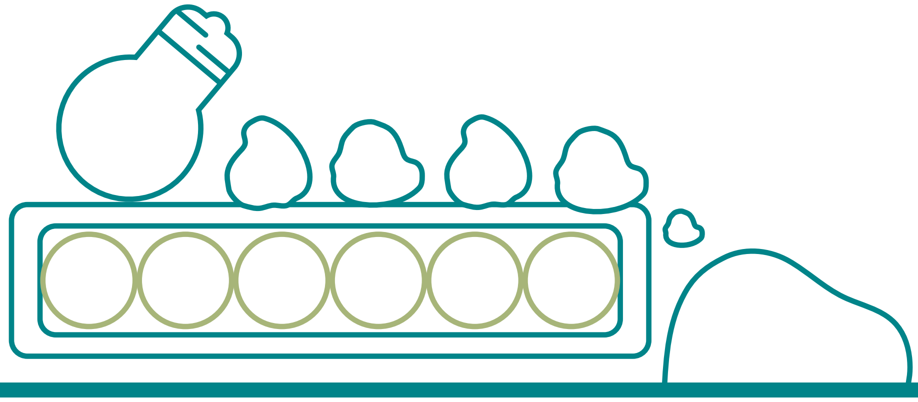
"If you cannot grow it, you have to mine it." As this old miner's aphorism suggests, almost all abiotic materials used by humans – but particularly metals, and industrial and construction minerals, including those that have been recycled – have ultimately been mined from the Earth's crust. The extraction and processing of crustal primary resources is a major human activity that exerts a strong influence on the availability of secondary resources: those that can be recovered from the human environment, sometimes referred to as the 'urban mine'. The uneven distribution of mineral deposits across the globe, together with increasing demand for the minerals and metals derived from them, has led to the development of advanced technologies for the large-scale extraction, processing and transportation of these materials. The UK produces only a small proportion of the minerals and metals it needs and is consequently heavily reliant on imported supplies. In this analysis we compare how raw materials are derived from primary and secondary resources and consider how to increase recovery from secondary sources in the UK.

Primary materials

Primary resources of metallic and other minerals occur in 'deposits', which are any accumulation of a mineral or set of minerals that may be economically valuable. The value of a deposit depends on how much mineral is available, what it costs to mine and process, how rare the mineral is (either locally or internationally), and its current or future market price. For example, gold is a very rare metal that commands a high price, so a deposit containing only a few grams of gold in each tonne of rock may be economic to mine. For abundant minerals such as iron, the ore must contain at least 40% iron before it can be mined. For widespread minerals like sand, almost the entire deposit may be marketable, if its quality is acceptable, with very little waste.

Most primary minerals and metals have a low 'place value': their price is high relative to the cost of transporting them. These materials are generally traded on a continental or global scale and the UK, together with most developed economies, is highly reliant on this international supply chain for most metals and minerals. However, bulk construction minerals, such as crushed rock aggregate and sand and gravel, have a high place value: their price is low relative to transportation costs[1]. Trade in these materials is much more localised and, as a consequence, the UK is almost entirely self-sufficient in domestically-produced aggregates. The place-related factors affecting UK trade in construction aggregates have a profound influence on the utilisation of secondary aggregate resources (see case study on p98).

Demand from population growth and economic and technological development means that the volume and variety of materials produced from the Earth has grown immensely in the past 200 years (Fig. 1)[2]. The global mining industry is now very large and it is expected to continue to grow, chiefly in response to high rates of industrialization and urbanization in emerging economies. In 2010, it was worth about $644 billion (£488 billion)[3], which constituted about 1% of global GDP[4].



Proportion of global energy used to crush rock 3-5%

In 2014, the global mining industry produced about 3.4 billion tonnes of iron ore and 260 million tonnes of bauxite, the main ore of aluminium[5]. These, and numerous other metals and minerals produced in smaller amounts, are traded extensively across the globe. Growth in emerging economies and rapid global uptake of low carbon technologies is also expected to fuel demand for metals and minerals[6,7].

The global mining industry has taken advantage of huge efficiency gains and economies of scale linked to major advances in exploration, mining and extraction technologies, and in transport logistics. This has provided industry with secure access to relatively cheap and consistent supplies of high-quality mineral and metal raw materials. Intermittent perturbations in the form of price hikes and temporary shortages have occurred, and will continue to do so. However, this is primarily due to market trading conditions rather than scarcity. For example, in 1979 to 1980 there was a sharp spike in the price of tantalum, used in electronic capacitors, which was caused by a perceived shortage in supply. However, the price rapidly returned to normal levels as new sources of supply were brought into production and technical advances permitted a reduction in tantalum usage without impaired performance[8]. The current supply mechanism has generally served the global economy well for many years. In part, supply chains and manufacturing methods, including those in the UK, have been configured to maximise the benefits delivered by this efficient primary metal and mineral supply sector.

Although primary metals and minerals are non-renewable resources, most geologists consider that physical exhaustion of the materials in the Earth's crust is very unlikely in the foreseeable future. As minerals are used, exploration continually identifies new deposits and the reserve base is replenished. Prevailing market conditions and technology determine the economic viability of these deposits[2,9]. However, primary extraction is energy (carbon) and water intensive[10]. We are, therefore, likely to reach the environmental limits (such as greenhouse gas emissions or water consumption) of our primary resources far sooner than we reach their physical limits. Despite this, the full environmental costs of primary production are not generally internalised in the price of metals and minerals.

As a consequence of UK dependence on global supply chains, a variety of other risks related to environmental, geopolitical, social and ethical factors may be of greater

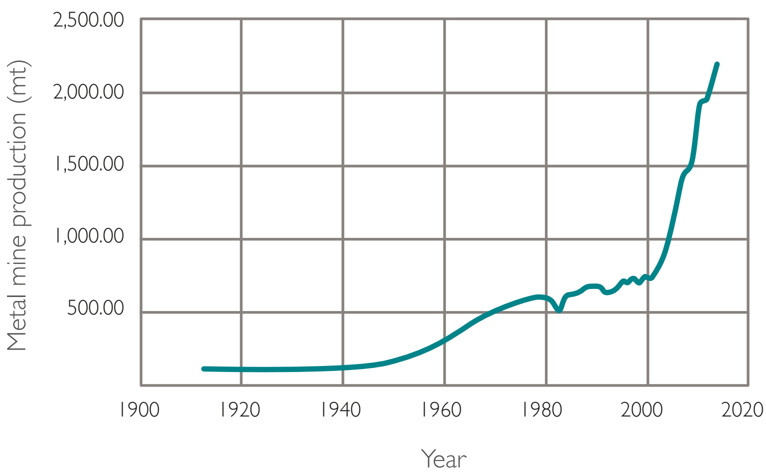


Figure 1: *Global mine production of metals, 1913–2014. Over the same period the number of commodities for which data are held in the British Geological Survey database increased from 39 (including 12 metals) to 73 (including 27 metals).*

BGS World Mineral Statistics database

and more immediate concern. Despite the current trough in commodity values, sustained growth in demand will inevitably see metal and mineral prices increase in the next decade. As a consequence, as has happened in the recent past, it is likely that many mineral- and metal-exporting countries will seek a larger share of the wealth generated by extraction. In most jurisdictions, this will be through taxation and royalties. But elsewhere, governments may ban export of unprocessed raw materials, forcing miners to develop local processing of domestically mined ores; or they may nationalise extractive operations. The requirement for mining to have a 'social licence to operate' has also assumed great importance in the past 20 to 30 years[11]. In both developed and emerging economies, public concerns have been raised over the environmental impacts of mining and its effects on local communities, traditional land-use patterns and landscapes. Tensions over resources will increase over the next few years, and the scramble for access looks set to continue throughout the world.

Although mineral endowments should enable poorer countries to embark on a path to economic development, the evidence shows that resource-rich developing countries often move toward poverty and instability. These factors are a major driver for informal artisanal and small-scale mining (ASM) in the developing world. Millions of people worldwide are economically dependent on ASM, and the social, environmental and economic issues associated with ASM pose a considerable developmental challenge. Of particular concern are the so-called 'conflict minerals' tantalum, tungsten, tin and gold, which are mined under conditions of armed conflict and human rights abuse, notably in the eastern provinces of the Democratic Republic of the Congo. Legislation introduced in the US in 2012 has forced companies to identify the source of the minerals used in their products, with the aim of promoting responsible sourcing. Similar legislation is being prepared in Europe. As a consequence, ethical considerations related to metal and mineral supply from the developing world are likely to become a more pressing issue.

The distribution in the Earth's crust of 'technology metals' (such as rare earth elements, indium, niobium, platinum, rhenium and many more), and the geological processes that lead to their concentration, are poorly understood compared to major 'industrial metals' such as iron, copper and aluminium[2]. Despite growing demand for technology metals, linked to their importance in digital, low-carbon energy and transport technologies, they are generally produced in very low volumes compared to industrial metals. For example, annual global production levels of platinum and indium are only a few hundred tonnes; and of rare earths and niobium, a few tens of thousand tonnes. As a consequence, the production of several technology metals has become concentrated in a few locations. The geopolitical and socio-economic conditions prevailing in many of these supplier countries are widely regarded as a risk to supply security. This is compounded by barriers to the commercial development of both primary and secondary (recycled) technology metal resources. These barriers include difficult extractive metallurgy, which might attract environmental opposition in some locations, as well as markets that tend to be relatively complex, opaque and volatile when compared to industrial metals. A further supply risk factor is that many technology metals are produced solely as by-products of the extraction of an industrial metal. For example, indium is produced only as a by-product of the mining and smelting of zinc ore, and there are no indium mines anywhere in the world. Similarly, most tellurium and cobalt are produced as by-products of the extraction of copper. These risks to primary supply, together with high prices and price volatility, impact on the viability of the recovery of metals and mineral-based materials from waste in the UK.

The consumer products of today are **much more complex** than in the past and they rely on a broad palette of technology metals for their function and performance

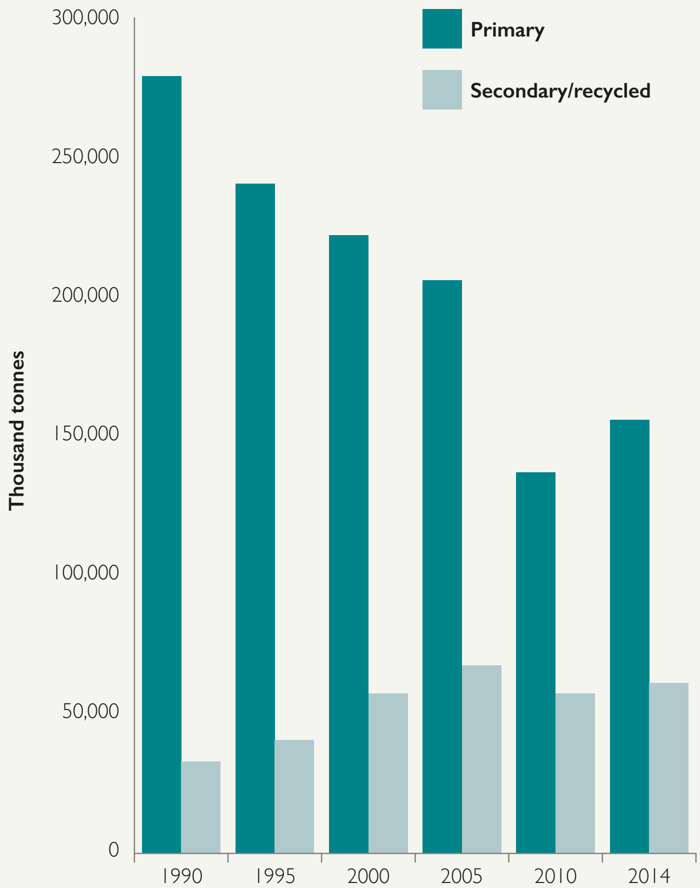
Case Study

Construction aggregates: the impact of environmental taxation on UK supply

Andrew Bloodworth, British Geological Survey

Construction aggregates are used in almost all building and infrastructure projects, such as roads, railways, housing, schools, hospitals, energy plants, offices and factories. They are granular or particulate materials that are suitable for use on their own, or with a binder such as cement, lime or bitumen. Aggregates are used in concrete, mortar, asphalt, or for fill or railway ballast. Construction aggregates constitute a very large material flow in the UK economy, comprising 175.9 million tonnes of construction minerals in 2014 (ref. 1) and 60 million tonnes of recycled and secondary aggregates[2].

Natural (primary) aggregates can be quarried and crushed from hard rocks (usually limestone, igneous rock or sandstone) or quarried and separated from accumulations of sand and gravel.



Significant quantities of sand and gravel are produced in the UK by dredging the sea floor.

Secondary aggregates are materials that are generally a waste product from other quarrying activities, such as china clay or slate extraction; or a by-product of certain industrial processes, such as blast furnace slag or power station ash. In addition, recycled aggregates are usually derived from construction and demolition waste, road planings or rail ballast[3]. Partly as a result of targeted environmental taxation introduced in the late 1990s and early 2000s, a significant proportion of UK construction aggregates is now supplied from secondary and recycled sources.

The Landfill Tax is a tax on the disposal of waste to landfill that was introduced in 1996 (see Chapter 13). It is intended to encourage efforts to minimise the amount of waste produced and to promote the use of non-landfill waste management options, such as recycling, composting and recovery. Although there are some exemptions, this tax encourages the production of aggregates from materials such as construction and demolition waste by imposing a cost on their disposal in landfill.

The Aggregates Levy was introduced in April 2002. It applies to any primary crushed rock, sand or gravel that is quarried commercially in the UK, including aggregate dredged from the seabed. To protect international competitiveness the tax is also levied on imports, but exports are relieved. The levy is intended to internalise environmental costs associated with quarrying operations (noise, dust, visual intrusion, loss of amenity and damage to biodiversity) in line with the government's statement of intent on environmental taxation. Its objective is to reduce demand for primary aggregate and encourage the use of both recycled and secondary aggregates, which are exempt.

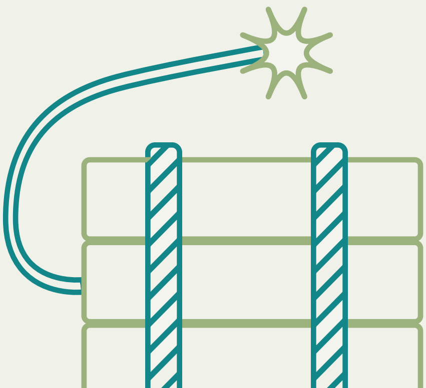
Figure 2: *Production of primary and secondary/recycled aggregate in Great Britain, 1990 to 2014*

BGS UK Minerals Yearbook 2014 and Mineral Products Association sustainability reports

In Great Britain, the proportion of secondary and recycled aggregate relative to primary aggregate production grew from 10.6% in 1990 to 28.2% in 2014 (see Fig. 2). UK aggregate production from secondary and recycled sources is one of highest in Europe, and is double the average of the EU28 (ref.4). Although the growth in the production of recycled aggregate cannot solely be attributed to the effect of environmental taxes, the proportion produced in the UK is much higher than in other European countries where primary aggregates and/or landfill remain untaxed.

During this same period, overall aggregate production in Great Britain fell from 313 million tonnes to 212 million tonnes. This decline in production and consumption reflects a reduction in the intensity of use of aggregates per unit of construction output over the same period, and the application of environmental taxes are thought to be one of a number of contributing factors behind this change[5].

Further growth in the use of recycled aggregate will be constrained by the availability of suitable resources for recycling. The majority of construction and demolition waste generated in the UK is already recovered[6], and a plateau in output over the past few years is commensurate with a predicted maximum 30% recycling input rate as a proportion of overall aggregate production in Great Britain[7]. Nevertheless, it demonstrates how successfully construction mineral producers have integrated the production of recycled aggregates into their processes, giving them access to additional markets and environmental gains.



Tensions over resources will **increase** over the next few years, and the scramble for access looks set to continue **throughout the world**

Secondary materials

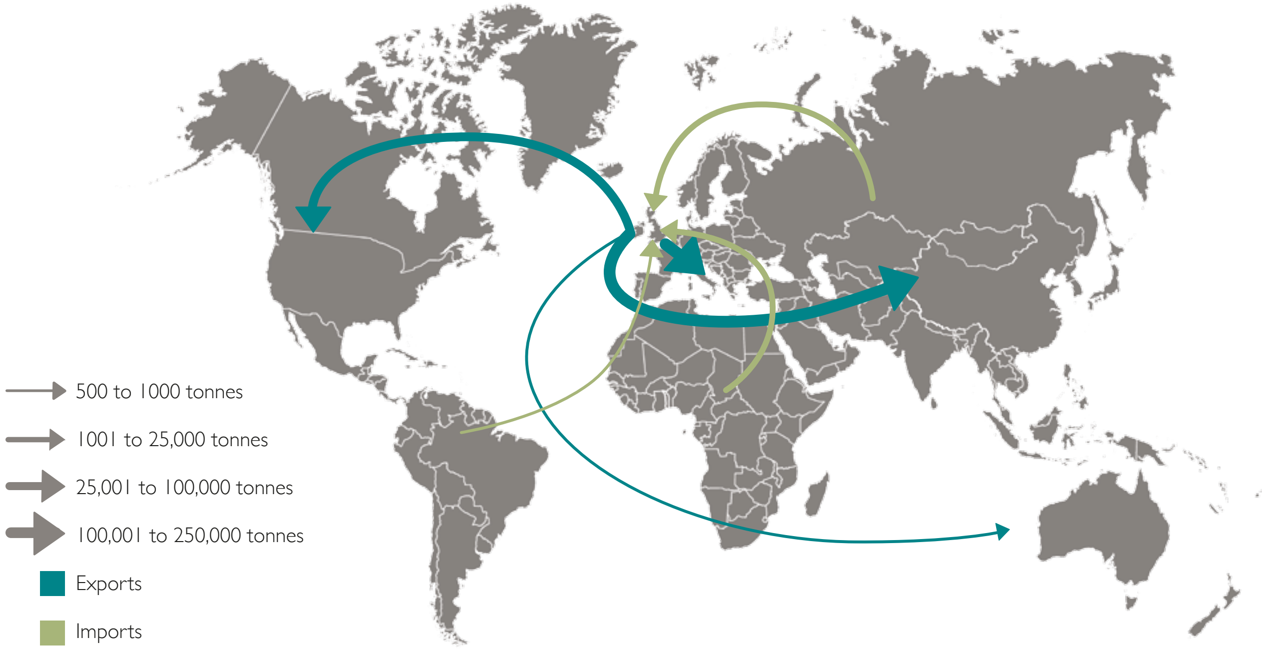
Recycling provides an important complement to supply from primary raw materials and also has a number of significant benefits. Most notable is the reduction of the environmental impacts of extraction (emissions, energy, water and land use). For example, the total energy used in the production of copper metal from ores (known as the embodied energy) is nearly four times greater than that from high-grade scrap[12]. For aluminium, the energy saving is even greater (see case study on p104). Recycling also extends the lifetime of primary resources and improves supply security by reducing import dependencies.

The global recycling industry handles over 600 million tonnes of 'recyclables' every year, with an annual turnover of more than $200 billion (£152 billion)[13]. There is considerable global trade in metal scrap (secondary metal with monetary value) and 'waste' that contains a significant content of higher value metals, and the UK participates in this trade as processor, importer and exporter (see Fig. 3). However, much of this is only collected and sorted in the UK, with the segregated material exported elsewhere for reprocessing. The recovery of metals from recycled scrap contributes about £5.6 billion per annum to the UK economy and directly employs about 8,000 people[14].

Secondary metals or mineral-based materials originate at various stages in the lifecycle of a product. Waste materials generated during fabrication and manufacturing, termed 'new scrap' or 'pre-consumer waste', are generally of higher value and purity than end-of-life (EOL) products and are commonly recycled in closed loop systems established during these stages.

Figure 3: *Trade flows of copper between the UK and the rest of the world in 2014.*

United Nations Comtrade Database[31]



Nevertheless, the stock of metals and minerals in EOL products is another source of secondary materials, also referred to as 'end-of-life waste', 'post-consumer waste' or 'old scrap'. It is theoretically more abundant than new scrap and therefore has greater potential to displace primary raw materials as a source of supply. Post-consumer waste is normally recycled through open loop systems that are complex in structure and relatively inefficient. As a rule, each stage involves different operators that carry out sorting, dismantling and pre-processing, through to the final metallurgical recovery of minerals and metals of interest. Each stage requires increasing technical skills and infrastructure, together with greater financial investments. High recycling rates can only be achieved if each of these stages is efficient[15]. At present, the collection stage is the least efficient because EOL products are widely dispersed geographically, and because the systems to sort, separate and process them are either inadequate or non-existent (see Fig. 4).

Another important factor that influences resource availability is the lifetime of the products that contain sought-after metals and minerals, which varies considerably from product to product. For example, steel and copper in construction may be in use for 30 to 40 years, while aluminium and glass in food packaging may have a lifetime of only a few months.

The consumer products of today are much more complex than in the past and they rely on a broad palette of technology metals for their function and performance. Approximately 45 different elements are used in the manufacture

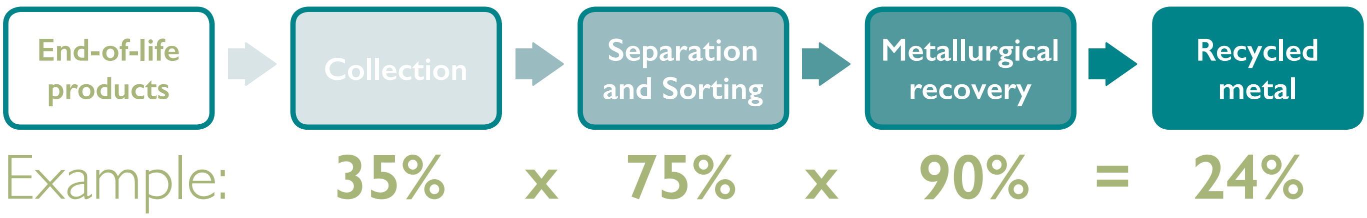


Figure 4: *The recycling chain of end-of-life products. The total recycling efficiency of an end-of-life product is calculated by multiplying each of the single-stage efficiencies. This example shows indicative efficiency rates for the recovery of major metals (iron and steel, copper etc) found in waste electrical and electronic equipment (WEEE).*

Modified from refs. 15 and 16. Efficiencies are average collection rate of WEEE in Europe[17]; average separation and sorting rate in the UK[18]; typical metallurgical recovery[16].

of digital electronic components, which are incorporated into devices ranging from mobile phones to motor vehicles[19]. In some products, they are present in higher concentrations than in natural ores[20]. For example, electronic scrap may contain 200 to 250 grams of gold per tonne, in contrast to a primary gold deposit that might have an average ore grade of 5 grams per tonne[15]. However, the actual amount of metal contained in a single device at the end of its life may be very small. For example, although beryllium is an essential component of beryllium-copper alloys used in a wide variety of electronic devices, it is not economic to recover beryllium metal from this source because the beryllium content of the alloy is very low (less than 1.25%)[21]. In addition, current product design, manufacturing and/or business models often make recovery of metals and mineral-based materials from waste uncompetitive with those produced from the primary sector. For example, the dispersion and combinations of metals in consumer electronics makes many of them difficult and/or costly to recover compared with metal recovery from natural ores where the technology has been developed, in many cases, over centuries.

Whether or not a metal is recovered at the end of a device's life depends on its intrinsic value, concentration and technical recyclability when combined with other materials in the device[7]. Unsurprisingly, the recovery of high value precious metals (platinum group metals and gold) is a key target of recycling, chiefly from autocatalysts, circuit boards and mobile phones (see case study on p103). Pyrometallurgical processing is used to separate these metals through the co-recovery of lower-value copper as a 'carrier' metal, as well as antimony and indium. However, the thermodynamics of this process mean that incompatible technology metals such as tantalum, gallium, germanium and rare earths are oxidised and are effectively lost in the smelter slag[22]. The recycling of many technology metals is currently most economically attractive when the target metals are present in high-grade concentrates, such as those from manufacturing scrap. For example, current technology used to make flat-screen displays is not very efficient, and approximately 70 percent of the indium used in this process finds its way into manufacturing scrap, which is then recycled[23]. However, the reality is that most technology metals used in complex assemblies such as circuit boards are not currently recovered at end of life because they are too low value, too dispersed and are generally combined with other materials from which they cannot readily be separated.

Similar problems related to metal combinations and contamination drive current practice in the recycling of steel. Copper contamination of steel re-melted from scrapped cars means that this steel must be diluted with primary steel made from iron ore before it can be used to manufacture low-grade reinforcing bars. This 'downcycling' of steel scrap is the current norm. Even high-grade steel alloys recovered from EOL products and buildings are not generally separated but mixed together, re-melted and reused in much lower grade applications[24].

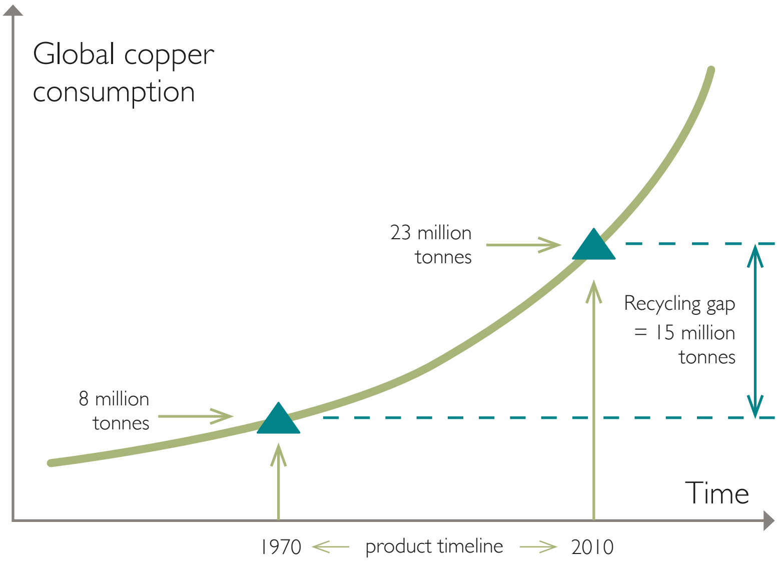
A greater contribution from secondary materials?

The scale of the global mining industry, and the consequent economic and technological efficiencies in the production and supply of primary metals and minerals, contrasts with a global recycling sector that is smaller and less resource efficient. In order to be competitive, the costs associated with identification, collection, processing and extraction of secondary metals and other mineral-based materials from waste must be similar to, or lower than, those associated with exploration, mining and extraction from natural mineral deposits. However, the imbalance in scale between the two sectors can make this hard to achieve.

As long as **global consumption** increases, we will continue to need primary metal and mineral-based materials

Figure 5: *When demand for a commodity increases over time, recycling alone cannot meet the higher demand – even if all products were collected and recycled with 100% efficiency at the end of their life. For example, global copper consumption in 1970 was about 8 million tonnes; by 2010, this had increased to 23 million tonnes. If all the copper incorporated into products in 1970 were recovered at the end of their life in 2010, there would still be a supply shortfall of 15 million tonnes, which could be filled only by primary production.*

Data from BGS



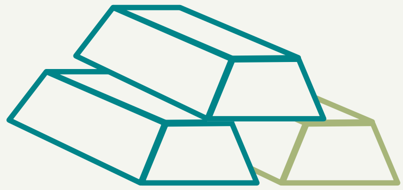
As long as global consumption increases, we will continue to need primary metal and mineral-based materials. The recycling industry has an important role to play in the provision of resources to facilitate economic growth, but on its own it cannot currently satisfy growing global demand for materials. There are inevitable material losses during the production, use and recycling stages, but at a time when global demand is increasing, the lifetime of consumer products becomes a key factor in supply from secondary materials. In a world of increasing resource use, even if all products were collected and recycled with 100% efficiency at the end of their useful life, there would inevitably be a shortfall in supply which would have to be filled by production from primary resources (see Fig. 5). However, a long-term future situation can be envisaged where consumption begins to level off and secondary resources from 'waste' may progressively displace mined material. This step-change may occur sooner in developed economies, including the UK. As a result, per capita use of metals such as steel will stabilise and, provided downcycling is avoided, demand can be largely satisfied from reuse of EOL material[24]. However, for this to happen, it is essential that the EOL products are not exported and that the appropriate recycling technology and skills remain available in the UK. This paradigm will probably take much longer to establish for technology metals where societal, environmental and technological changes are driving rapid increases in demand in both developed and emerging economies across the world.

> There is also a need to **change** the way the market currently operates

There is also a need to change the way the market currently operates. The focus of the existing economic model is on the supply of raw materials, which has brought economic growth, prosperity and lifestyle improvements to the developed world. The key factors that contributed to this success are developments in productivity, technology, labour and access to energy, resources and credit. However, it has not always been possible to match supply and demand, especially at times of rapid technological change and when raw material sources are restricted to a few countries.

Concerns over supply shortages of a number of technology metals have arisen in the past, most recently in relation to rare earth elements (REE). China dominates global production, but in 2006 began to impose restrictions on REE exports. In 2010, a 40% cut in REE export quotas gave rise to serious concerns over supply

Case Study



Securing platinum supplies

Gus Gunn, British Geological Survey

Platinum is a rare precious metal that normally commands a market price higher than gold. It has a number of physical and chemical properties, such as high melting point and corrosion resistance, which make it indispensable in a variety of industrial applications. Most important, however, are its catalytic properties that are vital in chemical manufacturing, petroleum refining and the control of vehicle emissions. A typical autocatalyst in a car contains only 1 to 3 grams of platinum, normally combined with the other platinum-group metals (PGM) palladium and rhodium. Worldwide, 40% of platinum is used in autocatalysts, whereas in Europe the proportion is close to 80% because of the prevalence of diesel cars, which contain a relatively high proportion of platinum in their autocatalysts[1].

The global supply of platinum is dominated by mine production, which reached 146 tonnes in 2014 (ref. 2), predominantly in South Africa (64% of total) and Russia (15%). In Europe, platinum mining is restricted to Finland and Poland, which produce less than 1% of the world total. On account of this high level of production concentration, platinum is classified as a 'critical' metal for the EU[3]. The vulnerability to the disruption of supply from South Africa continues to increase as a result of the escalating costs of mining, low productivity, labour disputes and problems with the availability of water and power. This situation has been exacerbated by the global recession and consequent reduced demand for vehicles. During 2015, the average price of platinum was $1053 (£798) per ounce, 24% lower than in 2014, marking the largest fall since 2009 (ref. 4). Few platinum mines in South Africa are profitable under current market conditions.

Mine supply of platinum is supplemented by a significant global contribution from recycling, some 64 tonnes in 2014 (ref. 1). However, the amount of platinum recovered from recycling varies by region, application and price. In many industrial applications, such as glass manufacturing, closed loop recycling is the norm and recycling rates of about 95 per cent can be achieved. But for many consumer products, end-of-life recycling rates are much lower because there is less assurance that the platinum will be recovered at the end of the product life. The rate actually achieved is largely determined by the weakest link in the chain, commonly the collection stage. Consequently, recycling rates for platinum from autocatalysts have a global average of 50% to 60%, and from electronic devices of 5% to 10%.

Various economic factors also affect the level of platinum recovered from recycling. In 2015, there was a major decline in platinum autocatalyst recycling rates, falling by 25 per cent in Europe[4]. This is attributed to the decline in platinum price; but also to the drop in the price of steel, which reduced the incentive to scrap vehicles; and to the fall in oil price, which deterred the scrapping of less fuel-efficient vehicles. Nevertheless, the stock of platinum in use in vehicles on the road continues to grow. Not only do vehicles remain in use for longer periods, but worldwide more vehicles are manufactured and the implementation of more stringent emission controls is leading to a continued increase in demand for platinum.

In order to increase the contribution of recycling to platinum supply, it is necessary to take a holistic approach across the whole value chain. Although the recyclability of platinum is potentially highly efficient, the end-of-life products must be efficiently collected, enter an effective recycling chain and stay there all the way to final metal recovery. For precious metals it is particularly important that electronic goods and cars with autocatalysts are not exported to countries that lack effective and environmentally-friendly recycling infrastructure.

To improve our understanding of how platinum moves through its life cycle, from mining to manufacture, use and recycling, a detailed analysis of global flows is needed. This would highlight where intervention is required to mitigate losses that are taking place. For example, it would enable policymakers to evaluate the relative merits of intervening to improve recovery from 'lost' autocatalysts, compared to a scheme that attempts to recover platinum from road sweepings. However, mapping a whole system in this way is challenging and data are hard to find. Close cooperation between researchers and those working in the supply chain would be essential.

Case Study

Aluminium: improved resource efficiency in Europe

Evi Petavratzi, British Geological Survey

Aluminium is the second most widely used metal after steel. It is mainly used in transportation, construction, packaging and consumer goods, with automotive and transport applications having the biggest market share in Europe (about 40%).

Primary aluminium production is a two-stage process. First, the aluminium ore bauxite is mined and refined to produce the mineral alumina; then alumina is smelted to produce aluminium. The metal is purified, mixed with other metals (alloyed) to the desired specification, and cast into ingots[1]. World production in 2014 was 260 million tonnes of bauxite and 58.4 million tonnes of primary aluminium[2]. Since 1970, global production of bauxite has increased fourfold, and primary aluminium fivefold.

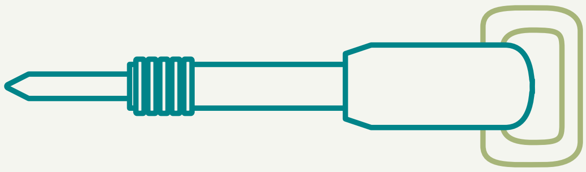
The aluminium industry has undergone major changes since the 1970s when it was highly concentrated and vertically integrated in a few industrialised countries that lacked primary bauxite and energy resources. Today there is less integration and concentration, and it operates mainly in bauxite-rich, low-energy-cost countries serving the emerging economies[3]. Australia, China and Brazil are the main producers of bauxite, with over 50% of the world's primary aluminium produced in China to meet its needs for major developments in infrastructure and transportation. In Europe the production level of primary aluminium has been relatively constant, with Norway and Iceland being responsible for approximately half of European production.

Aluminium recycling is an integral part of the wider aluminium industry. In Europe it generates almost €40 billion (£34.3 billion) in revenue per year, and in 2014 it produced 10.5 million tonnes of recycled aluminium[4]. Approximately 75% of all aluminium ever produced is still in use, a reflection of aluminium's excellent recycling properties, the long lifespan of some applications (typically 30 to 50 years in construction), and the fact that aluminium stocks have been built up only since World War 2 (ref. 5).

Primary aluminium production, especially smelting, is an energy-intensive process that consumes approximately 1% of global total energy, and the price of energy exerts a strong influence on the price of aluminium and on its availability. Energy consumption also contributes to greenhouse gas (GHG) emissions, depending on the fuel mix in use. Fossil fuels are most widely used globally, while Europe mainly uses gas to produce alumina and hydropower for smelting. Indeed, the industry's GHG emissions in Europe have halved since 1990 due to greater use of hydropower and gas[5]. Globally, however, GHG emissions are increasing due to the continuing growth in the use of coal as the primary energy source. Secondary aluminium production requires only 5% to 10% of the energy used in primary production, providing significant environmental benefits[4,5].

Europe is the greatest per capita recycler of aluminium in the world: recycling rates of aluminium from the construction and automotive sectors reach 90%, and from packaging 60%

€644 billion Current size of the global mining industry (1% of global GDP)



(ref. 4). Yet secondary production alone cannot meet the European aluminium demand, so production from primary aluminium, including imports, is required. In fact, Europe is a net importer of aluminium and a net exporter of scrap. Aluminium scrap is a sought-after commodity across the globe and exports of scrap from Europe have been growing over the last decade.

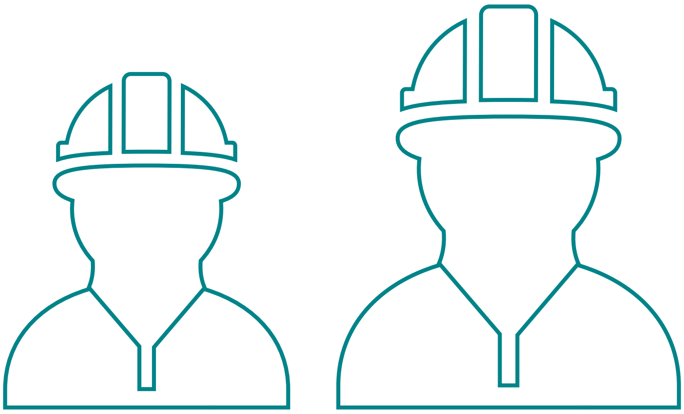
Despite significant improvements in the resource and energy efficiency of aluminium production in recent decades, there remains potential for further gains in Europe. Ensuring that aluminium scrap is retained in Europe could reduce the import dependence on primary aluminium and enable the recycling industry to expand significantly. Improving and expanding the collection, pre-treatment and recycling of end-of-life products have the potential to substantially reduce the energy consumption and related GHG emissions of aluminium production. According to the European Aluminium Association, Europe could gain access to an additional 21% of recycled aluminium from within Europe, if all scrap were collected, treated and recycled in a more efficient manner[4]. Finally, the demand for aluminium in Europe has not increased for over a decade and hence a closed loop economy is a realistic possibility if these efficiency improvements are achieved.

security, in turn leading to a rapid escalation of REE prices with some peaking at levels a hundred times greater than before 2010.

Such market volatility, allied with changing global economic conditions, higher environmental costs and market competition (amongst other factors), suggest that the current model may not be viable in the future. Market dynamics should shift towards managing demand over supply: this would involve changes in current business models, such as the provision of access to products and services, where ownership remains with the company that created them. Reverse supply chains (eg return back schemes) and refurbishment and maintenance schemes can ensure that equipment and materials return to the company that produced them. This would lead to reduced leakage of resources, technology and innovation, better safeguarding of the initial value of a product and related assets, and improved assurance that these can continue to be exploited until the technology and materials are obsolete.

Meaningful policy interventions are difficult to identify without understanding the stocks and flows of materials as they move from mining, concentration and extraction to manufacturing, use, reuse, recycling, dispersal and disposal[25]. This will require much better data on current stocks in the UK, and on the availability of materials from historic and active waste, including landfill, mine tailings and waste arising from processing and manufacturing activities. Measuring individual metal stocks and understanding the manner in which these move through the natural and anthropogenic environments will highlight potential supply bottlenecks and help identify resource inefficiencies[26]. This can be measured directly in terms of metal recovered or lost, or indirectly in the form of energy or water consumed in the process.

Quantification of losses as metals flow along the whole system will help to identify where the most effective interventions can be made in improving resource and/or economic efficiency. For example, only about 75% of the tungsten content of mined ore ends up in the concentrate



8,000

Number of people employed in scrap recovery in the UK

that goes to the smelter; the remainder is not recoverable with the available technology, and is discharged with the waste. This compares to recovery rates of over 90% for the gold in sulfide ores, and suggests that improving concentration technologies would have a major impact on tungsten resource efficiency[27].

Research and innovation are needed to reduce negative environmental impacts of primary production, and to break down technical barriers to metal/mineral-based material recovery from complex waste. Over the next 40 years, the environmental costs of mineral resource extraction, processing and use may begin to present a significant threat to primary supply. From 3% to 5% of total global energy demand is used solely to crush rock for mineral extraction[28]. The carbon emitted while supplying energy for this process, and particularly during the smelting of industrial metals such as iron, copper and aluminium, poses a significant environmental limit to primary resource use. Examples of low-carbon extraction technologies include in-situ leach mining of uranium, and microbial bio-leaching from extracted copper and nickel ores.

Further research and innovation are required to capture maximum value from stocks of metal that are available in EOL products and buildings. The UK economy utilises vast quantities of industrial metals such as steel and aluminium, most of which is substantially down-cycled when recovered from waste and EOL products. Innovation related to reuse, more effective disassembly, sorting, molten-metal processing, design and manufacture would promote more effective recycling and up-cycling of these materials[24]. Although different levels of complexity and scale apply to the recovery of technology metals from EOL electrical products, research and innovation are clearly required to improve product design; collection and disassembly systems; and to broaden the range of technology metals that can be economically recovered[15].

The impact of pricing a primary mineral to better reflect the external environmental costs of its production is seen in the case study about aggregates on p100. The imposition of environmental taxes on construction aggregates means that the UK now has one of the highest rates of aggregate recycling in the world, and as a result there are likely to be fewer UK primary aggregate quarries and attendant environmental impacts. However, almost all aggregate minerals in the UK are supplied from domestic sources. This relatively simple closed system means that policy interventions are likely to be more effective and immediate. In principle, pricing in the environmental externalities of the production of other commodities such as copper or aluminium is relatively simple. Pricing primary metals in this way would have the effect of pushing secondary metals through the recycling system, driving innovation in resource efficiency and metal recovery. However, international metal supply systems are much more complex, and such a scheme would probably be very difficult to implement in practice.

Conclusions and recommendations

Global consumption of minerals and metals is likely to continue on an upward trend as emerging economies undergo material-intensive development and new technologies require an ever-broader range of materials in ever-increasing quantities. While physical scarcity is generally not regarded as a constraint on supply, a range of other factors – geopolitical, social and environmental – have assumed increasing importance in determining access to primary resources in the ground. The most immediate of these is likely to be society's waning tolerance of the environmental impacts of increased mineral production; but in the longer term, the most pressing is the environmental capacity of the planet to cope with these impacts.

During the 1980s and 1990s, the global mining industry achieved major economies of scale that led to the development of an effective international system for the secure supply of mineral raw materials at low cost. However, there remain many opportunities to improve the efficiency and reduce the environmental footprint of exploration, mining and mineral extraction. In contrast, the recovery of metals and minerals through recycling is, in many respects, a relatively immature industry with considerable scope for improvements in efficiency and scale, and the potential to provide an increasing contribution to supply and related environmental benefits. The transfer of technology and business models from the primary sector to the secondary is likely to be particularly important.

In the UK, investment on waste infrastructure has grown strongly in the last decade, but this focused on the collection, separation and sorting stages of recycling[29, 30]. This growth has provided economic benefits to the UK through the export of separated and sorted EOL products to processing facilities in other parts of the world. However, the move towards closed loops and a 'circular economy' (see Chapter 1, box on p12) requires considerable additional investment in infrastructure for metallurgical recovery[30]. Economic recovery might be technically straightforward for some metals; but for other metals that oxidise easily, or are dispersed in low concentrations in slag, recovery can be very difficult or even thermodynamically impossible. As in the primary sector, specialised integrated smelters and refineries benefit from economies of scale. It is likely that the available stock of metals such as steel or aluminium could sustain such large-scale facilities in the UK. Closing the loop and recovering much smaller

If you cannot grow it, you **have to mine it**

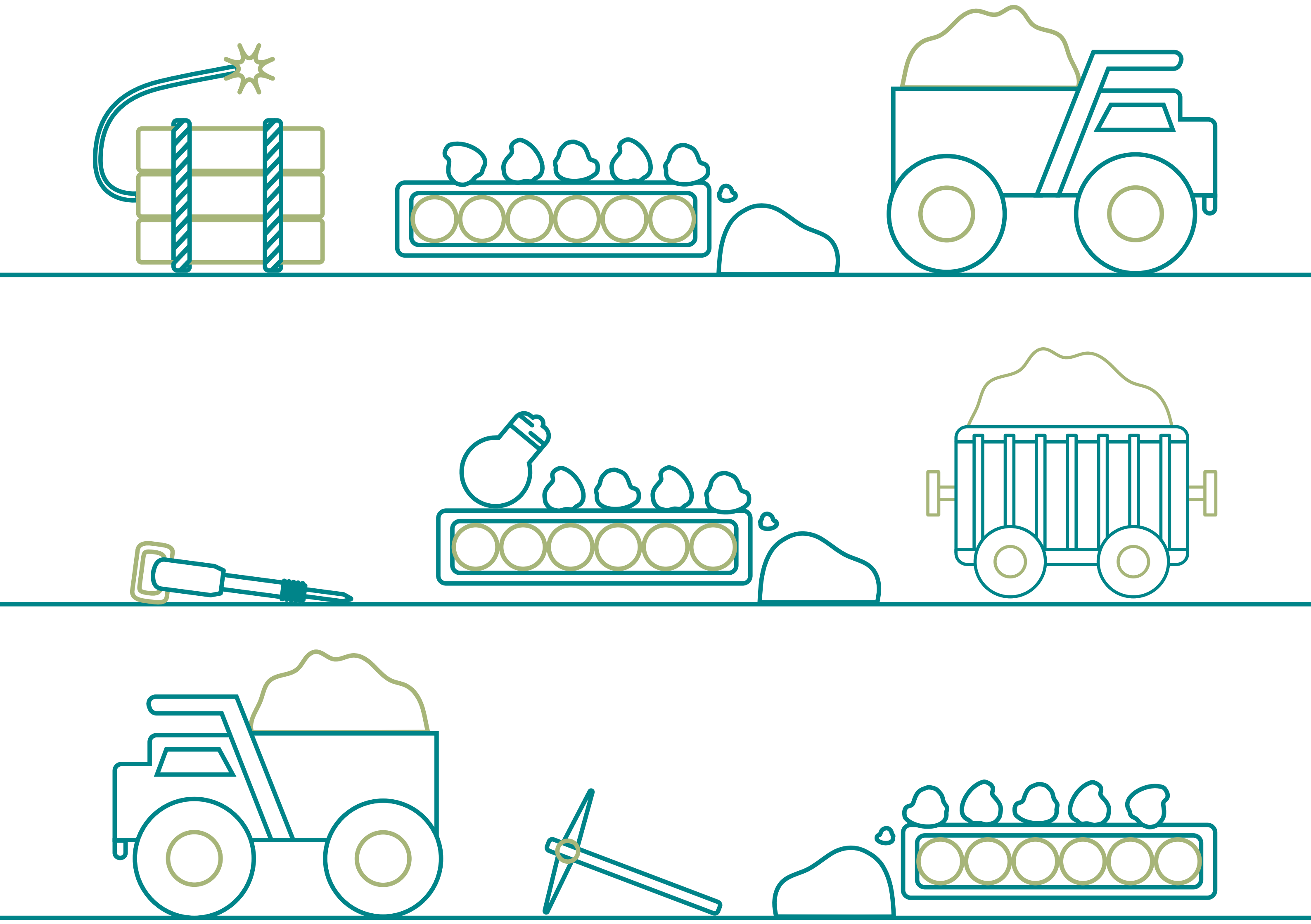
volumes of technology metals will require a continental- or global-scale approach in order to achieve the necessary efficiencies, environmental performance and economies of scale. Such specialist facilities are likely to be operated in only a few countries where dedicated processes are established for the recovery of certain metals from specific feed materials. A considerable amount of research is in progress to expand the range of feed materials processed and the metals recovered.

Our analysis leads us to make the following key recommendations:

1. There is a fundamental requirement for better data on the stocks of material in use in the UK, and how they move from mining and processing to manufacturing, use, recycling and disposal. These data would highlight future resource availability, potential supply bottlenecks and opportunities to improve resource efficiency.
2. Measures designed to enhance the circular economy must recognise that improved

recovery of metals from EOL products depends on achieving economies of scale. The volume and variety of metal stocks in circulation in the UK economy, together with their price, will dictate whether recovery is carried out at a national, European or global scale. Efficient and environmentally-friendly metal recovery from EOL stocks also requires support for research, innovation and skills in product design, disassembly, remanufacture and extractive metallurgy.

3. Even if there is a significant improvement in the recovery of metals from the human environment, a consequence of global population growth and urbanisation is that primary materials will continue as a major source of supply for the foreseeable future. As a result, major research is urgently required to substantially improve the environmental sustainability of the primary extractive sector, especially with regard to greenhouse gas emissions.



CHAPTER 8:

Construction and demolition

There is a high potential for recycling and reuse of construction and demolition waste, and the UK has made significant progress in this over the past decade. Concepts such as design for manufacture and assembly, building information modelling, and the circular economy are all having a positive impact, but there should be more focus on the whole lifespan of a development. Government needs to work with the sector on long-term strategies that will improve lifetime reuse, remanufacturing, recycling and management of the materials generated in new and existing infrastructure.

Dr David Greenfield, Managing Director, SOENECS Ltd and Chair of the Institution of Civil Engineers (ICE) resource management expert panel

Surplus material from the construction and demolition of buildings and other infrastructure is one of the largest sources of waste in the UK. The European Union defines it as construction and demolition waste (CDW) in the Waste Framework Directive (2008/98/EC)[1]. In 2012, the UK generated 200 million tonnes of waste, half of which was generated by construction, including excavation activities[2].

This chapter will explore the different types of CDW, the use of new techniques and technologies, highlight emerging best practice and explore the progress made over the past decade in the sector achieving a predicted £653 million in savings by 2025 (ref. 3). Based on this evidence, a series of recommendations for developing and implementing long-term strategies will be presented.

What is construction and demolition waste?

CDW consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled[4]. The European Union has identified CDW as a priority waste stream, primarily because there is a high potential for recycling and reuse of CDW, as some of its components have a high resource value. In particular, there is a reuse market for aggregates derived from CDW waste, which are typically used in roads, drainage and other construction projects[5]. Construction or demolition projects are part of the complex lifecycle of a built asset, which can span 50 years or more; the phase of that lifecycle determines the source of these wastes (see Table 1).

The highest volumes of wastes arise during the construction and end-of-life phases, but it is important to look at the whole lifecycle of a development to understand where the waste may occur and, more importantly, how it can be reduced, recycled or avoided.

One area that this lifecycle doesn't acknowledge is design. The role of architects in ensuring that waste is designed out (or even considered) is summed up best by Sophie Thomas, Director of Circular Economy at the Royal Society for the encouragement of Arts, Manufactures and Commerce (RSA), who in 2014 stated that "80% of all the environmental costs of a project are determined during the conception and design phase"[6]. The role of design will be explored in the circular economy section of this chapter.

Statistics

The construction sector is currently outperforming many other sectors for recovery of materials[7]. The UK generated an estimated 45.85 million tonnes of construction in 2012. Some 44.80 million tonnes of this was non-hazardous, 38.80 million tonnes of which was recovered. That means the recovery rate from non-hazardous construction and demolition waste in the UK was 86.6%, already 16.5% above the EU 2020 target of 70% (by weight)[8]. For example, construction company Wilmott Dixon says that it reduced waste generation by 38% from 2012 to 2015, through better procurement and use of materials, and sent less than 7% of its waste to landfill over that time[9].

While these statistics look very good, they

Lifecycle phase	Activity and waste generation
Phase 1: Product phase	Raw materials are obtained and transported to factories for manufacturing. Waste is generated at this stage, but not directly counted towards CDW.
Phase 2: Construction phase	Manufactured materials are transported to the construction site for installation and other on-site work. Wastes generated by both construction and excavation are counted as CDW.
Phase 3: Use phase	Once the building is occupied, waste is generated by maintenance, repair, replacement and refurbishment of equipment, including periodic site activities and replacement of components (which results in more extracting, transporting and manufacturing). Wastes generated at this stage may be included as CDW, if managed by facility management contractors. The wastes generated directly by occupants are, however, often overlooked and not included in CDW, even though it is fundamentally influenced by the design of the construction phase.
Phase 4: End of life	This involves demolishing the building, processing all waste, and transporting it to where it will be reused, incinerated or disposed of in landfill.

Table 1: *Lifecycle and waste generation of a built asset*

need to be put into perspective. According to a study by the non-profit Centre for Studies, Research and Actions in Architecture (CERAA), and Rotor, a group studying material flows in industry and construction (both based in Brussels), more than 80% of CDW in Brussels is composed of inert or mixed waste (the latter comprising two or more different materials) (see Table 2)[10]. The large proportion of inert and mixed wastes in CDW means that most of the recovery is achieved through energy-from-waste (EfW) processes, or by using it as a secondary aggregate. These statistics are very similar in the UK.

So from a tonnage perspective, the sector does very well. But more work needs to be done to move the hazardous wastes (which include plasterboard, paint cans, concrete, caulk containers, personal protective equipment (PPE), batteries, aerosol cans, chemicals and electronics)[11] from construction processes up the waste hierarchy, through recycling, reuse and particularly reduction of waste.

Management of CDW from excavation

In all construction projects, the first job is to prepare the site. In many cases this requires excavation, tunnelling or boring, which generates enormous volumes of material. The industry normally uses an integrated design approach, using this material to satisfy the fill requirements wherever reasonably practicable. In many cases, this includes reuse of all topsoil and agricultural subsoil as close to the point of generation as possible.

One such project that has the potential to generate approximately 130 million tonnes of excavated material is the proposed HS2 rail project. The project team states that more than 86% of this material will be reused within the project for the construction of engineering and environmental mitigation earthworks[12]. HS2 has bold ambitions, many of which are justified: large-scale projects are already delivering this kind of performance, including the other major rail construction effort in the UK, Crossrail (see case study on p118). Crossrail shows that there are huge opportunities for the management of excavation wastes, but that careful planning and advanced thinking are required to ensure that social, environmental and economic solutions are achieved.

Management of CDW during construction

On an annual basis, the construction sector is responsible for one-third of all global resource consumption, one-third of global energy consumption, and 12% of all fresh water use. The manufacture of building materials alone consumes about 10% of the global energy

Waste stream	Tonnage (T)	%
Inert	383008	59.4
Mixed	144905	22.5
Asphalt products "13 actors"	10702	1.7
Asphalt products "roads"	30628	4.8
Plastics	7	0
Paper, cardboard	0	0
Metals	25000	3.9
Wood	5450	0.8
Green waste	1500	0.2
Hazardous	41492	6.4
Other construction and demolition waste	1748	0.3
Total	644440	100

Table 2: *Construction waste types, expressed in tons and percentage*

supply, and building construction and demolition waste amounts to about 40% of solid waste streams in developed countries[13]. Construction waste is usually made up of materials such as bricks, concrete and wood which are damaged or unused for various reasons during construction. Observational research has shown that 10% to 15% of the materials that go into a building end up as waste[14]. There are several approaches to reducing this burden.

1. Design for manufacture and assembly

The construction sector can continue to innovate and increase sustainability, while reducing waste and increasing recycling, by following the principles of 'design for manufacture and assembly' (DFMA) (also known as build off-site or lean manufacturing). In the context of the construction industry, DFMA is an approach best described as "improving quality through the application of efficiency, reducing resources required while increasing positive aspects such as health and safety, quality, certainty"[15]. DFMA takes a number of forms, but the common factor is the application of factory (or factory-like) conditions to construction projects. Construction waste can be substantially reduced through off-site construction as a result of the following factors:

- The volume of throughput in a factory ensures that the materials that have been ordered are used in their entirety.
- Small quantities of waste arisings can be reused in the manufacturing process.
- Factory deliveries are invariably made in bulk, so larger orders can be packaged together in a single consignment, as opposed to numerous small orders packaged separately (as would be the case on site).
- Carefully managed scheduling, logistics and handling mean that disposable protection (for transportation) can be reduced or eliminated.

DFMA necessitates the use of building information modelling (BIM), both in the design phase and through the manufacturing, logistics and installation processes (see below). This in turn encourages best practice across the board and a 'right first time' ethos, which leads to further resource efficiencies:

- There are more opportunities for continuous improvement in a production-line environment where repetition of tasks is more common.
- The size of orders means delivery vehicles can be consistently filled to capacity.
- Longer-term relationships with local suppliers are possible, due to the permanence of the work base. This allows for economies of scale,

Case Study

Roadmap to resource efficiency

Gilli Hobbs, Strategy Director, Building Research Establishment (BRE)

In 2008, the Building Research Establishment (BRE) led the development of the 'Construction Resources and Waste Roadmap'[28], which aimed to present a long-term perspective and vision for improving construction resource use and waste management, in line with government objectives set out in the Waste Strategy for England 2007. A further objective of the roadmap was to consolidate findings from a number of linked projects, including BRE's National Construction Waste Benchmarking project and its Construction Resources and Waste Platform (a Defra-funded programme from 2004 to 2009, which supported construction resource efficiency research, exemplars and best practice guidance).

The roadmap built on work from 2006, outlined in 'Developing a strategic approach to construction waste (20 year strategy draft for comment)'[27]. This presented a number of scenarios for resource use, linked to future trends relevant to the construction sector. With 2016 being a halfway point in that 20-year strategy, it offers an opportunity to evaluate progress.

Back in 2005, the average amount of waste generated while building new homes (calculated using BRE's SMARTWaste monitoring system[29]) was 17.3 m^3 of waste per £100,000 of property value, and 19.2 m^3 per 100 m^2 of constructed floor area. Using these 2005 SMARTWaste-derived benchmarks as a baseline, two options were evaluated – 15% and 50% reduction of waste by 2025.

The SMARTWaste system has evolved greatly over the past 20 years, and is now a widely used web-based environmental reporting system (including measurement of waste, water and energy throughout the construction process). Over the past decade, SMARTWaste has collated data from over 1300 new-build residential sites, and found that the corresponding benchmarks now stand at 12.4 m^3 per £100,000 of value and 18.1 m^3 per 100 m^2 of floor area. This amounts to a waste reduction of 28% and 6% respectively, compared to the previous 2005 benchmarks. The first indicator will have been affected by inflation, so the second is more reliable. This suggests the first option – 15% waste reduction – was more realistic. A more detailed comparison of SMARTWaste benchmarks could offer more insight, for example, isolating all 2005 housing completions and comparing to all 2015 housing completions.

The 15% and 50% reduction scenarios presented in the strategy document assumed a far greater reliance on off-site manufacture than has happened to date. Without a significant transformation in the way dwellings are designed and built, it is unlikely that anything approaching 50% waste reduction could be achieved. Some progress has been made in understanding where waste is arising, especially in site-based practices, and taking practical actions that can lead to incremental reductions in waste generation. Given the current housing shortage, and revitalised interest in industrialised building, it is still reasonable to predict that off-site manufacture will play an increasing role in the provision of new housing[9].

There has also been a shift towards designing, building and managing facilities in a holistic, lifecycle-based and integrated way, and the development of building information modelling (BIM) is helping to make this a reality. The UK government mandated the use of BIM on publicly procured projects from April 2016, which has spurred efforts to consolidate and standardise information collation and management in the construction process. In the utopian vision of BIM, it will be possible to drive out waste (time, money, materials) throughout the building supply chain and lifecycle. Yet lifecycle assessment (LCA) has played a small role, so far, in promoting resource efficiency, despite much work being undertaken at an EU level[30].

BIM was not specifically referred to in the 2006 strategy report, but the need for better

information management in buildings was a key objective. The last 3 years has seen a transformation in the development of standards, tools and capacity building relating to BIM and information management. Around 2 years ago, BRE developed a research objective to use BIM as a vehicle to understand and promote improved resource productivity across the whole lifecycle of buildings. This work is now underway in several projects, including the Horizon 2020 project 'Buildings as Material Banks (BAMB)'[31], which will ultimately develop a BIM software prototype focused on improving reuse potential and transformation capacity of new and existing buildings.

Many other themes from the 2005 report have seen progress in the past 10 years, such as reduction in landfilling of construction and demolition waste, and increasing the proportion of recycled aggregates being produced. Conversely, other areas have stagnated: there has been little progress in achieving a significant focus and targeting of resource efficiency in refurbishment; or the establishment of consolidation centres that can act as stockholders for surplus materials, or as bulking stations for small waste streams.

knowledge sharing and other opportunities for product / process improvements.

- At end-of-life, dismantling or demolition is simpler, allowing a greater percentage of the building's materials and/or components to be preserved.

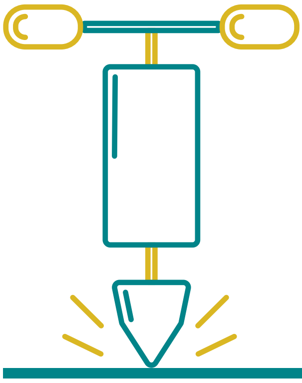
For example, Laing O'Rourke has a 23,000m^2 offsite manufacturing facility in Steeley, Nottinghamshire. The government has already invested £22 million in the factory, which produces precast wall panels and precast concrete slabs. It takes less than 6 hours from pouring the concrete to loading these components onto the back of a lorry[16], and this offsite manufacturing approach can substantially reduce construction waste (see case study on p121). Despite the huge potential for reducing waste by designing it out, the application of DFMA across the UK is small, due partly to a lack of investment in facilities.

2. Building information modelling (BIM)

The concept of BIM is to construct a building in a virtual environment, prior to constructing it physically. BIM has its roots in computer-aided design and computer-aided manufacturing (CAD/CAM), and uses advanced computer systems to build 3D models of infrastructure and hold large amounts of information about its design, operation and current condition. This virtual building helps stakeholders to work out problems and to simulate and analyse potential design and operational impacts. BIM is typically used right from the design stage of a construction project, to enable the design brief to be tested and the proposed construction solution to be changed at minimum cost[17].

BIM typically models 11 different stages of the construction process:

- Programming of the the lifecycle
- Conceptual design
- Detailed design
- Analysis



50%
proportion of waste produced by construction and excavation

- Documentation
- Fabrication
- Construction
- Construction logistics
- Operation and maintenance
- Renovation
- Demolition

BIM has been used to optimise design solutions and avoid clashes, so that issues of buildability are dealt with well before work and spending starts on site[15]. One of the main advantages is that the quantities of materials required can be more accurately assessed, meaning wastes can be reduced on site. BIM is already supported by the government: indeed, in 2011, the government embarked with industry on a four year programme for sector modernisation with the key objective of reducing capital costs and the carbon burden from the construction and operation of the built environment by 20%. BIM will enable the interconnected digital design of different elements in a built environment and will extend BIM into the operation of assets over their lifetime[18].

3. Government Soft Landings

In September 2012, the Cabinet Office announced that by 2016 all centrally-funded projects should be delivered in accordance with the Government Soft Landings (GSL) programme. The GSL programme was designed "to champion better outcomes for our built assets during the design and construction stages… powered by a building information model (BIM) to ensure value is achieved in the operational lifecycle of an asset"[19]. The GSL programme, incorporating level 3 BIM, should allow designers to incorporate waste reduction into the construction, lifetime and dismantling phases. It also stipulates that demolition should not occur.

The GSL is described by the government's BIM taskforce as a 'golden thread', whereby early engagement of the end user and inclusion of a GSL champion on the project team during design and construction through to operational handover is essential. This will allow the project team to set clear targets and measures for:

- Social outcomes: ensuring functionality and effectiveness for user and business requirements.
- Economic outcomes: identifying operational and capital costs early, to reduce costs in construction and operation.
- Environmental outcomes: meeting carbon and sustainability targets, including energy, carbon, water and waste[19].

The BIM Taskforce also suggests that this will allow the project team to "focus on commissioning, handover and training in partnership with users and operators to enable effective operation and early optimisation of asset". It adds that a post-occupancy evaluation should be embedded in the project plan "to assess performance for at least three years post-completion to establish actual outcomes and lessons learnt". This should allow for a more considered approach to the generation of construction wastes, and the way that waste is managed, during the operational lifetime of that project.

Case Study

Planning advice for new build flats

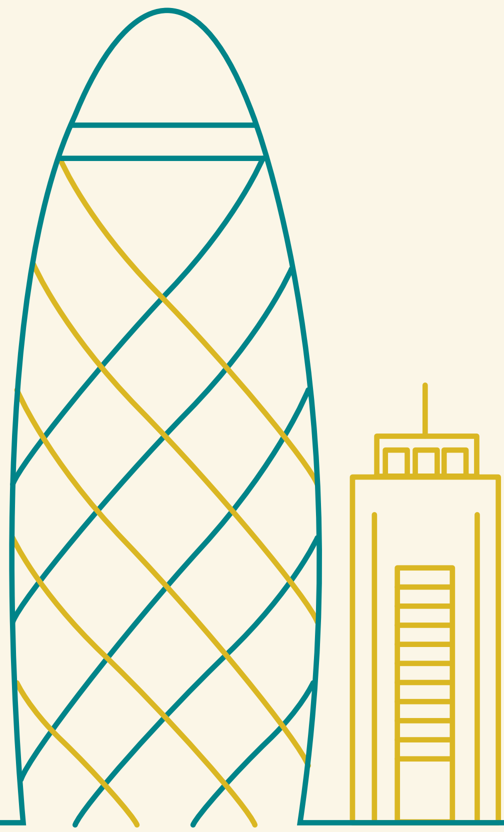
Beverley Simonson, London Waste and Recycling Board; Jamie Blake, London Borough of Barnet; Ian Blake, BPP Consulting LLP; and David Greenfield, SOENECS Ltd

The London Plan[20] – the Mayor of London's development plan for the city – predicts that by 2036 there will be an additional 1,000,000 households living within the greater London area. The vast majority of the required new homes will be medium- to high-density developments, in other words flats. The plan also includes a 50% recycling target for London by 2020. New development is not just constrained to London, and it follows therefore that proper consideration of waste management must form a fundamental part of the design and planning process for all new residential developments. It is essential that such consideration take place early in the planning of new developments, as 80% of all the environmental costs of a project are determined during the conception and design phase.

Given this context, the London Waste and Recycling Board (LWARB) and the London Environment Directors' Network (LEDNet) commissioned a consultancy partnership formed by BPP Consulting LLP and SOENECS Ltd to develop waste management planning advice for flatted properties. The overall requirement was to prepare a template policy or policies on planning for waste and recycling storage and collection in new-build flatted properties, with the ultimate aim of encouraging the design of waste management that will help London achieve its recycling targets. Two of the outputs from the project were:

- A template waste management policy to be adopted by all London boroughs that required a waste and recycling management strategy for all new developments
- A template waste and recycling management strategy for developers to complete at pre-application stage. This aimed to ensure that they have considered the five stages of how waste and recycling is managed from within the resident's home to disposal: occupier separation; occupier storage; collection / bulking; removal / on-site treatment; end destination.

By linking the planning and waste management processes, the intention is that developers will introduce systems that will allow occupants to increase the recycling achieved during the lifetime of buildings, thus reducing costs and increasing environmental performance.



Case Study

The circular economy

Duncan Baker-Brown, Senior Lecturer at the University of Brighton and Director of BBM Sustainable Design

The concept of the circular economy is only just emerging as an idea, and only beginning to be understood in some sectors of the UK construction industry. But it is gaining some traction. For example, the London Assembly is developing a route map for London's circular economy in partnership with the London Waste and Recycling Board (LWARB), and the Ellen MacArthur Foundation, a non-profit organisation that advocates for the circular economy. In 2015 they published 'London: the circular economy capital'[33], which identifies the built environment as one of its five focus areas. LWARB is now commissioning feasibility studies about how far circular economy principles can be incorporated into the UK construction industry.

Meanwhile, a number of well-informed UK-based architects are independently designing buildings that exemplify circular economy concepts, including ZED Factory, Architype, White Design, and BBM Sustainable Design. Organisations such as the UK Green Building Council and the Building Research Establishment are encouraging discussion of the topic at conferences and attempting to define what it might mean on their websites, but there is not much evidence of actual construction projects inspired by the circular economy.

Europe is further ahead in this area, encouraged perhaps by the establishment in 1987 of the Environment Protection Encouragement Agency (EPEA), based in Hamburg. EPEA was founded by Prof Dr Michael Braungart, one of the two co-authors of 'Cradle to Cradle: Remaking the Way We Make Things'[34], a key text in circular economy thinking. The EPEA provides, among other services, 'cradle to cradle' (C2C) training, which has influenced many of Europe's prominent circular economy consultants.

Established firms are also involved. Thomas RAU Architects in Amsterdam focuses on sustainable, closed-loop systems, and claims that it is responsible for inventing concepts well known to C2C converts such as 'material passports' and 'buildings as material banks' (BAMB). They also developed the 'circular lighting' concept with Philips Lighting, in which Philips leases and takes responsibility for the supply, maintenance and removal of their light fittings.

Design consultancies are actively pursuing working methods that achieve many circular economy goals. Rotor, a group of architects and academics in Brussels, is literally taking apart 'difficult' buildings (from the 1960s and 1970s) one screw at a time, and selling the material for profit. SuperUse Studios from Rotterdam, also architects and academics, are best known for constructing a house (Villa Welpeloo) in 2005 from 60% waste material that was sourced using Google Earth. And in 2014, the University of Brighton opened Europe's first public building made of 90% waste. Built by over 360 construction and design students, it creates 25% more energy than it consumes and serves as a creative design studio open to the public.

Management of CDW during the lifetime of an asset

There is a stream of waste that is often overlooked when considering construction: the impact construction has on the generation of wastes during the operational lifetime of the constructed development. In most cases, this stream could be classified as municipal solid waste or commercial and industrial wastes, as they are a result of usage of the constructed development. The unalterable fact is that the design and construction of a new development has a direct link to the way that wastes are managed during the operational lifetime (see case study on p115).

Collecting and processing waste in high-density environments such as cities is difficult and expensive. Design, behaviour-change and technological solutions that enable and encourage households and businesses to adopt more resource efficiency and cost-effective behaviours are being developed and implemented. Recovering mixed and often contaminated materials from a large number of individual properties will always pose challenges, and these are particularly acute in high-density dwellings and offices, where there are three main problems:

- Providing enough space to store recyclable materials, both for the individual dwelling, and to bulk up materials in the building while awaiting collection.
- Securing buy-in from residents and office workers to ensure that materials are allocated to the right containers and put out at the right times.
- Balancing the need for regular pick-ups with the transport and disruption that entails.

In many cases, developers build to sell buildings, not to manage them, so their priorities are the price of construction, meeting regulations, and, crucially, the kudos needed for an effective sale. Sustainability is not yet a kudos factor in any very sophisticated sense, so perceptions of what is 'green' become confused and can amount to 'green bling'.

Management of CDW during the refurbishment phase

The refurbishment stage of the lifecycle produces a multitude of different materials. In the past, much of this was recycled if it was easy; but with the cost of disposal so high, increased waste segregation and philanthropic endeavor reward the innovative. Many companies are changing their approach to maximise the reuse of materials while fulfilling obligations under tough targets set by the BREEAM assessment system (the Building Research Establishment Environmental Assessment Method). This was created to help investors, developers, design and construction teams and occupiers to use natural resources more efficiently[21].

For example, Encore, an estate management company, has a client whose office refurbishment project was not expected to achieve accreditation to a BREEAM level. By collaborating with their supply chain, Encore was able to successfully complete the project, diverting 100% of the material and sending less than 2% of waste to energy-from-waste processes[22].

More can be done to affect design at the appropriate stage, helping the design team to make informed decisions regarding materials reuse without hampering creative design. By connecting all partners in a cooperative effort to make the outputs align to client sustainability goals, the project has been a huge success. This may be an area where Government Soft Landings and BIM can assist further. There are still barriers to being able to fully exploit this approach, but Encore and companies like them are currently researching the potential for even greater collaborative supply chain and waste disposal.

Management of CDW from the end-of-life phases

The demolition waste arising from the end-of-life phase includes insulation, electrical wiring, rebar, wood, soil, concrete and bricks. It also may contain lead, asbestos or different hazardous materials.

Case Study

Crossrail

Lorna Russell, Environmental Assurance Manager, Crossrail Ltd

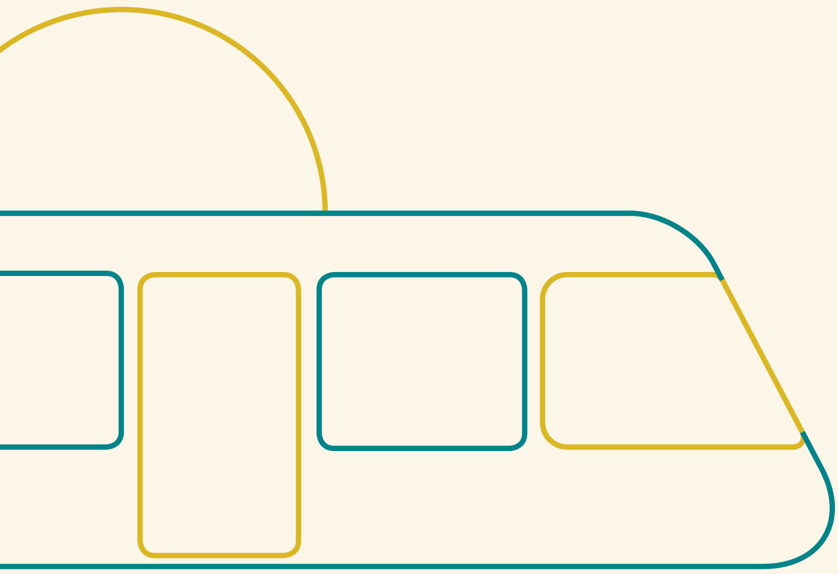
The construction of Crossrail has generated over 7 million tonnes of excavated material from stations, tunnels, portals and shafts, of which over 98% was beneficially reused. Crossrail specified the destination sites and means of transportation for the material, but also allowed some of the individual contractors to make their own arrangements for beneficial reuse as appropriate. This 'client-led' approach meant that a significant proportion of the material was used to create a landmark nature conservation project at Wallasea Island on the Essex coast. It also reduced the programme risk associated with a potential lack of suitable disposal sites during the main tunnelling and excavation works; enabled the development of infrastructure to transport material by water; and, from the early stages of the project, allocated rail paths to carry more material. Together, this ensured that 80% of the excavated material's journey (measured in tonne km) was made by rail or water.

Crossrail prepared an initial strategy for excavated material alongside the Environmental Statement, which assesses the likely environmental impacts of the project. The early adoption of a client-led solution enabled us to identify the preferred end-use beneficial reuse destination sites, along with the need for supporting infrastructure (such as transfer stations and wharfs, and early planning of rail paths).

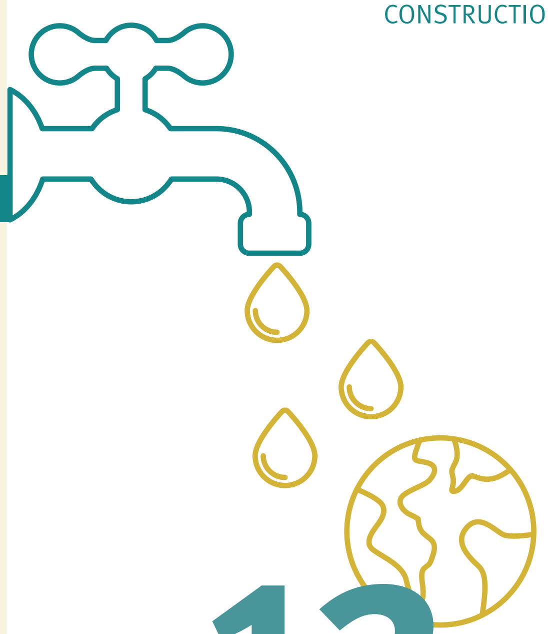
As design works progressed, Crossrail identified the Wallasea Island project as a possible destination site for the excavated material, and entered into a partnership with The Royal Society for the Protection of Birds (RSPB) to support the development of a nature reserve in Essex. To transport material to Wallasea, Crossrail constructed two new transfer stations: the Docklands Transfer Site in Barking, which received material by road from central London stations, shaft and portal excavations; and the Northfleet site in Kent, which received material by rail from the western tunnelling portal. It also developed wharf facilities at Wallasea, the Docklands Transfer Site and Northfleet.

Crossrail awarded a number of contracts for enabling and main construction works that involved the excavation of material. The reuse requirements for the material were incorporated into the contractual Works Information, which ensured that Crossrail's approach was cascaded to the construction contracts. Crossrail also appointed a contractor to operate the Docklands Transfer and Northfleet transfer stations, to transport material to Wallasea Island, and to place the material at the island. In total, just over 3 million tonnes of excavated material was taken to Wallasea Island.

The remaining 4 million tonnes of material went to a number of other beneficial reuse sites (see Map). For example, two alternative sites handled excavated material from early contracts before the preferred site was available; others

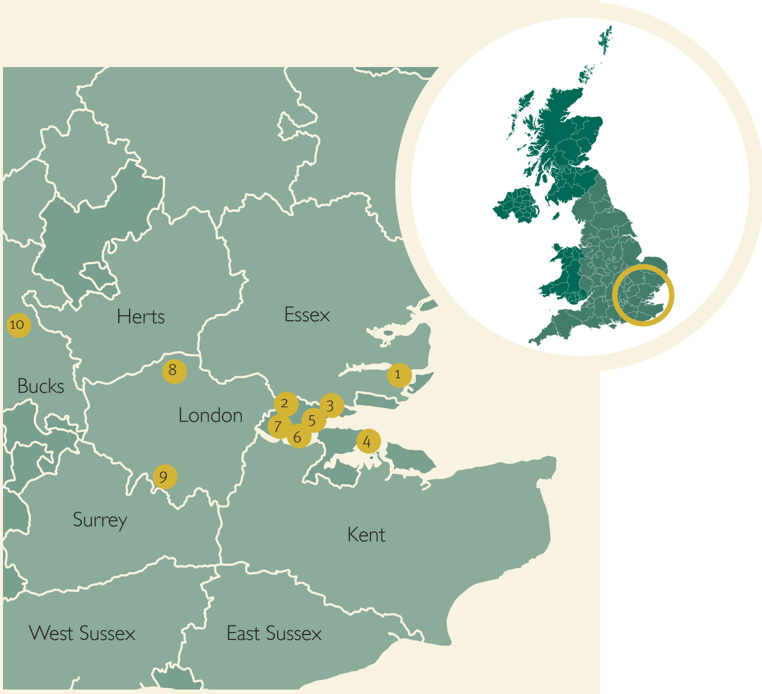


took material that was not suitable for disposal at Wallasea. In total, 98% of the material excavated during the construction of Crossrail has been reused to bring new life to nature reserves, recreational facilities, agricultural and industrial land in London and the south-east.



12%

of global water consumption by construction



Map: *The destinations of Crossrail excavation wastes*

1. *Wallasea Island: over 3 million tonnes used to create a 1,500-acre wildlife habitat at Wallasea Island in Essex* ***2.*** *Ockendon: landfill restoration engineering prior to creating a wildlife reserve* ***3.*** *Pitsea Landfill: supporting restoration of RSPB nature reserve* ***4.*** *Kingsworth: raise land to allow for construction of a commercial park* ***5.*** *Goshems Farm: grazing pasture for livestock* ***6.*** *East Tilbury Quarry: supporting restoration of RSPB wetland nature reserve* ***7.*** *Ingrebourne: golf course* ***8.*** *Fairlop Quarry: agricultural use and nature conservation* ***9.*** *Rainham landfill: landfill restoration* ***10.*** *Calvert Landfill: landfill restoration*

The desire to offset project costs by maximising the income value of materials recovered from demolition, along with the continued increase in disposal costs and tax, has driven the demolition industry to achieve very high levels of recycling and reuse while minimising disposal to landfill. Demolition waste has long been broken down and used as foundations and sub-bases for new construction, roads and other pavements. This is often referred to as industrial symbiosis, which the Waste and Resources Action Programme (WRAP) defines as an "association between two or more industrial facilities or companies in which the wastes or byproducts of one become the raw materials for another"[23].

There are many applications of this concept. One is the movement towards, and encouragement for, recycling of old concrete as crushed aggregate for new concrete. Another comes from Germany, where calcium sulfate that is available as an industrial by-product is used to make gypsum plaster, by careful factory blending with inert fillers and other constituents. This competes on an equal basis in the UK market place with the familiar pink gypsum plaster that is processed from a natural deposit[24].

There are many new companies looking to make this process as simple as possible for demolition contractors. Globechain has created an online platform that connects businesses, charities and people to enable them to reuse unwanted items within a global supply chain network. The aim was to create a way of providing a waste audit while giving some social impact value for members. One of their case studies shows the benefits for their client, Keepmoat, which reduced its total waste and handling of controlled waste by finding reuse opportunities for items ranging from medical equipment (such as shower seats and grab rails) to electrical products (such as microwaves and fridges), as well as upholstered chairs and furniture. For this project, 0.451 tonnes of material was diverted from landfill with an approximate saving of around 25% of the costs incurred in waste disposal[25]. While these figures may look low compared to the vast tonnages in the Crossrail project, this is a really important demonstration that many hazardous materials can be moved up the waste hierarchy, rather than going to landfill.

Current strategies and performance

The European Environment Agency (EEA) stated in its 2013 report, 'Managing Municipal Solid Waste', that: "Improved waste management is an essential element in efforts to make Europe more resource efficient. If a country is to generate greater economic returns at lower costs to the environment then it must find ways to extract more value from the resources that it takes from nature, while cutting the burden of emissions and waste."[26] The view from Europe matches our own in the UK, and since the turn of the century there have been some very innovative UK programmes, including Pathway to Zero Waste (PTZW), the European Pathway for Zero Waste (EPOW), the creation of the site waste management plans, the introduction of landfill tax and the creation of tools such as BREEAM and Leadership in Energy and Environmental Design (LEED).

This has not happened by accident. One of the key facilitators has been a twenty-year strategy called 'Developing a strategic approach to construction waste'[27], which was unveiled in 2006 by Defra in collaboration with the Building Research Establishment (BRE) and AEA Technology (see case study on p112). The progress made under that strategy shows that there is some innovation taking place in the sector. But innovation needs to change from the application of good ideas to a process that can be systematically managed, measured and controlled.

The circular economy

In 1981, Walter Stahel and Geneviève Reday-Mulvey published 'Jobs for Tomorrow: The Potential for Substituting Manpower for Energy'[32], in which they sketched their vision of an economy interconnected by loops – cycles of interatelated materials – and its impact on job creation, economic competitiveness, resource savings, and waste prevention. They called this model the 'circular economy'. They highlighted the importance of selling services rather than products, an idea referred to as the "functional service economy" and sometimes put under the wider notion of "performance economy" which also advocates "more localisation of economic activity". Since then, the circular economy has become an increasingly influential concept (see case study on p116).

As more evidence is gathered from the growing number of circular economy projects, it should enable more cohesive design and construction. For example, the UK's largest regeneration project, managed by the Old Oak and Park Royal Development Corporation (OPDC), is collaborating with the LWARB to

£653m

predicted savings through increased efficiency by 2025

Case Study

Design for manufacture and assembly at the Leadenhall Building

Eddy Taylor, Head of Sustainability and Carbon Management, Laing O'Rourke

At 225m high and 52 storeys, the Leadenhall Building is the tallest structure in the City of London. It was designed by Rogers Stirk Harbour + Partners and Arup, and constructed by Laing O'Rourke for the client, British Land. The distinctive wedge-shaped building has no central core and is stabilised by the expressed exo-skeletal frame.

Using Building Information Modelling (BIM) to enhance the design and facilitate collaboration, Laing O'Rourke worked with the client and design team to maximise the use of 'Design for Manufacture and Assembly' (DFMA). More than 85% of the building (by value) was constructed using components manufactured off-site.

For example, the stair cores – the stairway shaft and walls, with stairs cast inside –were made of precast concrete, rather than traditional, non-structural materials such as plasterboard partitions. This facilitated the early installation of prefabricated mechanical and electrical vertical risers (cavities that carry pipework and wires). Laing O'Rourke also developed a precast lightweight floor slab with grouted joints and precast internal walls and columns. These measures completely eliminated the need for concrete and reinforcement to be prepared on site, normally evident on high-rise buildings. These improvements not only helped prevent waste, but also shortened the programme and reduced the number of workers required to deliver the project.

Compared with other multi-storey, premium London-based office buildings with a shell-and-core design, Leadenhall produced much less construction waste thanks to the use of DFMA principles (see Fig. 1). Construction waste savings began to occur after about four to five months, coinciding with the completion of the groundworks and preliminary works, and the introduction of DFMA structural products.

In addition, the tonnage of construction waste arising per 100m^2 as a result of using off-site components was 60% less than that from in situ construction processes (see Table 3).

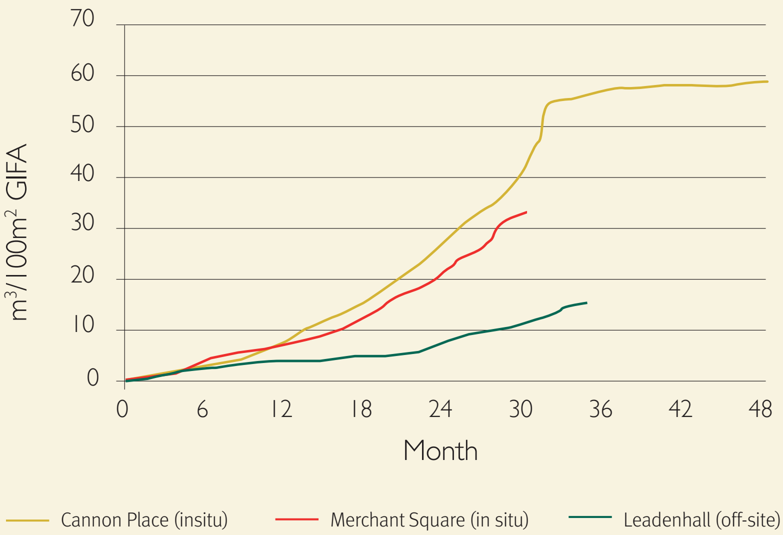


Figure 1: *Construction waste generated by off-site and in-situ construction (measured in cubic metres of waste per 100 square metres of gross internal floor area (GIFA))*

Laing O'Rourke

	Gross Internal Floor Area (GIFA) (m^2)	Construction Waste (m^3)	Construction Waste (tonnes)	Construction Waste (m^3/100m^2 GIFA)	Construction Waste (tonnes/100m^2 GIFA)
Leadenhall Building (off-site)	86,400	12,126	4,864	14.0	5.6
Cannon Place (in situ)	36,200	21,242	5,108	58.6	14.1
Merchant Square (in situ)	29,800	9,557	N/A	32.1	N/A

Table 3: *Construction waste metrics*

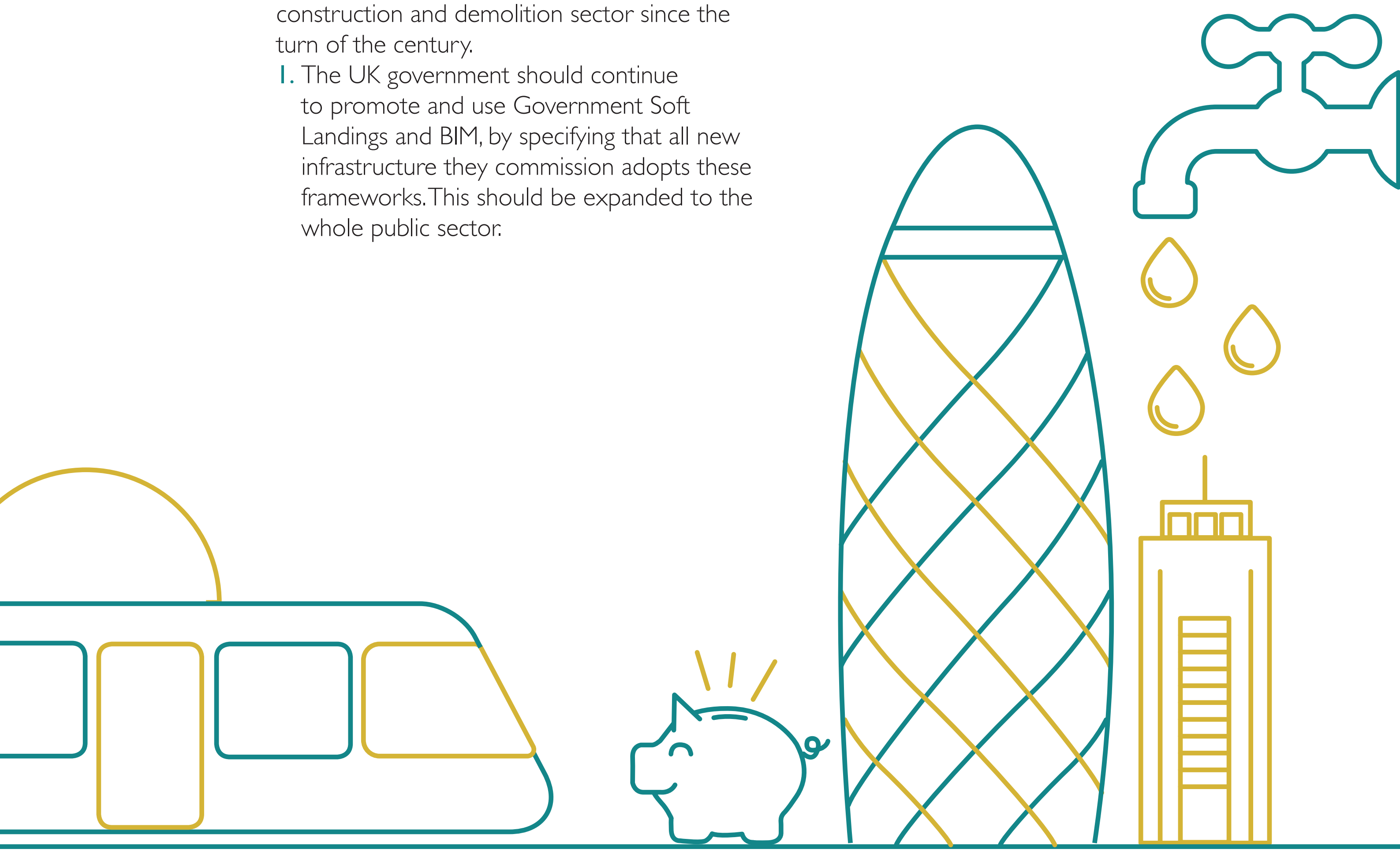
consider how the circular economy can be used as part of the regeneration and urban intensification process to deliver economic growth and jobs while reducing waste, pollution and carbon emissions. The outcomes of this project should give more evidence on the opportunities for the construction and demolition sector.

Conclusions

The chapter has given an overview of the predominant technologies, methods and opportunities arising from a considered approach to strategy, policies and business models for dealing with CDW. These include designing buildings to manage the flow of waste as a utility; BIM; use of circular economy principle; the impact of waste on social spaces within buildings; and self-sufficiency as a result of material management. Based on this evidence, the following recommendations offer a route to continuing the progress made by the construction and demolition sector since the turn of the century.

1. The UK government should continue to promote and use Government Soft Landings and BIM, by specifying that all new infrastructure they commission adopts these frameworks. This should be expanded to the whole public sector.
2. More focus should be placed on the whole lifespan of a development, and how recycling and waste management will be conducted during the operational lifetime to maximise the waste hierarchy and meet local targets.
3. The concept of the circular economy, while already reflected in concepts such as BIM, must become intrinsic to new infrastructure developments.

The use of long-term strategies has been proved to give the sector confidence, vision and leadership. Now is the time for further impetus from government.



SECTION: 3

Perspectives

Waste comes in many different forms and from diverse parts of the economy. A powerful way to think about waste is through the lenses of various different groups in society. Looking at waste in this way allows different links and connections to be made, and helps formulate effective policy targeted at specific groups. This section looks at how waste policy can achieve improvements on the scale necessary by looking through the key lenses of: the citizen, business, governance (at the city, local and national level) and the international dimension.

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In Brief

Scaling up industrial symbiosis programmes could generate

€3 billion

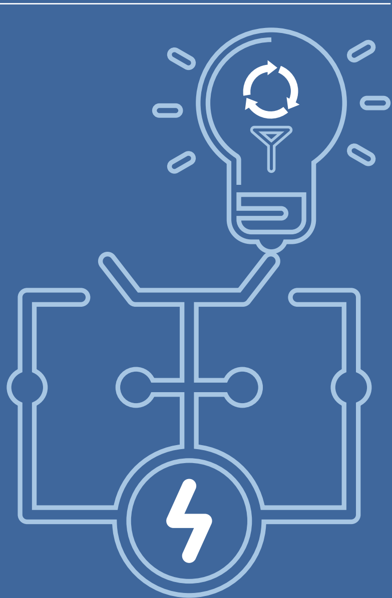
sales and costs savings

1977

First bottle bank installed in the UK

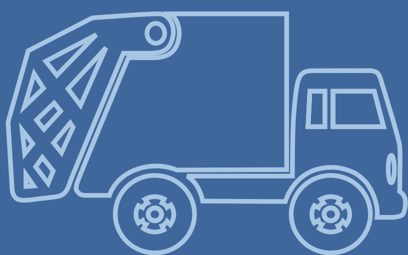
29

Number of UK waste electrical and electronic equipment recycling schemes



14%

Proportion of UK waste generated by households in 2012



CHAPTER 9: Citizens

To help citizens use resources more effectively and recycle more, we need to provide options that are simpler and more beneficial to their lifestyles. This could be achieved through new business models, such as Product Service Systems and Collaborative Consumption; consistent recycling services; or incentives such as 'pay-as-you-throw' charging schemes. Government could help by incubating and trialling these approaches, while providing clearer information about recycling to citizens.

Dr Liz Goodwin, former CEO of WRAP (now Senior Fellow and Director, Food Loss and Waste, World Resources Institute); Keith James, Special Advisor – Environmental Research, WRAP; Professor David Evans, Grantham Centre for Sustainable Futures, University of Sheffield; Dr Catherine Cherry and Professor Nick Pidgeon, Cardiff University and the Centre for Industrial Energy, Materials and Products (CIE-MAP); and Professor Margaret Bates, University of Northampton.

When it comes to resources and waste, what does the citizen want to see? All too often, research on sustainable consumption and production views the citizen either as an individual who must be persuaded to change their behaviour, or whose access to materials must be edited somehow. This places the citizen at the heart of the debate, but as a target rather than as a source of inspiration.

The citizen is vital to changing patterns of resource consumption. Improved resource efficiency – using less material and goods to provide the same output – has traditionally dominated the policy discourse. A common assumption has been that any increase in efficiency will lead to an equivalent reduction in need for the resource[1a]. However, efficiency gains can cause a reduction in the price of products and raise demand for the resource. Alternatively, the reduced cost may mean the consumer has more money to spend on other, potentially resource intensive, goods and services. This phenomenon is commonly referred to as the rebound effect, or the Jevons Paradox[1b].

To help citizens use resources more effectively, we need to provide options that improve lifestyles. The current perception of a better lifestyle often entails increased consumption: bigger homes, more travel and more possessions. But research has found no consistent correlation between happiness and levels of consumption[2]. So, if increasing consumption does not make us happy, what could?

Research has shown that when making purchasing decisions, the most important consideration for consumers was decision simplicity[3, 4]. This is also true of other aspects of our lives where decision fatigue is just as critical[5]. We need to make using less resources and producing less waste simpler and more attractive than using more and wasting more. In developing business models, we have to take a pain away from someone's life with our proposition[6]; it has to be attractive; it must offer a benefit; and it must take little, or preferably less, effort than the present option.

Citizens are "overwhelmed by the volume of choice and information they are exposed to, and marketer's relentless efforts to 'engage' with them."[4] There is ongoing debate about the degree to which consumers should understand the environmental arguments for using resources more effectively, and many of the businesses cited in the debate on the circular economy were motivated by customer demand or economic reasons, not environmental concerns. However, it is clear that when thinking about resources and waste, we need to provide a simpler option than the present choices – but we have to make this a natural choice. This chapter seeks to provide further insights and make recommendations around these and related issues.

Identifying and addressing wasteful behaviours

Waste prevention may very often be thought of as a single policy, but it is not a single behaviour. The reasons we waste food, choose more or less durable products, buy or lease certain items, buy reused items, and recycle are manifold, yet all contribute to the level of resources we use and the waste we produce. Further, it is important to recognise that each of these behaviours is comprised of multiple actions and decisions. For example, wasting food is not an isolated act. It is the outcome of various other behaviours related to the selection, purchase, preparation, storage, use and disposal of food. In-depth studies of these processes suggest that the behaviours giving rise to waste are not necessarily waste-related, and that food waste might be better understood as consequence of the ways in which people shop, cook, use their refrigerators, and organise their meal occasions[7, 8] (see case study on p131).

In addition to opening up a number of different points of intervention, these insights suggest that citizens do not actively choose to waste food. Most people care about the food that they waste and the consequences of doing so, but they also care about a lot of other issues. Citizens have to negotiate a lot of food-related concerns – such as the potential tensions arising when trying to cook 'proper' meals using fresh ingredients, eat as a family, all while reducing waste – as well as a range of other pressures on the co-ordination of everyday life. Without denying the negative impacts of letting food go to waste, it is important to remember that 'bad' waste behaviour very often arises from the very best of intentions[9].

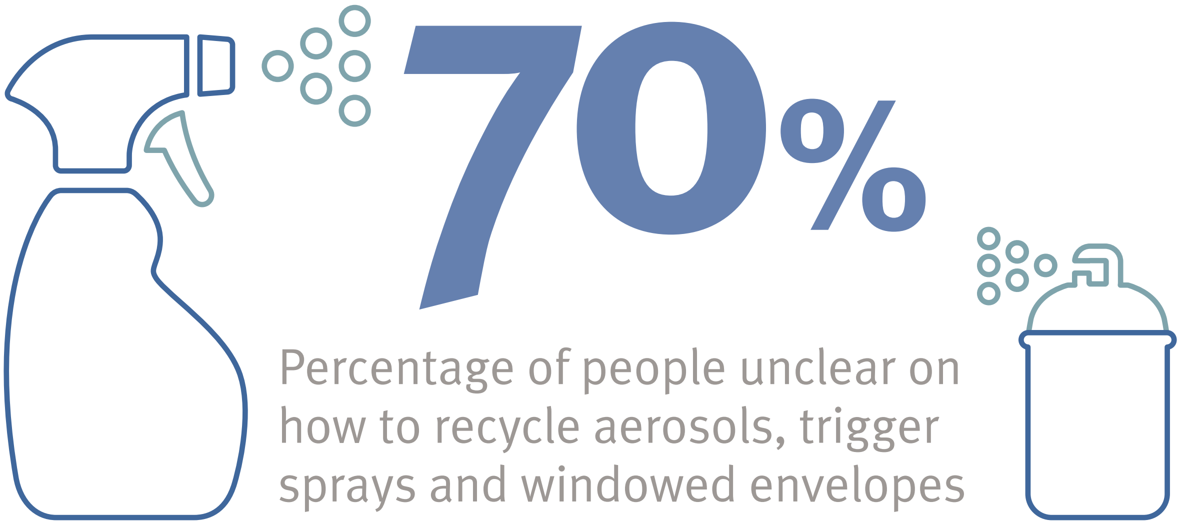
Without disputing the role for citizens in changing their behaviour, it is instructive to distinguish between the cause and location of waste[10], such as ensuring a choice of food is available. Waste that is attributed to the citizen may well be driven – whether directly or indirectly – by other actors and organizations. For example, it has long been claimed[11, 12] that certain products are designed with built in defects that artificially shorten their lifespans. This phenomenon is commonly known as planned obsolescence and can, in part, be used to explain the rate at which citizens discard and replace consumer objects. An in-depth study of how people actually get rid of the consumer objects they discard suggests that only 29% were sent in the direction of the waste stream[13]. The remainder were handed down, re-circulated, or otherwise saved from wastage. This suggests that citizens may already be highly engaged in waste reduction activities. At issue here are the ways in which citizens utilise their social networks in order to find or recover value in discarded things by, for example, repairing them or moving them along for others to use[14]. In addition to facilitating access to the skills required to extend the life of discarded objects (for example, by knowing somebody who can reupholster a chair), our connections to others allow for unwanted things to be reused without fear of disapproval. However, our networks may be insufficient for passing on. For example, we may be anxious about a new colleague discovering we used to wear less respectable clothing, whereas a younger sibling will already know.

In order to respond to the complexities of addressing wasteful behaviours and deliver inclusive and lasting change, action on multiple levels by multiple actors is required. This is illustrated in the ISM model[15] of behaviour change that was initially developed for the Scottish Government[16]. The ISM model suggests that there are several contexts of behaviour (individual, social, material), and that the levers employed in behaviour change interventions tend to address at least one of these.

- The individual context refers to initiatives that focus on economic incentives, information campaigns and approaches that seek to influence the attitudes and choices of individual citizens.
- The social context refers to initiatives that focus on norms, cultural conventions and approaches that seek to shift shared understandings of appropriate conduct. Here, social networks and institutions (such as schools and workplaces) are seen as important points of intervention.
- The material context refers to initiatives that focus on the technologies, objects and infrastructures (of energy provision or transport, for example) that shape, constrain, and enable different behaviours.

While the vast majority of initiatives focus only on the individual context, the ISM model suggests it is more effective to address all three simultaneously.

When applied to the challenge of addressing wasteful behaviours, the ISM model suggests



a move beyond approaches that seek only to engage citizens through financial incentives or information campaigns. This is not to dismiss the importance of these approaches, and in the case of behaviours where there are clear economic drivers (for example, single-use carrier bags), they have proven highly effective[17].

Changes in other wasteful behaviours have necessitated a multi-pronged approach. For example, the success of kerbside recycling can be attributed to interventions tackling a number of factors across the individual context (such as raising awareness); material context (such as providing a reliable collection infrastructure); and social context (making it inappropriate not to participate in recycling schemes when other members of one's community are doing so). However, there is no silver bullet and different waste behaviours will need to be addressed using a different mix of levers, which are likely to vary across different groups of citizens. For example, encouraging reuse amongst citizens who have insufficient or geographically dispersed social networks may require more radical intervention in the social and material context. This might involve the development of neighbourhood collection and reuse facilities that enable the more anonymous exchange of surplus things between relative strangers[14]. Importantly this, and approaches to other wasteful behaviours, is likely to require multiple actions by diverse actors including firms, governments and civil society organisations as well as citizens themselves.

The citizen and new business models

Whether viewed from the perspective of resources, energy or carbon emissions, a radical reduction in the UK's material footprint is needed. Moving beyond production efficiency improvements, a number of strategies have been proposed to rethink systems of production and consumption, often involving a reconfiguration of traditional business models. This may include: designing for increased product longevity, durability, and repairability; providing new services such as extended warranties, incentivised return and upgradability; shifting from an ownership model of consumption to service provision; and developing a sharing economy through peer-to-peer networks for selling, sharing or renting. These strategies are aimed at reducing per-capita embodied energy through more intensive and efficient use of materials and products. There is already public awareness and concern regarding the embodied carbon/energy within the materials and products from which we create our modern lifestyles[18]. Utilising innovative business models for designing, using, and delivering our products and services will, however, also raise profound social challenges. In particular, such changes make implicit assumptions about the role of citizens, both in relation to the extent to which people are prepared to adopt new forms of provision and in the novel relationships that they will require between businesses and consumers, or between consumers and other citizens.

Case Study

Recycle now

Rachel Gray, Behaviour Change Manager, WRAP

Recycle Now is the national recycling campaign for England. It is supported and funded by the UK government, managed by WRAP (Waste and Resources Action Programme), and used locally by over 90% of English authorities. Since its launch in 2004, it has supported a near-doubling in recycling in England, from 22.5% to 44%. Recycle Now aims to address the latter 3 of the 4 key barriers that householders face when recycling. These barriers are:

1. **Situational.** These are the most common, and are related to the recycling services. One key improvement is to support the development of more consistent services, whereby every household in England can recycle a common set of dry recyclable materials and food waste, collected in one of three different ways[1].
2. **Knowledge barriers.** Recycling services have evolved in the past few years, with changes to the frequency of collections and materials accepted. This means that people need to constantly relearn how to recycle correctly, causing confusion. WRAP's Recycling Tracking Survey found that of those people who recycle sometimes but not always, 58% say: "I'm not always sure about whether or not it's recyclable"[2].
3. **Attitudinal barriers.** Most people are not interested in recycling, largely because the benefits are remote. When asked to describe themselves in terms of recycling, one-third of people (32%) told the survey that "recycling is a good thing but I don't spend too much time worrying about it". Moreover, 58% stated: "It bothers me that households aren't told more about what materials / products our recycling gets used for / turned back into"[2].
4. **Behavioural barriers**. Waste disposal is habitual, and tied to everyday routines linked with different household spaces (eg the kitchen or bathroom). The journey of waste through the home plays a key role, and aesthetics matter. Many people lack systems to collect recycling in each room. Washing and rinsing creates specific barriers for some materials, and people often say that it takes too much time and effort to recycle. For example, 25% of households say that cardboard from the bathroom will sometimes or regularly go into the residual bin as opposed to being recycled; 34% do not recycle plastic personal care bottles from the bathroom; and 46% do not recycle aerosols from the bedroom[2].

Recycle Now carries out the following activities to help householders overcome these barriers:

- The Recycling Locator is an online application that helps householders to find out what to recycle and where, by entering their postcode.
- Recyclenow.com details what to do with packaging and unwanted items, and offers information about what happens to recycled waste.
- It provides facts, figures and messages about the benefits of recycling, along with details about the all the items that can be recycled from every room in the house, and examples of how local people make recycling work in their houses.
- Works with partners (such as school teachers and the Scout Association) to encourage young people to recycle.
- Works with the On-Pack Recycling Labelling organisation to help provide consistent on-pack information.
- Provides support and advice to councils to help them communicate with their residents.
- Runs a dedicated Recycle Week each year, bringing a wide variety of activities and partners together.

This section reflects upon how citizens are likely to respond to changing business models within a more 'circular' economy.

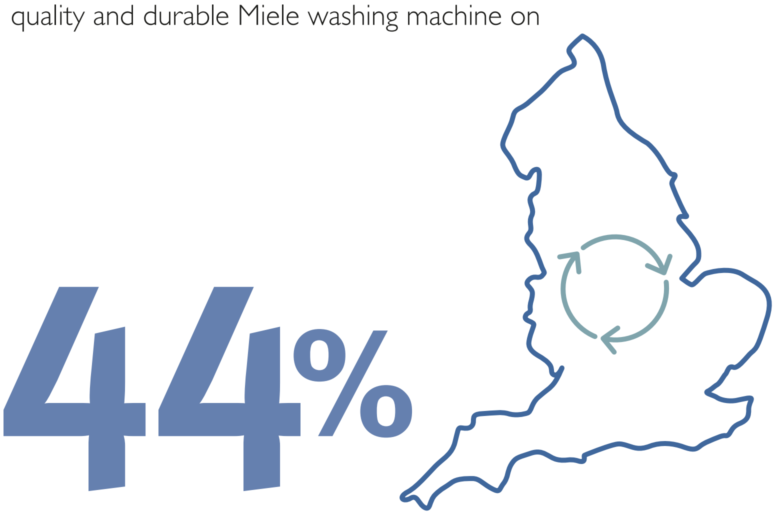
1. Research overview

As part of the RCUK Energy Programme's Centre for Industrial Energy, Materials and Products (CIE-MAP), Cardiff University is leading research to explore the social meanings, practices and values surrounding the social and technical futures that may evolve from new resource-efficient business models. In order to gain a better understanding of the full range of possible low-material futures and scenarios that are envisaged by stakeholders, Phase 1 of the research involved conducting interviews with experts in new business models, resource efficiency and the circular economy. Their visions of the future suggest a whole-scale reimagining of systems of production and consumption, dominated by imaginaries of a smart, connected society. New business models were implicated in many ways, all aimed at reducing the demand for material resources through: reuse, repair or remanufacturing of products; reducing ownership and increasing service provision; or encouraging peer-to-peer sharing, lending, buying, selling and gifting. Commencing in autumn 2016, Phase 2 will conduct a series of deliberative workshops with members of the public, exploring the future of consumption and the different implications that new business models may have for everyday life. This will be followed by Phase 3, a nationally representative survey of members of the British public further exploring the issues and ideas raised within the workshops. The key research objectives are to elicit public perceptions, values, meanings and emotions surrounding alternative systems of production and consumption and the new business models that they imply. The hope is that through this innovative research programme, we will be able to pinpoint key areas of public agreement and resistance regarding proposals for materials demand reduction, and identify the values that underpin people's decisions and attitudes towards change. A full report of the findings will be published on completion of the project in autumn 2018.

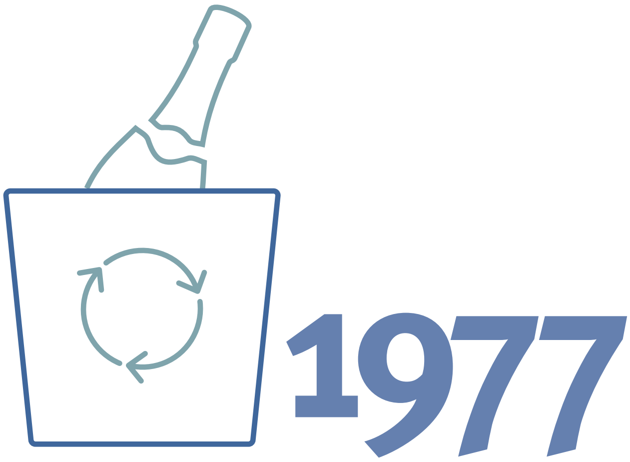
Drawing on contemporary social research on public attitudes to energy system change, and on attitudes towards energy used in people's everyday lives, we ask whether members of the wider public will welcome, oppose, or even actively drive innovative resource efficiency strategies. WRAP (Waste and Resources Action Programme) identifies that consumers have a strong preference for buying and owning new products[19]. However, it also identifies that there is a strong appetite for repair and rental services, trade-in and purchasing second-hand when delivered by trusted, major retailers. On average, almost two-thirds of consumers questioned said they would be likely to use the services if they were delivered by DIY retailers, specialist electrical retailers and manufacturers. Consequently, we will explore two examples of new resource-efficient business models: Product Service Systems and Collaborative Consumption.

2. Product Service Systems

One approach to increasing resource efficiency is through the development of Product Service Systems (PSS). These new business models challenge traditional ownership-based models of consumption by focusing on service provision rather than sales. For example, in The Netherlands, Bundles offers a 'Pay per Wash' service to customers[20], providing a high-quality and durable Miele washing machine on



waste recycled by local authorities in England



First bottle bank installed in the UK

a contractual basis similar to that of a mobile phone (it costs from €14.95/month for up to 6 washes per week, which includes installation, detergent, repair and removal). The service is marketed as providing a quality and convenient experience at an affordable cost, as well as reducing waste and resource use. The reduction in waste comes from more intensive use of products reducing the need for additional products.

Such schemes may or may not be attractive to people, and they may only gain broad public acceptability if any change aligns with a set of values that citizens may hold. Take the energy system, for example: when the goals of current UK energy policy are outlined to people (encompassing the environment, energy security and affordability), many express a strong desire to improve our energy efficiency and achieve reductions in energy demand[21]. At the broadest level, new technologies or systems of consumption should be demonstrated to embody greater efficiency and avoid waste, while also helping to protect nature and the environment. Any system change also needs to ensure security through reliability, affordability, availability and safety, presenting long-term solutions to the energy challenge, as well as representing an improvement on previous service provision.

For any new business model to succeed, it will need to align with this public vision of a future that is resource and energy efficient, but also affordable and secure – values to which PSS speak. However, the research also highlights some core values which might not be so easily met through this approach, in particular where changes challenge people's individual autonomy and freedom (ie by removing the ability to personally control, through ownership, an appliance); or raise questions of social justice, fairness and transparency. If, for example, a PSS model led a person to become dependent upon a single service supplier and it was then revealed that this relationship had been used to take unfair advantage of vulnerable customers, an issue of (dis)trust might arise.

3. Collaborative Consumption

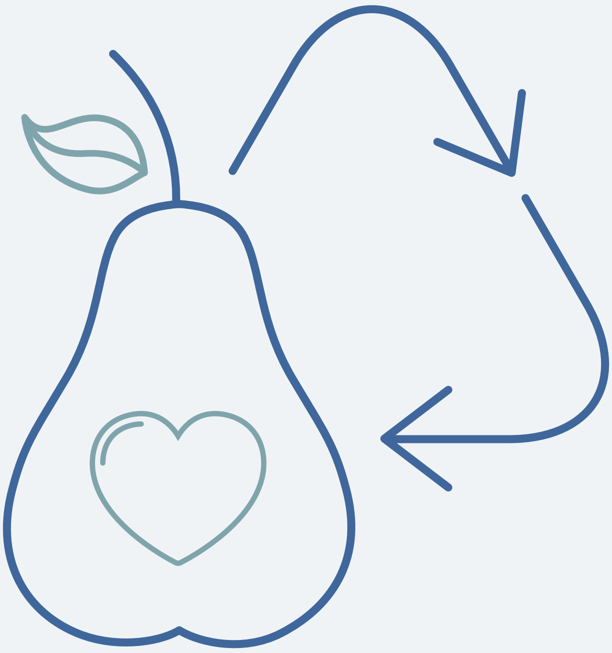
The term Collaborative Consumption covers a broad range of practices that rely on a peer-to-peer approach to consumption. Utilising the power of the internet, practices such as selling, renting, swapping, sharing and gifting can be scaled up, matching people with the products and services they need, effectively bypassing retail businesses. The most commonplace examples are peer-to-peer marketplaces, such as eBay and Airbnb. More radical proposals aim to create a sharing economy that enables the efficient use of shared resources within a community. One example is a Library of Things[22], which provides common household items such as tools, appliances and luggage on loan. While Product Service Systems in effect seek to simply shift patterns of ownership while broadly retaining people's current behaviours and practices of product use, Collaborative Consumption by contrast is likely to have more radical implications for the ways in which we conduct our daily lives and interact with other citizens and businesses.

For example, a recent project that analysed people's 'energy biographies' – their stories of energy use and change across their lifetimes – explored patterns of everyday energy use, as well as the changes to consumption that occur through various life-course events, such as bereavement, having a family, or leaving home[23]. Rather than representing (arguably) rational choices based on available information or beliefs, consumption practices were found to be actively moulded by a range of different influences, including: the technological infrastructure on which everyday life depends; the shared practices in which we all participate; the relationships and emotional experiences which shape our individual life-histories; and the

Case Study

Love Food Hate Waste

Professor David Evans, Grantham Centre for Sustainable Futures, University of Sheffield



In 2007, WRAP launched its Love Food Hate Waste (LFHW) programme to help UK citizens tackle food waste in their homes. This wide-ranging initiative exemplifies current thinking on wasteful behaviour in three ways.

Firstly, LFHW recognised that wasting food is not a single behaviour. Consequently, the campaign promotes a number of different behavioural messages to help citizens reduce food waste. Promoted behaviours include: planning meals and making shopping lists; storing food correctly and using fridges and freezers to prolong its life; measuring portion sizes to avoid preparing too much; and finding creative ways to cook and eat leftovers.

The LFHW programme is now developing a new strategic approach to preventing food waste in UK homes. A pivotal focus of this new approach will be derived from in-depth audience research that will allow LFHW to tailor interventions. The new strategy was launched in October 2016.

Secondly, it makes use of multiple levers and intervenes in several contexts of behaviour. The key initiatives address the individual context by raising awareness of food waste across different media and channels: from traditional print media to digital media, including web and social. LFHW also addresses the social context through community engagement and skills development activities (such as 'let's get cooking' clubs).

Finally, LFHW intervenes in the material context via the provision of objects that help manage food and reduce waste. Tools include devices to help measure appropriate portions in food preparation (such as spaghetti measurers); shopping lists and recipe cards; and digital versions of these items, such as the portion planner on the LFHW website and mobile app.

The Love Food Hate Waste programme has also engaged a number of different stakeholders to amplify the campaign. WRAP has worked in partnership with a range of firms, brands, local authorities and community groups to deliver initiatives to help citizens reduce food waste.

Between 2007 and 2012, annual household food and drink waste in the UK decreased by 19% (1.3 million tonnes). Half of this reduction may be explained by food price inflation and the worsening of economic conditions during this period; the other half is due to the Love Food Hate Waste programme[1]. Given the difficulty of determining its precise contribution, WRAP focused on activity in west London to isolate and measure the impact of running a comprehensive LFHW campaign. The results suggest a 14% decrease in food waste over a six month period (October 2012 to March 2013)[2]. These impacts required a direct investment of £168,472 from the Boroughs of West London; however, it is it is estimated that for every £1 invested, the boroughs saved up £8 in disposal costs, amounting to more than £1.3 million per annum in total.

For any new business model to succeed, it will need to **align with this public vision** of a future that is resource and **energy efficient**, but also affordable and secure

evolution of the different communities in which we are located. Accordingly, energy use is not simply functional, but also serves to shape our individual identities and what we come to see as a 'worthwhile life'.

As part of this identity formation process, people come to form strong emotional attachments to particular practices, both sustainable and unsustainable (sometimes even in the face of a clear recognition of that unsustainability). In promoting the sharing of products, Collaborative Consumption challenges current modes of consumption, but also changes the networks and relationships within which such valued practices exist. This may take the form of requiring new social interactions between previously unconnected citizens, or in questioning personal ownership and the desire for new, rather than pre-owned, products. In one sense, this represents a radical attempt to scale-up more resource efficient consumption practices as part of different ways of living a worthwhile life. But these proposals also risk raising significant challenges to the existing identities and attachments that are embedded within everyday consumption, and hence might make them difficult to nurture or sustain. A clear conclusion is that we need a far better understanding of the ways in which new consumption practices hold the capacity to enhance (or alternatively disrupt) people's existing identities and values.

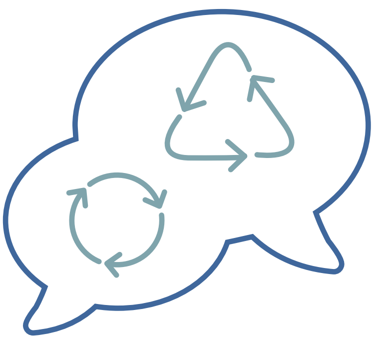
Understanding recycling behaviour

From a citizen perspective, recycling initially seems like a straightforward activity that involves nothing more than putting the correct item in the correct box, bag or bin. Unfortunately, spurring this apparently simple behaviour is actually far more complex. Some 59% of waste collected by local authorities in Wales is now being recycled, compared with just 44% in England. Unlike in Wales, the figure for England has stayed relatively static, raising concerns that the percentage of waste recycled has plateaued.

This would not be a cause for concern if recycling was plateauing because reuse, along with waste minimisation and prevention, was gaining ground – that would suggest we were consequently recycling a lower percentage of a much smaller amount of waste arising. However, according to the Environmental Services Association, most of the easy gains in UK recycling have already been made, and getting more people to recycle (or the same people to do more of it) will not be easy, particularly given the resource constraints and other, political factors[24]. Other environmental and resource-efficient initiatives such as light-weighting packaging also make it harder to meet weight-based targets. To enable citizens to recycle more, they need systems that are easy to understand, because there is still confusion about what can be recycled. WRAP suggests that 70% of those asked are unclear as to what to do with items such as aerosols, trigger sprays and windowed envelopes[25]. Just under half (46%) of UK surveyed households say that on the last disposal occasion, they disposed of at least one material in the general rubbish bin that their council collects as part of the kerbside recycling collection[26]. This is important because, as confidence about what can and can't be recycled increases, so do levels of recycling[26]. Households are also uncertain about the degree of washing or rinsing required[25], with 41% of surveyed households putting items in the general rubbish as a result[26].

The first bottle bank was installed in the UK in 1977, and we have spent the subsequent decades trying to persuade citizens to participate in recycling and adopt better waste management behaviours. In large part, this has been approached by making systems more convenient for citizens, such as widespread introduction of kerbside collections. Yet across the UK we still have recycling rates that will need significant increases to reach targets set in England through the Waste Regulations 2011; the EU Waste Framework Directive targets of recycling 50% of household waste by 2020; and targets in the waste strategies for Northern Ireland, Scotland and Wales which go beyond this. Increased consumption and accompanying levels of waste have led to an interest in reinforcing policies and strategies addressing the top of the waste hierarchy. Efforts to develop and enhance prevention, reuse and recycling have improved in the past decade, but still have not managed to stabilise or even reduce waste levels. Consequently, much research has been undertaken to understand motivations for pro-environmental behaviours, and what factors influence participation.

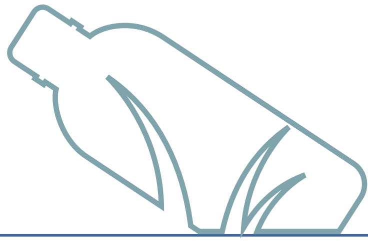
WRAP undertook a detailed analysis of recycling factors and found that contextual variables such as demographics explain 16% to 29% of the variation in recycling rates, while local authority variables explain 39% to 65% of the variation in recycling rates[27]. Factors such as higher levels of deprivation and urban populations (rather than rural) are associated with lower recycling rates, but do not have the same impact as some local authority controlled variables such as the type of collection schemes. Effective weekly residual containment capacity was significant in all datasets for all of the UK. An increase in general waste ('black bin') capacity from 120 litres to 240 litres is associated with decreases in recycling rate by 7.2±2.9 percentage points. This was due to decreases in dry recycling yields and increases in residual waste yields. Separate food waste, and mixed food and garden collections, are both associated with higher recycling performance compared to authorities with no food waste collection. It is clear, therefore, that if we wish to increase recycling rates then the most effective way to do this is through changes to local authority provision.



It is clear that **communication** plays a key part in recycling behaviours

One way to increase participation and boost recycling rates that has received great interest is the use of incentives[28]. In 2011, the Department for Environment, Food and Rural Affairs (Defra) launched the Reward and Recognition Fund (RRF) to explore new approaches for rewarding and recognising people for adopting positive waste behaviours (food waste, recycling, reuse, waste prevention and reduction). From 2011 to 2014, funding was made available to pilots to engage and encourage people to recycle and reuse, using individual prize draws, individual rewards, community rewards, competitions and recognition. An evaluation of the scheme found that the measured effect varied widely across types of schemes[29]. Overall, schemes did not experience a sea change in recycling tonnage, participation or claimed behaviour. Kerbside recycling schemes tended to see marginal percentage increases in tonnage, while schemes focusing on communal recycling and reuse saw greater changes in tonnage. This difference may be because these latter behaviours are less common and less established than kerbside recycling, and are starting at a lower point of participation and capture. An absolute assessment of cost effectiveness was difficult to establish, given the wide variety in overall costs, behaviours targeted (ie reuse, kerbside recycling, communal recycling), and scale and design of the schemes. However, data suggests that the schemes were generally expensive to run, ranging from £0.10 to £84.72 per household/individual targeted (with a median of £7.41); or £0.93 to £467.65 per household/individual that participated (with a median of £30.55). These costs often exceeded the estimated savings generated over the programme's time frame for the scheme.

These results chime with other research[30], which found that value for money is unproven in UK reward schemes and in some cases could cost more than the benefits they deliver. It is particularly important to note that the low



It is important to remember that **'bad' waste behaviour** very often arises from the very best of intentions

cost of collection for waste collection (£0.40 to £0.60 per household per week) limits the options for local authorities, without continued additional funding[31]. Only 8 of the 31 schemes continued after RRF ended. Across the schemes, improvements in recycling and reuse tended to be linked to better services, communications and promotion, rather than being attributable directly to the scheme's reward element. The conclusion is that rewards and recognition, in these schemes, have the potential to validate, reinforce and, possibly, improve a pre-existing behaviour, rather than acting as a catalyst for new behaviours or encouraging new service users[29].

A much discussed strategy for household waste is to apply the 'polluter pays' principle through the implementation of a variable fee structure, or pay-as-you-throw (PAYT). This policy targets household waste at its source, making households responsible for the quantity of waste discarded. This creates an incentive for increased recycling, composting, and ideally a reduction in waste generation. The option to charge householders is well established in other parts of Europe, to reward good waste management behaviours and encourage recycling. The Association of Cities and Regions for Recycling and Sustainable Resource Management concludes[32] that PAYT (if backed by sufficient recycling infrastructure and supported within a framework of environmental policy measures) has a strong potential to reduce waste and increase recycling, and the growing collection and sale of recyclables can increase revenues. Results show that PAYT has the potential to adapt well to local conditions, to encourage (residual) waste reductions, to increase considerable recycling and (home) composting and to be well-received by stakeholders. The region of Flanders in Belgium introduced PAYT in 1995, and within 5 years the recycling rate had reached 60%; in 2015, it reached 70% (ref. 33).

The Localism Act 2011 removed Local Authority powers to charge residents for the weight of rubbish produced. This is based on the view of the Government in England that such a measure would create the potential for harm to public health and the environment from increased fly-tipping and backyard burning.

Aside from PAYT, local authorities could choose to provide smaller bins for unsorted mixed waste, and/or reduce their collection frequency. Less frequent collections can offer significant cost savings for local authorities. In Wales, Gwynedd attributed annual savings of £350,000 to the change, and have achieved 58.75% recycling/composting rates. In England, Bury council reported an 8% rise in recycling rates from a similar change. Pilot trials in the City of Edinburgh[33] saw the rebranding of existing separate paper and packaging banks as mixed recycling bins; fortnightly glass collections were replaced with on-street glass containers; and kerbside recycling collections replaced with communal mixed recycling bins. Over the pilot period, new on-street bins increased glass recycling by 300%, while mixed recycling was seen to rise by around 38% where on-street bins replaced kerbside box collections. Meanwhile, recycling bins placed next to landfill bins were less likely to be contaminated with general waste, while the amount of recycling collected was influenced by convenience for residents.

Householders need a clear and consistent message so that they understand what is expected of them and how they can become responsible recyclers (see case study on p128). It is also clear that householders like clear and specific messages such as "Moisturiser, shampoo, hair gel – we want all those plastics too"[25]. In the UK and Antwerp, householders respond better to positive messages with local impact and relevance[25]. However, it is important not to forget that part of the confusion is caused by the variety of different materials and collection methods across the UK, meaning that no two systems are identical.

A 2015 review of recycling and recycling rates in the UK estimated that mandatory food waste collection (weekly) and reduced residual waste collection would yield a 6% increase in recycling rates to a local authority; PAYT a 12% increase; and improved communications a 3% increase[34]. However Falkirk Council[33] found that the reduced collection frequency for residual waste was the key factor in driving participation in their food waste scheme.

It is clear that communication also plays a key part in recycling behaviours, and can be an effective means of increasing recycling[34, 35, 36]. For example, a communications campaign in Barnet increased recycling rates by 4%, while in Cumbria increases of up to 29% were achieved[36]. WRAP also provides specific guidance to local authorities on running food waste collections[37], building on research and case studies. However, there are concerns that officers and resources are less available for these activities at times of reduced budgets. In combination with uncertainty in secondary materials markets, this means that local authorities are unlikely to be able to address the plateauing of recycling rates.

Recycling apps are used by a number of local authorities. The Swansea Recycling app provides all the information on waste and recycling collections in the palm of your hand through a smartphone app[38]. Other examples include South Oxfordshire District Council's Binfo alerts system[39]; and the Recycle App[40], which is an off the shelf multi-platform mobile application system created specifically for providing cost effective reporting, messaging, environmental, waste and recycling services for residents of local councils in the UK.

It is also possible to make recycling easier to communicate. In 2016, WRAP developed a framework for greater consistency in England[41]. This establishes a vision that by 2025, every household in England can recycle a common set of dry recyclable materials and food waste, collected in one of three different ways. This could add 7 percentage points to the household waste recycling rate in England. If neighbouring authorities collect the same core set of materials in a more consistent way, opportunities for cross-boundary working increase. Experience from existing partnerships suggests that this can deliver financial savings in the region of 10% to 15%, with up to 73% of local authorities having the potential to benefit financially.

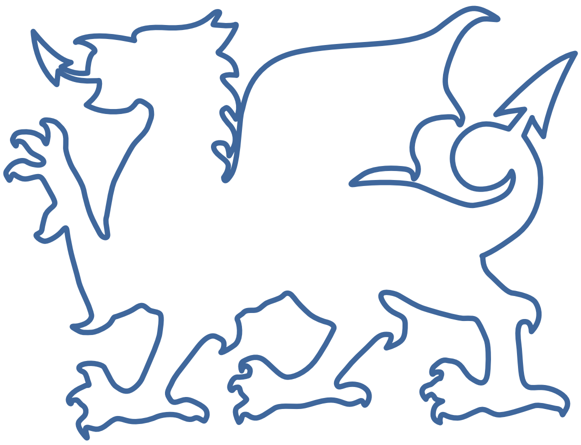
It is also true that we do not capture enough of the recycling which is generated when people are away from their homes. Other countries are better at this. In the United States, iRecycle is the premier application for finding local, convenient recycling opportunities, providing access to more than 1,600,000 ways to recycle over 350 materials. In the UK, WRAP's postcode locator[42] has seen significantly higher levels of use during 2015.

Conclusions and recommendations

As citizens and consumers, we are already actively engaged on issues relating to resource use and waste, from considering whether someone else can benefit from products we no longer want, to actively trying to reduce our waste and recycle more. However, we do this in a world in which we are responding to a number of priorities and drivers, making it difficult to consistently adopt behaviours that reduce our waste and make better use of material resources. The question for

59%

waste recycled by local authorities in Wales



policymakers and businesses is therefore: how can we create systems and opportunities that make it easy for people to behave in the way in which they want to behave?

People do not actively choose to create waste; it is a consequence of a range of pressures. Some are in the control of the citizen, but other pressures are external, such as product design, the availability of services and the simplicity of the product or service offer.

Action is required on multiple levels to help people respond to these pressures, understanding the context of their behaviour and making change as simple as possible. The most compelling factors may be issue specific, and could cover economic, environmental, social or other considerations. Love Food Hate Waste and Recycle Now are two mechanisms to encourage citizens to adopt different patterns of behaviour, but they must be seen as part of a suite of activities rather than isolated interventions. Business can provide clear information on the advantages of new business models to citizens. Government, whether national or local, has a role in providing clear information to citizens on issues such as recycling, as well as providing the infrastructure to allow optimum recycling.

While citizens want choice, they also want simplicity. When considering recycling, citizens would like to see consistency of service. Defra's research has shown that offering people financial incentives to recycle has little effect. Instead, provision of better services, communications and promotion all help people to adopt behaviours that increase recycling. This highlights the need to have a people-oriented approach, rather than simply the perspective of assuming economically rational behaviours. Government should look for cost-effective ways to deliver against this aspiration.

To be successful, resource efficient business models have to offer citizens a service that provides them with a benefit in some way. As with waste prevention and recycling, this can be achieved by linking the service to the values that underpin their decisions and attitudes towards change. Government has a role in incubating new business models that align with objectives on reducing resource-use, while offering citizens a simple alternative that improves their lifestyles. Businesses should take an active interest in specifying products for durability, repair and reuse, and exploring how technology can support behaviours (eg new pathways to the consumer, or the so-called Internet of Things). Businesses should also consider having the right performance indicators, which go beyond maximising profit from a single sale to recognising customer lifetime value, environmental benefits and social benefits. These are all likely to be of interest to citizens, and could drive sales growth.

Contributions:

David Evans wrote the section on identifying and addressing wasteful behaviours; Catherine Cherry and Nick Pidgeon wrote the section on the citizen and new business models; Margaret Bates wrote the section on understanding recycling behaviour.

CHAPTER 10:
Business

Businesses are increasingly adopting the principles of the circular economy. Recycling rates of business wastes have soared over the past 20 years; companies are reducing costs by designing out wastes; and collaborative networks are sharing best practice and spurring industrial symbiosis. Policymakers can accelerate this transition by developing simple policy levers, such as a carbon incentive, and pushing public sector purchasing frameworks to include circular economy aspects.

Andy Whyle, Environment & Sustainability Specialist, Ricoh; and Richard Kirkman, Technical Director, Veolia

Over the past 100 years, business and society has significantly changed its view of the solid wastes arising from consumers and industrial processes. A century ago, removing solid wastes from the city was primarily a public health issue. But in the 1970s, priorities shifted to waste and landfill controls; air-quality requirements that prevented people from burning rubbish at home; and pollution control of municipal, commercial and industrial wastes. Over the past 20 years, the financial opportunities in reducing, recycling and recovering waste – as well as avoiding landfill taxes – have shifted the culture around waste.

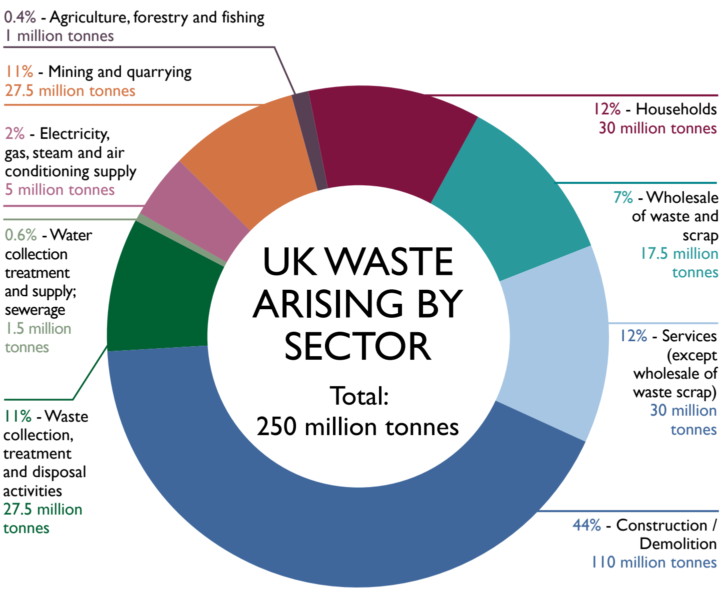


Figure 1: *UK waste arising by sector in the UK, 2015.*

Source: Veolia

Today, businesses' waste strategies are increasingly concerned with long-term sustainability, climate impacts and 'circular economy' thinking (see Chapter 1). Whereas recycling involves reprocessing waste materials into products, materials or substances, the circular economy embodies the entire supply chain, and the integrated analysis of materials, energy and water needs associated to economic activities. By analogy to nature, recycling occurs when a leaf falls from a tree and is reused as nutrients by the tree; a circular economy perspective would include the rain (water), sun (energy) and entire ecosystem required to facilitate the tree's healthy growth.

Businesses are now paying significant attention to re-engineering and redesigning their products and manufacturing processes. The expense of materials and energy has spurred them to reduce cost by designing out wastes, and (along with packaging regulations) to slim down packaging weights. Natural resources need an input of energy and labour in order to extract and prepare them so that they have a positive value. Although the same is true of wastes arising, they have the added benefit that there is less energy input to the system and less environmental impact associated with producing valuable resources from the material.

Of all the solid wastes arising in the UK (see Fig. 1), the materials with the main environmental impact (and highest opportunity cost) are the biodegradable fractions from municipal, commercial and industrial streams; and the technical materials such as metals and minerals, which have a high economic value once recovered.

The high volume, non-biodegradable, and largely inert material (such as construction and demolition wastes – see Chapter 8) can present an opportunity where the recovered value exceeds that of the virgin extraction costs. But the environmental impact of reusing these materials as backfill for quarries and landfill is lower, because they generate minimal gases and leachates.

Over the past 20 years, a consistent landfill taxation policy has provided high certainty to business, and has consequently been a significant driver of businesses' waste policies (see Fig. 2). This has allowed a move from about 5% to 50% recycling and composting of municipal waste, along with significant advances for commercial wastes that are moving towards 'zero waste' policies. Business has embraced segregated collection of its waste, and industry has taken a holistic view of the challenges of water, waste and energy.

Waste is sometimes considered to be something that will simply disappear as we introduce better recycling, better design, and provide services as an alternative to products. This is true as long as we consider the different aspects of materials logistics, energy and water use when we work on holistic solutions. There will always be some physical material produced from public and private activities, and the objective is to utilise those materials for something valuable rather than attribute to them the title of waste.

A business that enables the economy to grow, while minimising the amount of virgin resources that are extracted, is successfully decoupling waste from growth. But the focus is no longer just environmental, it's also about the bottom line. The circular economy saves resources and saves money, offering the potential for 'free growth' that requires no government or external funding, just a change of mindset.

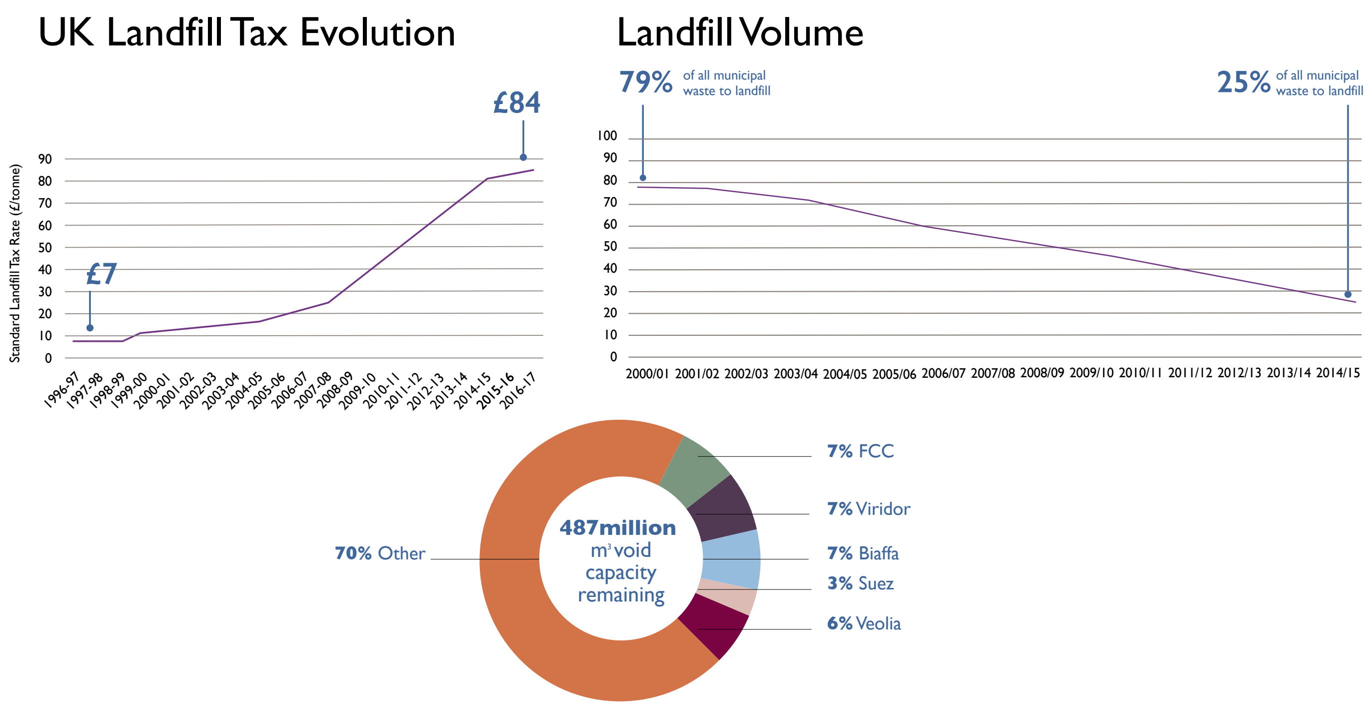


Figure 2: Changes in UK landfill tax (top left), volumes (top right) and remaining capacity (bottom) operated by specific contractors.

Source: Veolia

The World Economic Forum has forecast that the circular economy will contribute $1 trillion per annum globally by 2025 (ref. 1). But until now, there has been no specific analysis of the potential gains to be made in the UK. A recent Imperial College London report outlined the business case for adopting a circular economy[2]. The results demonstrate that using resources in a closed loop system has the potential to contribute £29 billion (1.8%) of GDP and create 175,000 new jobs in the UK (see Fig. 3).

Given the success of the landfill tax in delivering change over a 20 year period, policymakers could consider a similar mechanism – a clear, simple policy lever, such as an all-encompassing carbon incentive – to promote circular approaches and unlock the £29 billion potential of the circular economy, bringing higher productivity and growth to the economy.

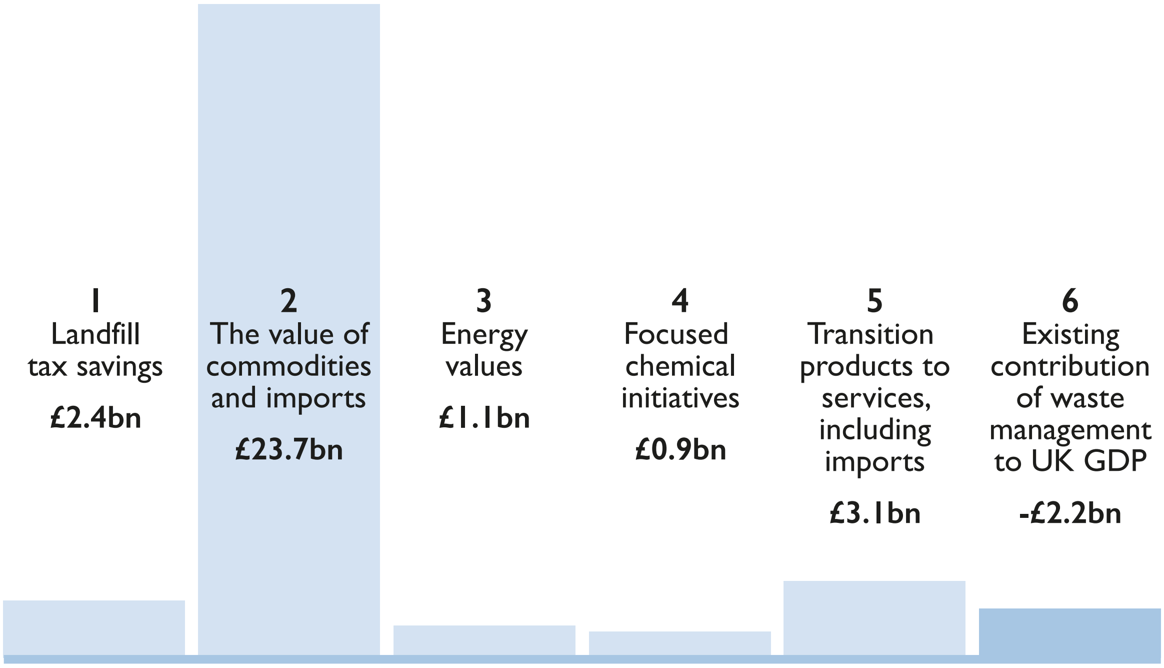


Figure 3: A transition to a circular economy could contribute £29 billion to GDP, based on savings or profits in six key areas.

Source: Veolia/Imperial College London

Delivering resource productivity through design

Businesses fundamentally manufacture products or provide services, which they sell to make a profit. Generally speaking, if this is done efficiently it increases resource productivity and the longevity of the business. All products undergo a design phase, but do not always take into consideration a total lifecycle approach. This 'linear economy' approach can lead to higher production costs, impacts on the environment, and decreasing sustainability, ultimately affecting business continuity.

Adopting a circular economy approach opens opportunities to decrease business costs, increase the lifecycle of the materials used, while embedding responsible (sustainable) business growth. Any organisation wanting to stay in business for the long term will need to adopt a circular economy design approach to ensure they have access to the materials they need to make their products, and ultimately survive.

For example, The Great Recovery is a project run by the Royal Society for the encouragement of Arts, Manufactures and Commerce (RSA) and supported by Innovate UK. It looks at the

Collaboration between businesses, educational establishments and innovators can develop responsible growth

challenges of waste and the opportunities of a circular economy through the lens of design[3]. It asks designers to gather input from stakeholders across the value chain, including material experts, manufacturers and packaging engineers, recycling solution providers, logistics managers, consumers and users. This captures the opportunities to extend the lifecycle of a product and its constituent materials. The circular economy aspects are designed considering four models, each with their own sets of key knowledge holders, who can help the designers to establish an extended design team. These four models are:

1. **Design for longevity.** First, try to design the product so that it meets the needs of the customer for as long as possible (by giving it a long life, or providing for modular replacements to update the product)
2. **Design for leasing or servitisation.** This relies on a contractual agreement (usually business-to-business) that can include a reverse logistic element (ie the ability to return it to the manufacturer) to ensure the product's value is not lost.
3. **Design for remanufacturing.** Broken components are replaced, restoring the product to its original state with a warranty to cover the next life of the product.
4. **Design for material recovery (or recycling).** Materials are completely broken down before some are restored to the manufacturing processor. This includes using recovered material in the place of virgin resources.

These principles lie at the heart of product lifecycle models developed by companies such as Ricoh and Jaguar Land Rover (see case studies on p141 and p147).

One of the key recommendations from The Great Recovery is that the design industry needs more skills training, by embedding circularity into the design education system, along with

other business and educational programs. For example, the MSc in Strategic Sustainable Business at Aston Business School[6] takes a highly interdisciplinary approach, embracing the practical and theoretical requirements of understanding sustainability and the circular economy within a business context. The course includes design, engineering, business, scientific, philosophical, psychological, strategic and leadership elements.

In one of the course's teaching modules, called 'Strategic Business Sustainability', Dr Helen Borland introduces a circular, closed-loop strategic business approach. This starts with an understanding of elements of the planet's underlying operating system for global sustainability, such as ecosystems theory, laws of thermodynamics, Gaia theory, climate cycles, resilience and planetary boundaries, and how humans impact these through carbon emissions and ecological footprints. It then progresses to the strategic requirements and assumptions necessary for creating closed-loop, circular business strategies. This is illustrated through the formation of transitional strategies (reduce, reuse, repair, recycle and regulate); and transformational strategies (rethink, reinvent, redesign, redirect and recover).

This teaches the philosophical and psychological elements, as well as the leadership framework, needed to create long-term strategic sustainable businesses. (Ricoh's long-term sustainability strategy and circular economy operation acts as a case study for the module). It also shifts participants from an anthropocentric mind-set to an eco-centric one that then enables them to effectively tackle risks and opportunities within their businesses around carbon emissions, climate change, resource, water and energy conservation issues, and circular economy development. It helps to create businesses for the future that are flexible enough to adapt and work within environmental and social constraints.

Meanwhile, the Aston Sustainable Business Research Club (ASBReC) studies all areas of sustainable and responsible business. This includes examining the 'receptivity' of senior management towards sustainability and the circular economy, and how this translates into identifying the skill sets needed for key staff within their organisation. They also have links with other groups across Aston University that specialise in waste-to-energy recovery and bio-energy, servitisation and the circular economy, sustainable and reverse supply chains, SME business growth, operations management and 'big data'.

The conclusion is that 'strategic business sustainability' should be a matriculation criterion for every design, engineering and business degree, to encourage a multi-discipline, future-proofed student learning experience, based on the lifecycle of the products and services that businesses create.

Building this circular economy awareness into the education programmes of future designers and business leaders embeds the advantages of a long-term strategic approach and shows how to realise the business benefits. When these individuals are driving the businesses of the future, they will foster greater stability and responsible growth. This will improve the physical environment through reductions in soil, water and atmospheric contamination; but it will also increase resource productivity and, potentially, require less waste legislation. The circular economy will have become the new 'business as usual'.

Collaboration in the circular economy

Sustainability in business should not be a competitive issue. Fundamentally, it would be pointless to take this journey alone. Sharing and adopting sustainability best practice can improve business performance while collectively contributing to global environmental targets.

Case Study

Ricoh's Comet Circle

Andy Whyle, Environment and Sustainability Specialist; and Xavier Battinger, Director of Business Development Office, Ricoh

Ricoh is a global technology company specialising in office imaging equipment (such as photocopiers), production print solutions, document management systems and IT services. It has been a pioneer of circular economy thinking, designing and manufacturing its products for reuse and recycling, reducing its reliance on virgin resources[4].

In 1994, it established the Comet Circle principle, a lifecycle model in which products and parts are designed and manufactured so that they can be reused and recycled, making a significant contribution to both resource conservation and business performance. Its remanufactured GreenLine products are offered with the same warranty as new devices, yet at a lower price to customers. These have a significantly lower carbon footprint than devices made from new resources, whilst significantly reducing the environmental impact across the lifecycle.

Ricoh's 'Zero Waste to Landfill' operating standard has been in place since 2001, and it has set a target to reduce the use of new resources by 87.5% from 2000 levels by 2050. This has resulted in its current product range being smaller and lighter, using parts with longer lifecycles, while increasing reuse and recycling.

Case Study

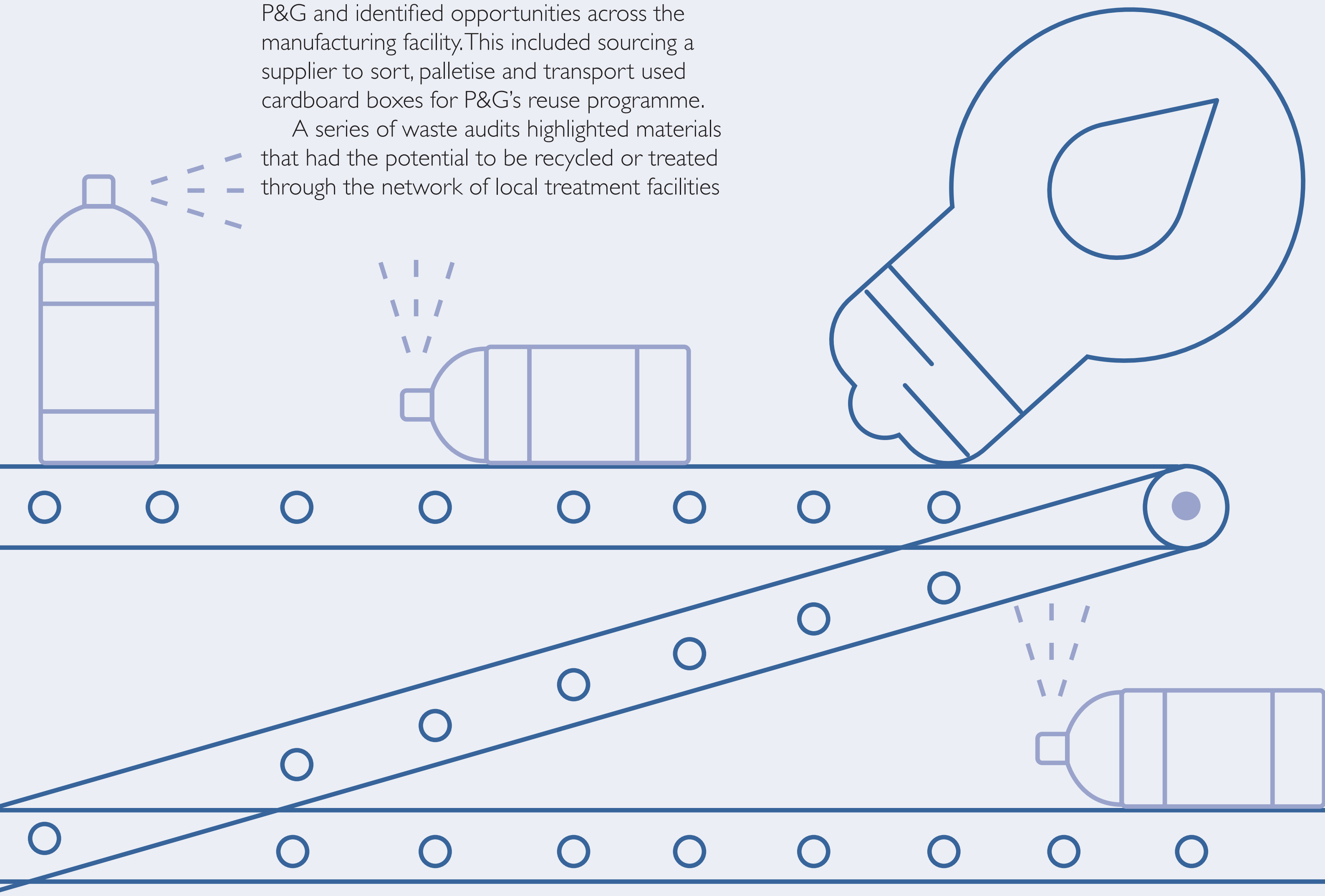
Circular thinking applied to manufacturing

Richard Kirkman, Technical Director, Veolia

Procter and Gamble (P&G) manufactures household names that include Gillette, Pampers, Pantene and Fairy Liquid. In recent years, the company has significantly changed the way it views waste. By actively pursuing a global 'zero manufacturing waste' initiative, since 2010 P&G has reduced water use by 20%, greenhouse gas emissions by 4%, and energy use by 15%.

The company has achieved 'zero waste to landfill' across 68 of its global manufacturing sites. The first facility in the UK to meet this target was the Gillette aerosol manufacturing facility based in Reading. The waste contractor reviewed and analysed all waste streams with P&G and identified opportunities across the manufacturing facility. This included sourcing a supplier to sort, palletise and transport used cardboard boxes for P&G's reuse programme.

A series of waste audits highlighted materials that had the potential to be recycled or treated through the network of local treatment facilities operated by Veolia. This allowed P&G to recycle every component in its aerosol cans, which included extracting the gases, recycling the metal can itself and processing the organic liquid inside for use as a secondary liquid fuel (SLF). SLF is subsequently used as an alternative fuel source for kilns in the cement industry.



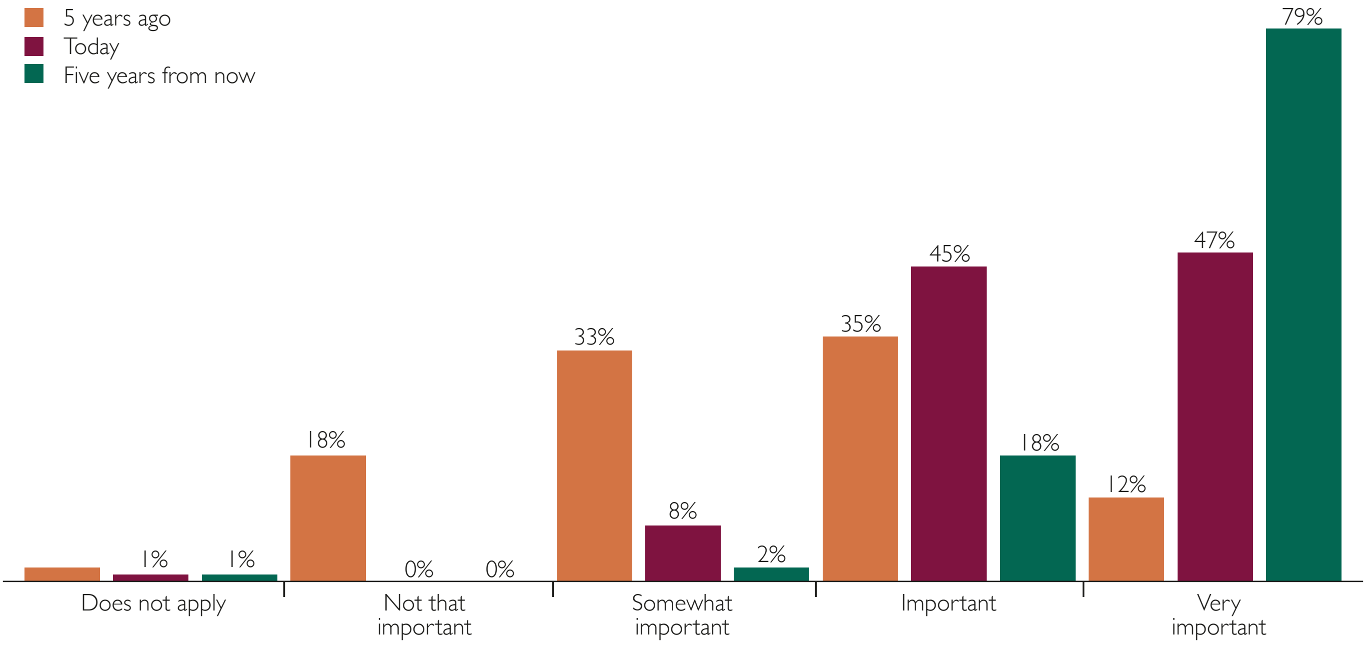


Figure 4: *A recent GreenBiz survey asked respondents to rate the importance of collaboration with outside organisations (in order to further their own organisation's innovation capacity) at three points in time: 5 years ago, now, and 5 years in the future.*

Source: GreenBiz

Companies that are leaders in the sustainability arena are continually looking to scale their efforts. US media organization GreenBiz conducted research in 2015 to discover how companies can create value in order to spur innovation[7]. One of the key findings is that the perceived need for outside collaboration is significantly increasing (see Fig. 4).

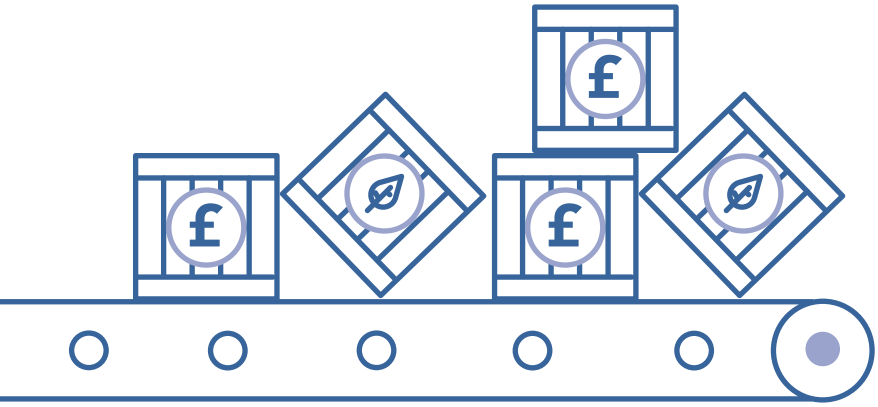
Collaboration between businesses, educational establishments and innovators can develop responsible growth, whilst increasing regional productivity through Local Enterprise Partnerships (LEP). Business Environmental Networks already understand that sharing sustainability best practice only helps to develop it further, creating models that become more generic as their deployment increases. For example, the Business Environmental Support Scheme Telford (BESST)[8] is a business-led sustainability forum that takes leading international corporations and develops best-practice models to improve their business performance. The knowledge is then shared with other businesses to enhance their own sustainability, and subsequently contribute to the shared knowledge.

This shared stakeholder approach attracts contributions from circular economy solution-providers and innovators, developing economies of scale in knowledge and capabilities. It also provides the Environment Agency with the access it needs to deliver business-facing programs; and helps circular economy solution-providers like Veolia to engage with collective businesses and deploy new opportunities, increasing the value and lifecycle of the wastes they produce.

The collaborative approach also assists circular-economy developers like International Synergies[9] to deliver industrial symbiosis workshops. Its National Industrial Symbiosis Programme (NISP) was the first of its kind in the world, rolled out across England in 2005 with support from Defra. Its impressive results have been replicated in 31 countries on 5 continents, and led to the UK hosting the G7 Workshop on Industrial Symbiosis in 2015.

NISP identifies mutually profitable transactions between businesses (from small companies to multinationals) so that underused or undervalued resources (including waste, energy, water and assets) are brought into productive use. Between 2005 and 2013, projects enabled by NISP had a return on investment of 9 to one, enabling businesses to generate over £1 billion in new sales; reduce costs by £1 billion; create and safeguard over 10,000 jobs; reduce carbon emissions by 42 million tonnes; and cut landfill by 47 million tonnes.

Product labelling can help to ensure that packaging is **adequately designed**, used and treated after use



Sustainability in business should not be a **competitive issue**

The increased sustainability of the participating organisations improves their bottom line profitability and environmental performance, increasing business resilience and continuity. This continuity stabilises and grows business productivity, contributing towards the LEP's regional low-carbon, environmental and growth targets. The successful BESST model has now been deployed in two other business networks in the Marches LEP, and has inspired the West Midlands Green Business Clubs Network[10] for Sustainability West Midlands.

This concept could be developed by creating a Sustainability Centre of Excellence, initially within a local university. This will provide a focus for:

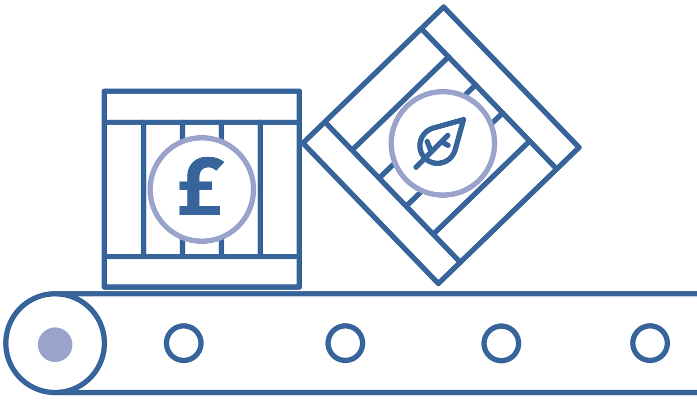
1. Funding: allocated by the LEP.
2. Research and education: targeting business needs, to improve circular economy and resource efficiency efforts.
3. Job creation and inward investment: providing start-up facilities for innovators and small and medium-sized enterprises (SMEs) to develop their initial designs into marketable, sustainable, circular-economy-based products.
4. Resource efficiency: giving Business Environmental Networks access to results, so that they can deploy them to increase resource efficiency and therefore business productivity.

This concept will provide a central point of reference for sustainability stakeholders, where research, innovation and product development can take place. These products and methodologies can then be displayed to potential users, who can then make effective business cases for their deployment and use.

Government policy should drive LEPs to create Sustainability Centres of Excellence where there is potential for Business Environmental Networks, educational establishments and SME innovation to increase circular economy development and deployment into business strategy.

Extended Resource Ownership (ERO)

Extended Resource Ownership (ERO) means that businesses review the entire lifecycle of their products for value-added opportunities. A generic circular economy model has been developed as part of University College London's 'Conducting a Life Cycle Assessment (LCA): from Theory to Practical Application' course[11], and it can be adapted by any business to select the appropriate aspects needed to develop into a circular economy organisation.



The model includes:

1. Stakeholder-based and circular economy-based design: building in lifecycle aspects of the materials used and identifying opportunities to de-package packaging.
2. Demand chain engagement: agreements with suppliers to reuse process wastes or return transport packaging.
3. A strategically driven Sustainable Business Process.
4. Demand chain agreements with consumers, to agree return of transport packaging.
5. Demand chain agreements with consumers establishing reverse logistics contracts or incentivised returns, to enable remanufacturing and resource conservation.
6. Returning assets for reuse assessment (at a 'green centre'). This includes remanufacturing and assuring assets for another lifecycle; and parts harvesting (removing good parts and assuring for use in remanufacturing).
7. Reducing process waste: embed lean and green continuous improvement methodologies to increase productivity and reduce wastes.
8. Reusing process waste on site: as raw material inputs (reducing costs) or by applying them to natural capital projects.
9. Recycing process waste ('waste-2-product'): improve segregation of process wastes to meet material requirements by segregation; process on site; industrial symbiosis with external businesses; set general waste reduction targets (eg 'Zero Waste to Landfill' – see case study on p142); improve the quality of segregated waste for recycling increases the revenue it offers.
10. Wastes that cannot be processed on site are sent to circular economy solution providers with increased technology and capacity. This reclaims further value and extends the lifecycle of materials by providing them as feedstocks to other industries or consumers.

Prevention of wastes through improved **process control** and efficiency is an immediate business **cost saving** in raw material loss

Prevention of wastes through improved process control and efficiency is an immediate business cost saving in raw material loss. This also avoids having to process that waste and prevents it from escaping into the environment. Forward-thinking organisations embed continuous improvement philosophies (eg a 'Lean and Green' approach) that improve process yields and reduce waste, while making the link to environmental impact reduction.

For example, plastics have become one of the main raw materials within the UK's manufacturing sector, with 3.3 million tonnes of plastic materials processed in 2015. If incorrectly disposed of, plastic waste can end up in our seas and food chain. To address this, the British Plastics Federation runs Operation Clean Sweep[12]. It aims to raise awareness of the issues caused by pellets, flakes or powders reaching the environment, and also to provide best practice to companies to ensure they have the right systems in place to contain and clean up any spilt material. There are now 53 members signed up to OCS from across the UK plastics industry.

If investment is needed to reuse and recycle process waste, partnership agreements can be established with solution providers to install their assets within the business process. This could be on a 'profit-gain-share' model that retains material value at the source, adding to the business bottom line through raw material savings or enhancing revenue. Although the basis for the model is manufacturing based, it is transferrable to other sectors. Any organisation has inputs and outputs – even those based on servitisation models, or entirely virtual IT solutions – and circularity can help to optimise these.

Extended Resource Ownership means that businesses **review the entire lifecycle** of their products for value-added opportunities

Policymakers could ensure that public sector purchasing frameworks include circular economy aspects. Where applicable, these contracts should have reverse logistics elements built in to enable remanufacturing or resource recovery, ensuring maximum return of material while extending lifecycle value.

Packaging

Product labelling can help to ensure that packaging is adequately designed, used and treated after use. The UK's current packaging labelling system includes information about energy efficiency, mainly for electrical equipment, and the nutritional content of food. But details about the water and materials (waste) implications of consumer goods is lacking. It would be reasonable to expect that a labelling system might be adopted to facilitate better recycling of fast-moving consumer goods, possibly using mobile apps or augmented reality technology.

To date, the UK's packaging regulations have relied on the PRN (packaging recovery note) and PERN (packaging export recovery note). This ensures that companies producing packaging pay for PRNs, which demonstrates that they have ensured recovery of a targeted amount of packaging for the main material types.

The system has incentivised the recovery of materials, but has now stagnated since the targets are almost met and the notes are rapidly losing value. The system is also skewed to exports, which means we are not growing our UK reproduction capacity, resulting in many paper and plastics recycling plants closing.

The PRN is currently issued on the final product yielded from recyclate (eg a 1 tonne bale of mixed plastic will yield around 65% of usable plastic). However, for the same exported bale, a 100% PERN is issued, meaning a higher subsidy is paid on export. This system needs to be reviewed in order to deliver more recovery of materials and reprocessing within the UK.

A wider review of the current packaging incentives is necessary to encourage better design and recycling outcomes to underpin the EU Circular Economy Strategy. The UK government could find a way to encourage the highest-quality recycling of packaging at the best possible cost to producers, while maintaining markets for secondary raw materials. The current PRN and PERN system has served its purpose, and it is now time to review this model in order to on-shore the recycling of paper, plastic, metal and glass and protect UK markets and jobs in the secondary resources sector.

Collection

Collection is the core logistic of handling waste materials in cities, while segregating that waste effectively is the key to balancing the costs of wastes that have no value (eg mixed) and those that have value (eg, fibres, plastics, metals, food). This in turn can optimise costs and fund elaborate collection schemes. In this area, policymakers could boost recycling and recovery through the following measures:

- Encourage the standardisation of waste collections for both rural and urban environments. This would enable people to become educated over time about how to recycle better, which will in turn reinvigorate recycling.
- Encourage the separate collection of glass from other recyclables.
- Encourage the separate collection of food.
- Inform and educate waste producers about how to use recycling services, building on the existing good work that has already been done by WRAP (the Waste and Resources Action Programme), local authorities and the commercial sector.
- Link the new standardised collection system to messages on products and materials to make recycling simpler.

Leadership

Responsible businesses increasingly define best practice and industry standards in the supply chain for waste and resource management. Ricoh, Marks & Spencer, Jaguar Land Rover, Boots, United Utilities and Veolia are all notable members of the Business in the Community organisation, and they are spearheading strategies that are changing how the supply chain procures, manufactures and treats materials.

In order to give all businesses a chance to participate in this good practice and profit from the wider benefits, an independently-recognised benchmark would incentivise the SME market. It may also be time to implement a scheme to track waste flows, using the tools associated with 'big data' (the ability to sense, measure, track and report large data sets).

Big data provides many opportunities in the circular economy. Businesses are required to classify wastes (using European Waste Catalogue codes) to ensure the duty of care of waste disposal. This has been linked to the waste hierarchy to drive recycling. To develop and use this data, and apply it within a matrix of waste utilisation possibilities, businesses need to systematically review their process wastes for circular economy opportunities.

A similar framework has already been deployed under UK energy regulations. The Energy Saving Opportunities Scheme Regulations 2014 require all private organisations with over 250 employees or a turnover of €50 million to complete a detailed energy audit covering at least 90% of energy use[13]. The success of this scheme could be duplicated for water and waste (materials). In order to thrive in the long term, businesses need resources (human, capital and material); competitive advantage; and foresight. If we also take into account the use of water, energy, and the materials needed to manufacture, use and recover a product, there would be clear financial benefits to business.

Counting the cost of carbon might offer a way to encapsulate all of these factors, since it remains the only externalised environmental impact for most products. For example, if carbon were to be costed at about £30 per tonne, the carbon saved in the past 20 years in the waste sector would cost around £600 million. In return, that could unlock £29 billion of potential value in the circular economy.

Case Study

Jaguar Land Rover's REALCAR

Adrian Tautscher and Mark White,
Jaguar Land Rover

Britain's largest automotive manufacturer, Jaguar Land Rover (JLR), is using up to 50% recycled aluminium in new cars in a project called REALCAR (Recycled Aluminium Car)[5]. Supported by Innovate UK, the project is bringing significant benefits to the company and its suppliers, while demonstrating how the circular economy can bring major environmental benefits to manufacturing.

Since 2002, the company has been using aluminium in its vehicles' bodies to reduce weight, improve fuel consumption, lower tailpipe emissions and reduce costs to the user. However, aluminium is more energy-intensive to produce than steel, making it both environmentally and economically more expensive. JLR needed a way to reduce both cost and environmental impacts during production of the material. The result was the REALCAR project, a closed-loop value chain that minimised the use of primary material and maximised the use of recycled aluminium during manufacturing.

Recycled aluminium requires up to 95% less energy during production than primary material, while its lightweight properties helps JLR in its goal to achieve a 30% reduction in key environmental impacts during the entire lifecycle of its vehicles by 2020.

The recycled aluminium is being used in the Jaguar XE, XF and F-PACE; JLR has invested in new and upgraded scrap aluminium segregation systems at 3 of its press shops. A successor project, REALCAR2, aims to increase the percentage of recycled material further, and JLR now hopes to have 75% recycled aluminium in its car body structures by 2020.

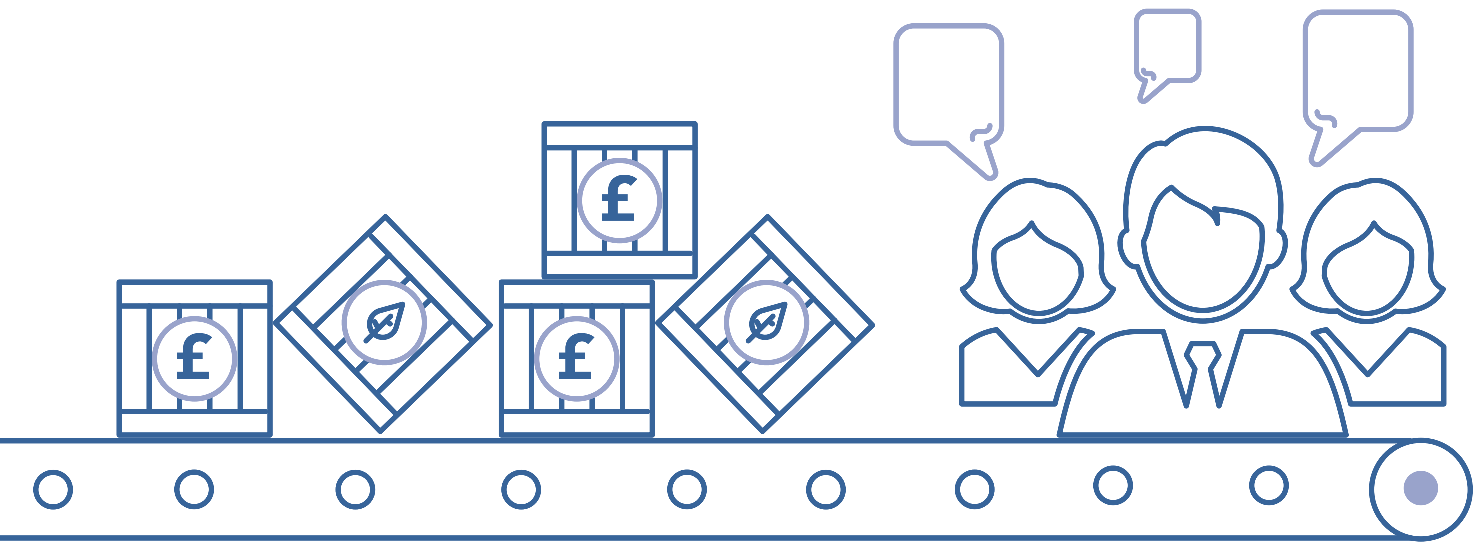
Conclusions

The evidence in this chapter leads to two key recommendations:

1. **Unlocking the circular economy.** Policy makers could consider a clear, simple policy lever, similar to the landfill tax mechanism, to incentivise circular approaches and unlock the £29 billion potential of the circular economy. This might include the introduction of an all-encompassing carbon incentive, replicating the success of the Energy Saving Opportunities Scheme. In turn, unlocking the potential of the circular economy will bring higher productivity and growth to the economy. Collaboration and support are also essential, with circular economy leaders creating and sharing best practice models through business networks and centres of excellence to embed the business benefits.
2. **Extended Resource Ownership (ERO):** Businesses need to move beyond the current, linear, end-of-life product-based management, to an integrated supply chain circular economy approach. This includes:

- de-packaging packaging
- supply chain forward and reverse logistics
- sevistisation / incentivised return
- remanufacturing / reuse of material
- 'Waste-2-Product' development (maintaining resource quality / value)

Policymakers can push public sector purchasing frameworks to include circular economy aspects. Where applicable, these business-to-business contracts should have reverse logistics elements built in, to enable re-manufacturing or resource recovery. This extended ownership drives businesses to maintain control of the materials they sell to their respective markets, ensuring maximum return on material costs and extending the lifecycle values.

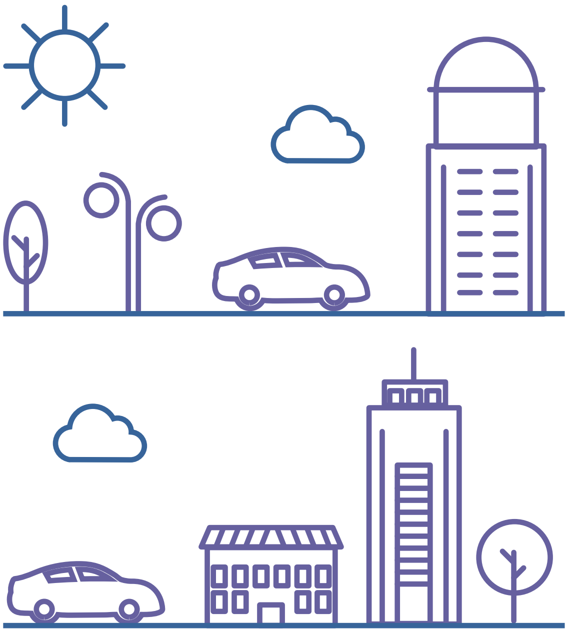


CHAPTER 11: Cities

Waste management in cities is a partnership between the city and its citizens, which depends on issues such as ownership and responsibility, and hence citizen attitudes and behaviours. System maps are helpful in highlighting the dependencies between waste and other city systems, such as energy and water. Understanding the consequences of these relationships can reveal opportunities for beneficial economic, social and environmental change, avoid 'silo thinking' and help to engineer successful waste systems.

Christopher Rogers, Professor of Geotechnical Engineering, University of Birmingham

Waste in cities starts with people: it is a by-product of living, working and playing. It might be generated because there is an oversupply against need, or through a lazy or wilful disregard for resource conservation. But from a citizen's perspective, most waste is generated by a



Cities are equally places of **creativity, construction, business, manufacturing** and **commerce**

perceived or actual loss of value, either as a result of deterioration, or because an item has gone out of fashion (artificial obsolescence) or has been superseded by some new device or process. As cities are themselves agents of progress and change, they are indirectly involved in (perceived) value reduction.

Cities are equally places of creativity, construction, business, manufacturing and commerce (see Chapters 5, 8 and 10). As with citizens, these processes both consume and create waste, and they do so on an industrial scale. Finally, there is waste associated with servicing citizens: waste is a by-product of bringing goods and services to people. Waste packaging, for both food (see Chapter 6) and products (see Chapter 10), has an obvious impact, yet waste is also generated in the movement of people and things. For example, there is an energy cost in moving people, goods and resources through cities, and any inefficiencies in this movement represent a waste. Similarly, leaky water pipes waste water, energy (in harvesting, processing and distribution) and purification chemicals. Moreover, even when these systems are highly efficient, vehicles create greenhouse gases and solid particulates, the airborne PM10 and PM2.5 contaminants that worsen air quality and damage health. If we are to consider the totality of waste due to a city's operations, then arguably we should include carbon dioxide, nitrogen oxides, other greenhouse gases and airborne particulates that so fundamentally influence citizen health and the way our planet operates.

Case Study

Energy from waste

Martin Freer, Professor of Nuclear Physics and Director of the Birmingham Energy Institute, University of Birmingham

The City of Birmingham has ambitious plans to reduce carbon emissions, create a low-carbon infrastructure and modernise how it deals with waste. These priorities are captured in the 'Carbon Roadmap' produced by Birmingham's Green Commission[1], which sets out the city's ambition to reduce total CO_2 emissions by 60% by 2027 from 1990 levels. To that end, the city's agenda around energy and sustainability has focused on:

- How Birmingham should in future be heated and powered
- How we travel and get around the city
- Improving the energy efficiency and affordable warmth of buildings
- Creating decarbonised local energy generation capacity.

Besides working towards achieving a 40% recycling rate by 2026, Birmingham City Council (BCC) is exploring options around how to optimise its use of waste through its current waste contract, which runs until 2019. This involves understanding not only how to use the waste heat from a waste incineration and energy recovery facility for electricity generation, but also district heating schemes. The Birmingham District Energy Scheme is a central plank of the Birmingham City Council's low carbon strategy, and is a partnership between Cofely (now Engie) and BCC. This utilises an advanced district heating and cooling scheme, with combined heat and power plants, which was installed by Cofely.

The state-of-the-art Energy Recovery Facility in Tyseley takes 350,000 tonnes of Birmingham's municipal solid waste each year and converts it into electricity at a rate of 23.5 tonnes per hour. The output is 25 megawatts (MW), which is exported to the National Grid. Close by on the Tyseley site is the new Birmingham Bio Power Plant, which uses gasification technology to generate electricity from recovered wood waste. This new 10.3MW biomass plant, developed by Carbonarius to produce renewable energy, cost £47.8 million to build. The local energy system has the potential to exploit not only the electricity, but also the waste heat, from these plants.

These two energy-from-waste facilities form part of the Tyseley Environmental Enterprise District, which covers over 230 businesses and around 100 hectares of traditional industrial land, and employs 5,000 people. Companies include Webster and Horsfall, Grayson Thermal Systems, SCH, Europackaging and Thyssen Krupp Aerospace. The site is connected to the city via a rail, road and canal network, and has become the focus for transforming how the City of Birmingham could establish integrated energy systems more effectively. Birmingham has now developed the 'Energy Capital' concept, which frames its ambition to combine development in waste, energy and transport to benefit the immediate region of Tyseley as well as the wider city (see case study p157).

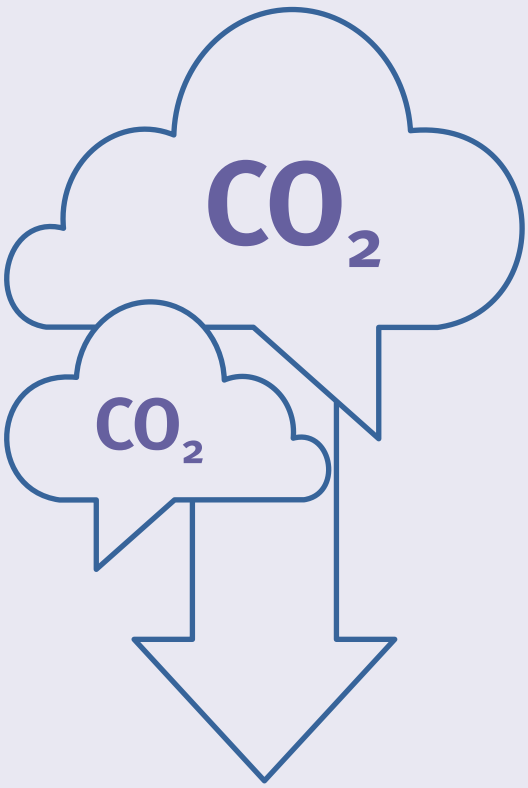
This illustrates how the waste system integrates symbiotically with both hard (eg infrastructure) and soft (eg business) systems in Birmingham. The aim is to create an infrastructure that links waste with electrical power production via the exploitation of waste heat streams. This benefits local businesses and potentially, through district heating networks along the canals, to the city centre for space heating the city's buildings.

As part of this, Tyseley Energy Park, which is part of Energy Capital, is being developed to create a local ecosystem that will:

- Enable new green technology development by providing a platform for testing new technologies in this space, particularly those associated with thermal energy management, waste heat distribution and efficient recovery of heat
- Establish new product and process opportunities for UK-based businesses seeking to gain entry into this developing market through use of, for example, innovative procurement mechanisms
- Leverage existing and developing capabilities from the region's universities involved in energy research.

Stakeholders include the recently established Energy Research Accelerator (a partnership of 6 Midlands universities and the British Geological Survey), BCC, and the Energy Systems Catapult in Birmingham.

The foundation of this development is the Tyseley incinerator. Built in 1996, it is an iconic building that courted controversy in some circles for allegedly contributing to climate change, causing air pollution and reducing recycling rates in the city. Yet its place at the heart of the Tyseley Energy Park highlights the interconnectedness of several city systems and wider environmental systems, and proves the need for a remarkably broad view of the costs and benefits when dealing with waste.

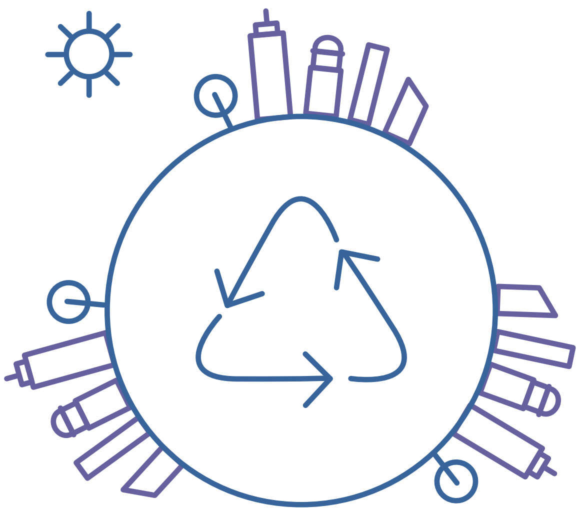


While climate change and human health are vitally important issues that can manifestly be improved by well-designed interventions in waste systems[1] – and there are methods for analysing the multiple benefits that might be delivered by such designs[2] – they lie beyond the scope of this chapter.

This chapter is limited to solid waste that emerges as a result of our city systems and the way people in cities live and behave. Accepting that a change in citizen behaviour (see Chapter 9) can fundamentally alter this pattern of waste generation, it should be recognised that waste in cities is a partnership between individuals and the city itself. At the household scale, this partnership relies on those who create the waste both sorting and presenting the waste to the city operatives, and the city operatives removing that waste and returning the vessels in which it was presented back to the owners. Given that this is a partnership in which the individual makes a direct economic investment, via local taxation, one might expect that the individual would assume some joint responsibility, and even enthusiasm, for participating in this process. However, the converse is often true: the waste system is implicitly or tacitly considered to be the responsibility of the state, as represented by the local authority (see Chapters 12 and 13). This transfer of ownership of responsibility to the local authority is one reason why citizens sometimes disengage from the operation of the waste system. One way to partially address this issue is to make clear that the citizen is not only paying for the service, but that the cost would reduce by improved citizen behaviours. Although this is a city issue, it is also covered in Chapter 12.

An important feature within this process of creating waste is property rights. Once something has been purchased and ownership (or unrestricted rights to its use) transfers to the individual, then the individual might feel reluctant to release it back into the system if it is considered still to have a value. This can translate into storage within the house (in drawers, cupboards, garages or lofts). It can even translate into storage in self-storage units, which allow individuals to occupy more space in cities. This contributes to the balance of stocks and flows in cities: something that might have utility, and hence value, for someone else is being prevented from being utilised by others because of 'property rights', and it becomes locked in as part of the city's stock. This point lies at the heart of the balance between individualism and collaboration, cooperation and community – the essence of cities. For example, there is an argument that the urban fabric of cities can encourage us to share more and, in doing so, create a more resilient society[3].

The value that individuals place on materials and waste could be greatly influenced if they read the 'Story of Stuff'[4]. This makes explicit the 'externalities' of products – the waste that is generated in creating materials – and implicitly changes the value that we place on waste. If waste is a state of mind, then education is the key to changing that state of mind. But in order for this to be effective, the value of materials and waste has to be properly understood and the messages have to be taken to heart. However, the personal actions of a few well-informed citizens alone are rarely significant, and thus cities have a role to play in fostering this understanding and bringing about collective change.



The waste system will have **common components** in different cities, but each city exists in a **unique context**

City waste systems

1. Waste in a city context

It is helpful to consider all of the processes associated with waste as a system[1], which allows us to create system maps and identify the influences on this system. The waste system is one of a number of city systems, most of which are interdependent to a lesser or greater degree: intervene in one, and the others are affected in some way. The waste system will have common components in different cities, but each city exists in a unique context, having developed as a result of different local histories and geographies, and these local contexts will be reflected in the waste system for any particular city.

Moreover the contexts are changing, in some cases remarkably rapidly, and these changes need to be considered if the systems are to operate effectively in both the near and far future[5]. The two primary local contextual change influences on waste (population growth and urbanisation), combined with a global trend of an increasing middle class – 'global gentrification', perhaps – is fuelling the progressive growth in the volume of solid waste that cities produce. While cities generated approximately 1.3 billion tonnes of solid waste in 2012, it is estimated this will increase to 2.2 billion tonnes per annum by 2025 (ref. 6). This might (or might not) represent a serious challenge, depending how waste is dealt with. For example, it could be viewed as an increase in potential resource, as opposed to an ever-greater volume of material to be treated, stored or otherwise taken out of circulation.

It is important, therefore, that waste systems are resilient (ie they continue to function effectively in the face of change), so that they are sufficiently flexible and adaptable to accommodate change. These issues of context and nimbleness in response to contextual change provide lenses though which city waste systems should be viewed.

2. City waste categorisation

Of the five waste sectors covered in the report (Chapters 4 to 8), those most obviously relevant to cities are household and municipal (which can include the waste arising from gardens, parks and green infrastructure maintenance, or 'green waste'); industrial and commercial; and construction and demolition. However, the other two sectors – agricultural waste, and mining and resource extraction – also have strong links to city life.

Waste can be classified in many other ways[7]: by physical state (solid, liquid, gas); and then within solid waste by original use (packaging waste, food waste etc); by material (glass, paper etc); by physical properties (combustible, compostable, recyclable); by origin (domestic, commercial, agricultural, industrial); or by safety level (hazardous, non-hazardous). More fundamental questions around what constitutes waste underpin all of these options (see Chapter 1). But to create effective and affordable waste management systems, conceptualising waste as lying on a spectrum of value, from a potential resource through to a hazard, can help in developing business models for dealing with waste. However, partly in response to the fact that each city operates in a unique context, there are many different models currently being adopted in UK cities. This is unhelpful in both translating good practice between cities, and engendering a common understanding amongst citizens of how to interact with the waste systems.

This chapter adopts a general term – municipal solid waste (MSW) – to refer to the combined waste stream dealt with by local authorities. It includes the waste collected by local authorities themselves; the waste generated in the delivery of local authority services; as well as that deposited at local recycling points and rubbish tips, including small-scale construction waste. MSW, as for liquid waste, is usually dealt with locally, and the 'system boundary' for waste can generally be considered to be either the city or city-region boundary. Waste that crosses these boundaries can be characterized as an element in a national or global waste system, and might be expected to differ in terms of being high volume, high value or hazardous.

As with cities, rural waste will be context specific. However, cities will generally combine many activities so that the sum of the waste outputs might be similar in content, if not necessarily in relative volumes, from city to city. In contrast, rural waste has the potential to vary to a far greater degree. This simply emphasises the needs to appreciate the current local contexts and their potential for future change.

3. City waste dependencies

A systems view of waste, which makes clear the dependencies and interdependencies with all other city systems, enables rigorous analyses of the beneficial synergies and adverse consequences of taking actions on waste in cities. A MSW system map can take different forms, each illustrating different features of MSW management and the opportunities that are afforded. A dependency diagram for MSW provides a graphic illustration of exactly how complex the waste system is, and how difficult it is to design and manage effectively (see Fig. 1). Yet this cannot be considered to be complete, for two reasons: each professional could add more features from his or her perspective; and every unique local context will potentially introduce additional dimensions that need to be included.

4. Influence on local, national and international agendas

The dependencies and interdependencies illustrated in Fig. 1 demonstrate how the conception, design and operation of a city's waste system can positively influence other agendas. The core considerations when planning an integrated MSW system include: a city's vision with regard to resources; political stability and support; scale of operation (and whether there is a 'critical mass' of material to make an alternative business model effective); adequate funding; enabling legislation; and support of the citizenry[9]. Several of these factors are necessarily related to the nation's, city's and citizens' goals, so there are multiple potential benefits that can be derived from a well-planned and operated waste system (see Chapter 4).

More specifically, there are six broad groups of drivers for development in waste

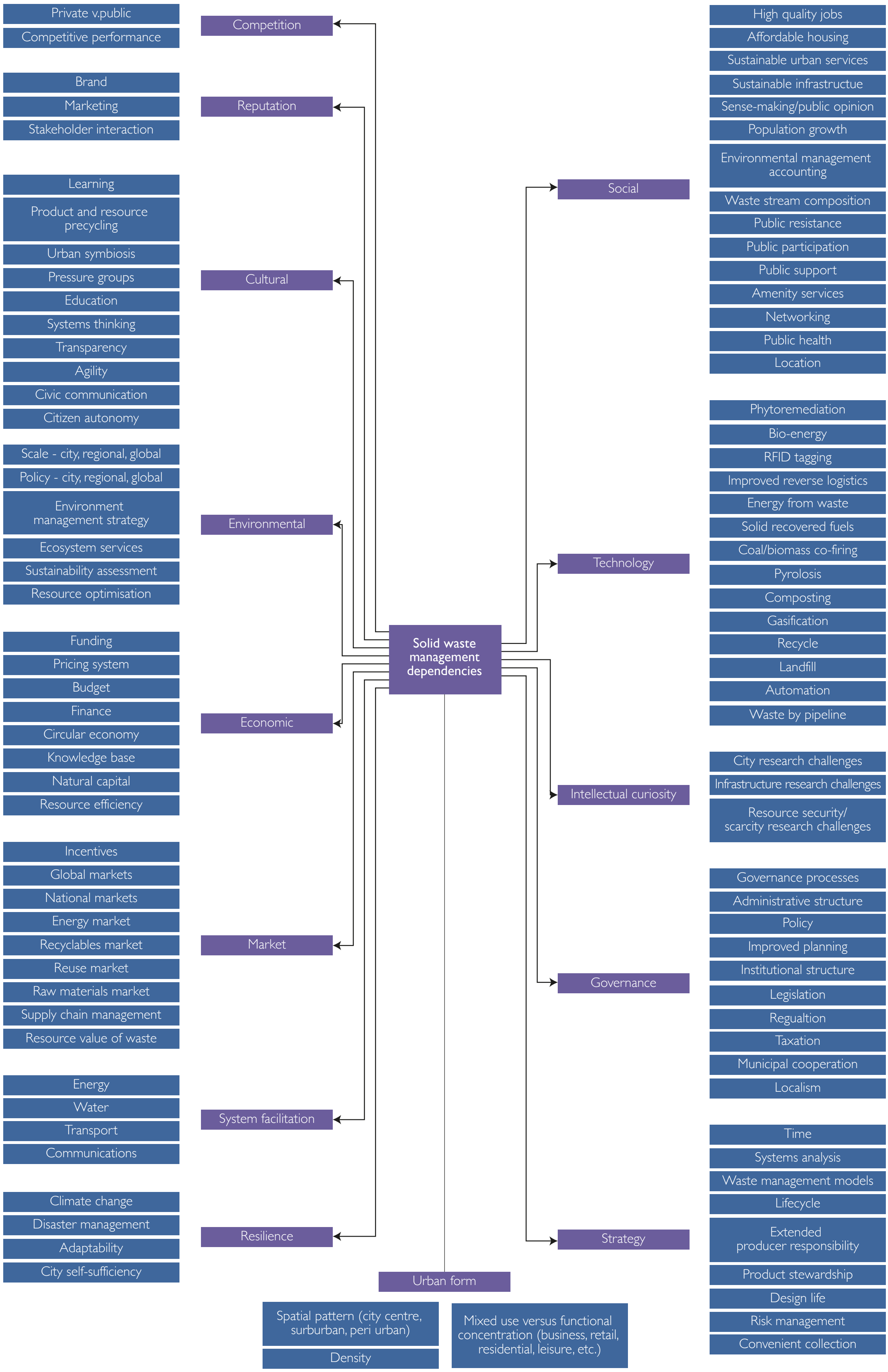


Figure 1: *Municipal solid waste (MSW) management dependencies*

Source: Adapted from ref. 8

Making space for **waste** is an integral aspect of modern **urban design**

management[10]: public health; environmental protection; the resource value of waste; institutional issues; responsibility issues; and public awareness. In the UK, public health is largely taken for granted and is perhaps no longer a strong driver. But environmental matters continue to exert a strong influence, evidenced for example by legislation to mitigate climate change (global impact) and requiring application of best available technology to waste treatment (local impact).

The hierarchy of waste (see Chapter 1, Figure 3 on p16) helps to establish its resource value, incentivising reuse and recycling, sharing[3] and reducing waste production (local and national resources impact). Institutional concerns have served as a driver for inter-municipal co-operation, to realise economies of scale, and hence engender cooperation across city boundaries (regional impact), while the concept of extended producer responsibility raises questions of who owns the problem of waste (business impact). Public awareness forces waste management onto the political agenda (local and national impact). Cities have their own visions, while citizens have their own aspirations and political influence – in seeking to achieve these visions, all of the city systems should be constructed to contribute positively. The idea that multiple benefits beyond the waste system can, and should, be realised when changing systems in cities is enabled by many sustainability assessment frameworks. For example, the SPeAR model[11] assesses performance under the 4 broad categories of economic, social, environmental and natural resources, and this is helpful from the 'waste as a resource' perspective. It is also enabled by consideration of the indicator systems used to measure city performance[12].

Interdependencies between waste and other city systems

1. Infrastructure interdependencies

The interdependencies within a systems view of waste depend on key elements that include inputs, outputs, functions, controls and mechanisms.

Inputs are consumed in the execution of a function, such as managing solid waste. This function often depends on four core infrastructure systems: energy and water, which usually act as inputs; and transport and communication, which act as facilitating mechanisms. Other features of the system, such as maintenance schedules and operating rules, control how the function operates. In general, a dependency exists between two parts of the system if an output from one forms an input to the other.

Figure 2 shows two examples of these interdependencies – using MSW to generate energy, and as a feedstock for metal recycling

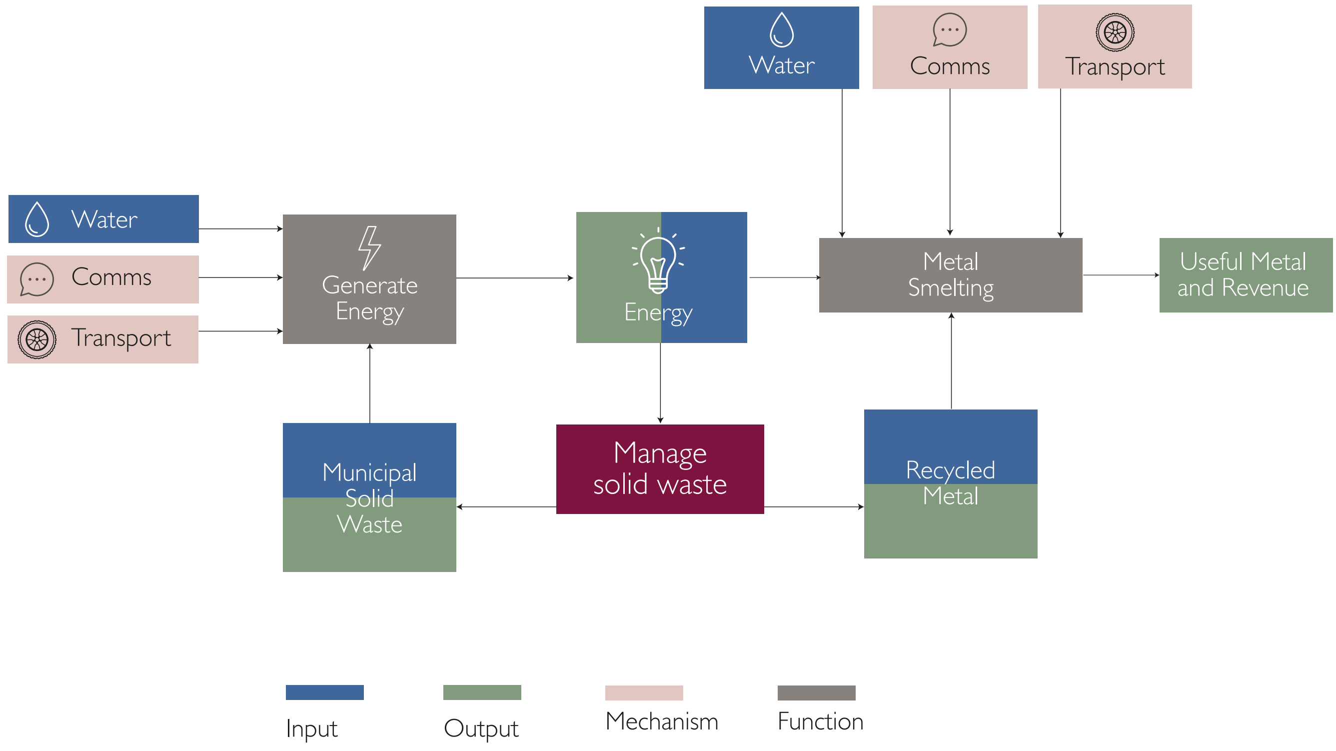


Figure 2: *Examples of solid waste management interdependencies. In the first example, the Generate Energy function requires the input and consumption of water, along with the mechanisms of transport and communications. This yields an output of energy, which becomes an input to solid waste management. In the second example, recycled metal is an output from solid waste management, and becomes an input to the Metal Smelting function; energy and water are inputs to smelting, and communications and transport are mechanisms.*

Source: Christopher Rogers and Christopher Bouch

– but a full system map might show dozens of such relationships, including glass, paper, packaging, and so on. Such a map reveals the opportunities that might arise for capturing value from the system processes, and thus the basis of business models.

There are many MSW dependencies depicted in Fig. 1 that do not explicitly feature in Fig. 2, yet nevertheless influence how the system works. For example, the urban fabric (ie buildings and streetscapes) will dictate how, and how effectively, the system operations are carried out from the waste operator's perspective. It also determines the magnitude of their resource requirements, both as they exist now and how they might develop in the future (ie taking account of demographic and other contextual changes). Moreover, the influence of the urban form extends to particular challenges associated with living at high density: how much space is available for sorting and storing waste, and how this differs with different living densities across a city. Making space for waste is an integral aspect of modern urban design, and yet finding spaces for different categories of waste is far from straightforward in urban areas that have evolved over decades or centuries – similar to the problem of providing car parking in dense urban streets that were built without car parking in mind. Importantly, these spaces need to be convenient for users. Where space is a challenge for individual households, communal collection areas provide an alternative, and if used well these could improve citizen behaviours; they might, indeed provide an opportunity for beneficial change. The more traditional approach can involve adverse social consequences: collection boxes or bins blocking pavements, in some cases being unsightly or odorous; waste and recycling collection lorries disrupting pedestrians and traffic etc. One means of removing such inconveniences is the adoption of 'waste by pipeline' (see case study on p161), the business case for which requires a complete appreciation of the local system (inter)dependencies. Such a system is, perhaps, easier to introduce in larger new developments than by retrofitting, although a combination of political will and a compelling business case should not be overlooked in the creation of sustainable systems for the long term.

Case Study

Industrial symbiosis in UK cities

Dr Rachel Lombardi and Peter Laybourn, International Synergies Ltd

In 2012, half of UK waste was generated by construction and demolition (C&D), a further quarter (24%) came from commercial and industrial (C&I), while households contributed 14% (ref. 1). This mix of sectors determines not only the composition of municipal solid waste (MSW) but also the political and legislative framework that creates its context: ownership, value, potential for reuse, and so on. Consumer-focused techniques such as kerbside recyclates collection and pay-as-you-throw aim to incentivise a certain consumer behaviour to reduce MSW generation. In contrast, C&I and C&D waste reduction is incentivised through permitting, regulations and policy instruments such as landfill tax.

Industrial symbiosis is the practice of identifying productive uses for resources otherwise going to waste, thereby moving them up the value chain. Currently, this approach deals primarily with C&I waste because it generally provides relatively homogenous material streams that are suitable for reuse. The same tactic has proven effective with C&D waste materials.

In the UK, Birmingham was the first city to explicitly include an industrial symbiosis approach to regional economic development in its Big City Plan in 2011. Birmingham City Council commissioned International Synergies Limited to analyse existing resource flows, infrastructure and economic activity; and then identify strategies to improve resource efficiency, and find opportunities for the strategic economic development of a development site at Tyseley. As the proposed actions were based on local resources, skills and infrastructure, the analysis produced a bespoke, sustainable solution that was grounded in the local context.

This type of analysis structures opportunities into 3 time horizons:

- Today, when both resources and reuse solutions exist
- Tomorrow, when solutions are known but not yet in place. This presents opportunities for inward investment and expansion to complement existing resources or infrastructure
- Future vision, providing the strategic compass for activities today and tomorrow.

In Birmingham, 2 key themes emerged: metals recovery, building on Birmingham's long history with metals fabrication and manufacturing; and low-carbon fuel opportunities, to meet Birmingham's ambitious carbon reduction commitment of 60% by 2027 (see case study on p150). The potential economic, social and environmental benefits from the industrial symbiosis opportunities we identified were estimated to generate: 400 to 500 direct jobs; a reduction of 55,000 tonnes of carbon emissions per year; cost savings in excess of £1.9 million per year for existing businesses; additional revenue for Birmingham-based businesses of £8 million to £10 million per year, with a total gross value added (GVA) impact of around £12 million to £15 million per year. In the four years since the study, Birmingham City Council has established the Tyseley Innovation Network; a wood-based gasification facility has come online; and the city's waste strategy is being reviewed – using an industrial symbiosis approach – to find further low-carbon opportunities. Tyseley is becoming a must-see for industrial 'tourists'.

In the borough of Basildon, Essex, we conducted a similar analysis to determine the transformation potential of Burnt Mills Estate using eco-industrial park principles, including industrial symbiosis. Short-term opportunities were identified to develop local markets for secondary materials, prioritising wood, secondary aggregate materials, plastics and waste electric and electronic equipment (WEEE). In the intermediate term, the analysis highlighted opportunities to invest in low-carbon energy technologies for the area. Based on a 5-year plan to turn the estate into an eco-industrial park, initially via a resource recovery hub, the potential economic, social and environmental benefits were estimated to generate: 187 direct jobs; a reduction of 381,000 tonnes of carbon emissions per year; cost savings in excess of £2.2 million per year for existing Burnt Mills businesses; £142 million of private investment; and 132,000 tonnes of landfill diversion.

This bespoke approach to regional economic development through intelligence-based industrial symbiosis (RED IBIS[2]) is gaining traction outside of the UK, particularly in China and Turkey.

2. Modelling and operational processes

Waste management strategies have changed over time. At first, waste was simply dumped outside city walls; then it was removed by flowing water (with highly unpleasant consequences for major rivers in cities such as the Thames[13]); and more recently it has been used to fill convenient holes in the ground (landfilling in disused or worked-out quarries). Once such spaces had been exhausted, and the recognition that space has a value took hold, a more forward-looking set of business cases started to emerge (see case studies on p150 and p157). This sequence demonstrates how a change in values of waste, space and the systems with which they interact, leads to very different processes.

Various models have been developed to help cope with the complexity of MSW management, although a 2004 review found that none of the models had considered the complete waste management cycle, from the prevention of waste through to final disposal[14]. A recent comprehensive approach to systems modelling attempts to put this right, but in so doing it requires nearly 900 pages[1]. A middle path between the incomplete and the very detailed is needed.

Lifecycle thinking is a concept that is getting increased attention worldwide, and has the advantage of being linked to sustainability principles[15]. Some people caution that a focus on the waste hierarchy principle may not produce the most sustainable waste management solution for all situations[7]; instead, an integrated, lifecycle approach should be used, which models the whole solid waste system, including any combination of options (see below), to provide both an environmental and economic overall assessment. Once again, this emphasises that a 'whole system' view is needed.

Other approaches to modelling include a combination of the established practices of pre-cycling (ie reducing waste by avoiding bringing any items into homes or businesses that will generate waste); along with circular economic policy and recycling insurance (ie insurance that limits a producer's liability for unknown future recycling costs to a known current premium). A new economic instrument – 'pre-cycling insurance' (ie a generalised form of recycling insurance that supports all forms of pre-cycling) – has been proposed, so that decision-making can be led by the market rather than by prescriptive regulation or educational campaigns[16].

Moreover, the system maps do not necessarily work the same in both directions. For example, recycling requires its own 'reverse' logistics channels, which differ in several respects from forward logistics flows (ie those from producer to consumer, often via some sort of retail supply chain). It is unusual for products to be returned to a shop for recycling purposes, so rather than flowing backwards through the same channel, a reverse channel has to emerge, or be created, for recyclable material to accumulate, transport, and process the material for remanufacture into a recycled product[17].

3. Options and technologies

There are a number of general concepts currently associated with effective waste management, all of which are playing, or have the potential to play, a role in MSW management in cities. These concepts will fundamentally influence waste system maps. One obvious example is eco-design, which aims to extend a product's use period; make it easier to disassemble, repair or upgrade; and manufacture the product from materials that can serve as inputs to another process[6]. Other straightforward examples of system influence[6] include:

- The Green Economy, which has a focus on "improved human well-being and social equity while significantly reducing environmental risks and ecological scarcities", hence linking strongly to environmental systems.
- Resource Efficiency, which involves rethinking from the perspective of the resources that go into each stage of a product or process.
- Cleaner Production, with its explicit focus on reducing the use of hazardous substances in products and their production processes, and generation of emissions and wastes.
- The Lifecycle Approach, which moves thinking from 'cradle-to-grave' to 'cradle-to-cradle'.
- Eco-Innovation, which can take many forms.

Other concepts that adopt a more nuanced approach can alter the balance of the system map in a more fundamental manner. For example, providing a 'product as service' relies on business models in which the consumer buys the service provided by the product, rather than owning the product itself. This can support the return of valuable materials into production[6].

Similarly, waste treatment technologies will influence the system maps, each having its own particularities[1]. These include phytoremediation, bioenergy, radio-frequency identification (RFID) tagging, improved reverse logistics, energy-from-waste, solid recovered fuels, coal/biomass co-firing of thermal power stations, pyrolysis, composting, gasification, recycling, landfill, and automation. Taking the energy-from-waste (EfW) example, research using geographical information systems and multi-criteria analysis modelling has compared the impacts of several UK EfW strategies. The different strategies were defined by the size and number of the EfW facilities, as well as the technology chosen, including conventional incineration and advanced thermal treatment. The conclusion was that distributed, small-scale EfW facilities scored most highly on the chosen decision criteria, and that scale is more important than technology design in determining overall EfW policy impact[18]. This is a good example of how whole system mapping is needed to arrive at the optimum outcome.

4. Business models

Any cost-effective waste management strategy should consider all forms of cost (monetary and adverse consequences of any type); all forms of value (whether economic, social, environmental etc); and various forms of investment, such as economic or social capital (see Fig. 3 for a generic approach). Furthermore, the business models associated with the strategy inevitably influence the system maps. For example, increasing concerns about the protection and improvement of the environment has transformed environmental commitment into a new strategic channel through which to achieve competitiveness in firms[19], strengthening the linkage to environmental systems. An interesting example of where system mapping could enable change is in the case of green supply chains, which have been shown to save resources, eliminate waste and improve productivity. However, it has also been found that many companies are not radically changing to more sustainable environmental practices despite pressure from the investment community, the government and consumers. This is attributed in part to the difficulties in measuring and tracking the successful implementation of a green supply chain[20].

5. Culture

Sustainable development, which is closely tied to effective waste management, calls for a shift in the way in which natural capital is managed and used. Much effort has been expended analysing the sustainable development process, and mechanisms by which natural capital levels can be maintained. Cultural capital (non-financial assets that support social mobility, such as education) is an important, but much neglected, element in this process[21], and yet this too will influence the balance of system maps because a failure to acknowledge the views of citizens can compromise the effectiveness of proposed interventions.

For example, cultural issues often affect the

Proportion of UK waste generated by households in 2012

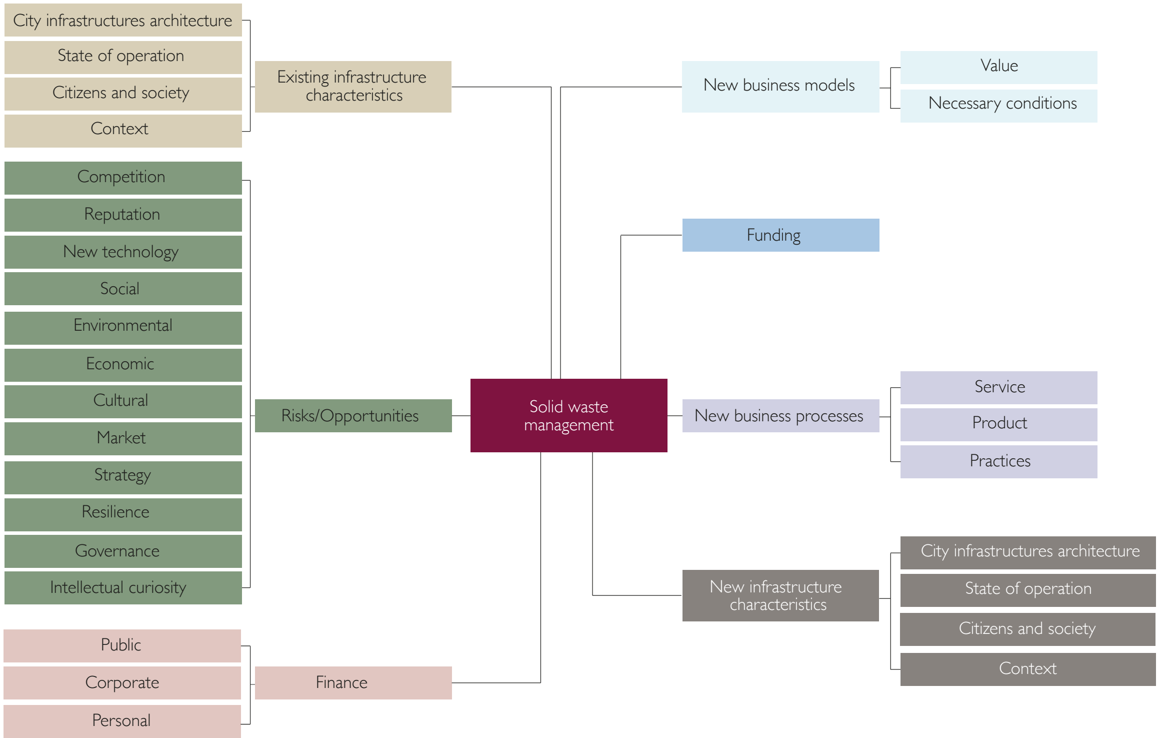


Figure 3: *Factors to consider when exploring alternative MSW business model opportunities. The characteristics of the existing infrastructure system, together with an understanding of the current context in which the system is operating (the risks and opportunities of doing things differently, and the current sources of finance) need to be understood before proposing new business processes, business models and/or funding mechanisms, which in turn will often result in new infrastructure characteristics.*

Source: Christopher Rogers and Christopher Bouch

siting of waste management facilities in densely populated countries like the UK. In a study of a waste incinerator in Japan, where development land is in similarly short supply, the affected population's principal concerns were pollution and the potential for an adverse effect on health. Consequently, social acceptability proved a dominant feature in the planning and operation of the waste system, making it necessary to work closely with local residents. This then had to be reflected in the systems map[22].

The current trend of 'closing the loop', moving from the concept of 'end-of-pipe' waste management towards a more holistic resource management, similarly influences the system map, in this case in favour of an emphasis on institutional and responsibility issues, and public awareness influencing the political agenda[10].

6. Governance

Civic engagement is another important factor in the successful development of plans for waste management in cities, and hence the governance processes, once more emphasising the interconnectedness of the components of the system maps. Social capital parameters such as social trust, institutional trust, social networks and compliance with social norms need to be considered[23], and it is important for waste management policy to be co-created with the public and other stakeholders[24]. Finally, integrating regional and global environmental concerns into urban policy and management practices remains a challenging issue because of the inherent temporal, spatial and institutional scale mismatch between urban policies and regional and global environmental issues, and these likewise must feature in the system map[25, 26].

The future of cities and waste

Any predictions about the changing nature of waste, and the growth in waste volumes, involve some form of extrapolation from the past and present. While these predictions are both necessary and helpful in the short term, they have limited value for medium- and long-term guidance. This is because contextual change is likely to alter the principles and rules on which the predictions or projections are based[27].

For example, alternative concepts for effective

Underground piped waste

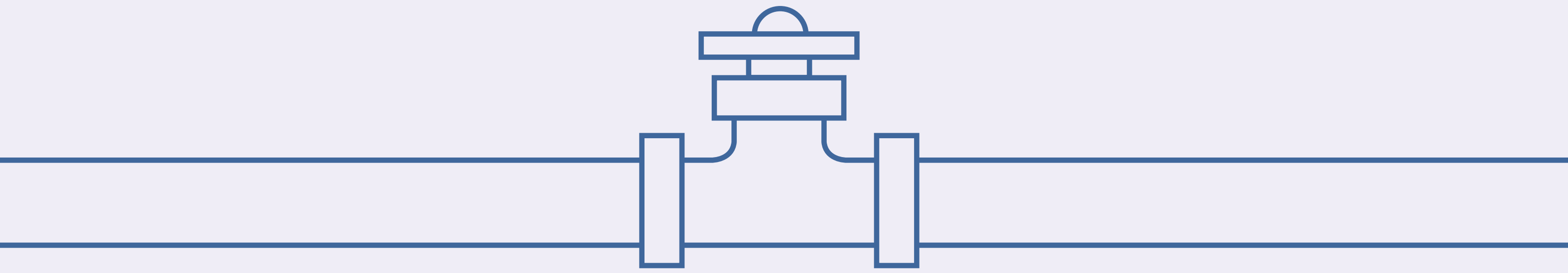
Dexter Hunt, University of Birmingham

In 2008, the UK's first underground pneumatic piped waste management system was unveiled as part of the highly prestigious £2.5 billion Wembley City development housing project. From 2008 to 2012, this ENVAC system moved more than 500 tonnes of waste from 700 residential and shopping units, increasing recycling rates by 50% compared to the London average, while reducing on-site traffic (and carbon emissions) associated with kerbside waste collection by 90% (ref. 1). The system is expected to serve 4,200 units by 2023.

The pneumatic system is not new, having been developed to move household waste in Sweden in the 1950s; a US patent was lodged in the 1960s. The fully automated system at Wembley consists of 3 parts[2, 3]:

1. A series of 4 waste inlets above ground: one for mixed recyclables with paper, one for food and organics, one for residual waste and one for card or cardboard. These are akin to conventional colour-coded bins that ensure the waste is separated into fractions. Additional inlets can allow for more fractions, which is the case for other examples around the world, including Barcelona. In total, there are 252 inlet chutes; they open twice a day, one fraction at a time, releasing waste into an underground, pneumatic piped network that literally sucks waste away. The process for emptying the chutes takes around 30 seconds.
2. This underground network moves waste at about 70 kilometres per hour from the disposal points to the terminal waste reception facility, located between the Olympic stadium and the arena. The same main arterial pipe is used for each of the waste stream fractions in turn. Routine maintenance and removal of blockages is facilitated by a series of observation doors located every 100 metres over its 2.52 kilometre length. During the waste movement process, accumulated impurities within the air are removed through a series of filters prior to its release into the atmosphere.
3. Once the waste arrives at the terminal waste reception facility, each fraction is directed towards $30m^3$ airtight containers. The waste is compressed so that it is ready for collection and transport through road haulage. Dry recyclables are sent to the Greenwich repurposing facility, organic waste is transported to the West London Composting facility, and residual waste is transported to the Edmonton incinerator.

Wembley City demonstrates a 21st century approach to domestic waste management. The system provides a clean, quick, and efficient way of dealing with waste, significantly reducing its environmental impact and reducing operational costs[4] while providing better social cohesion[5]. This 'three pillar' sustainability approach to waste has required the developer (Quintain) to take a long-term view with the investment to build, operate and maintain the 85 acre development.

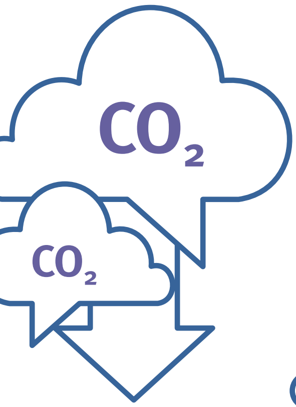


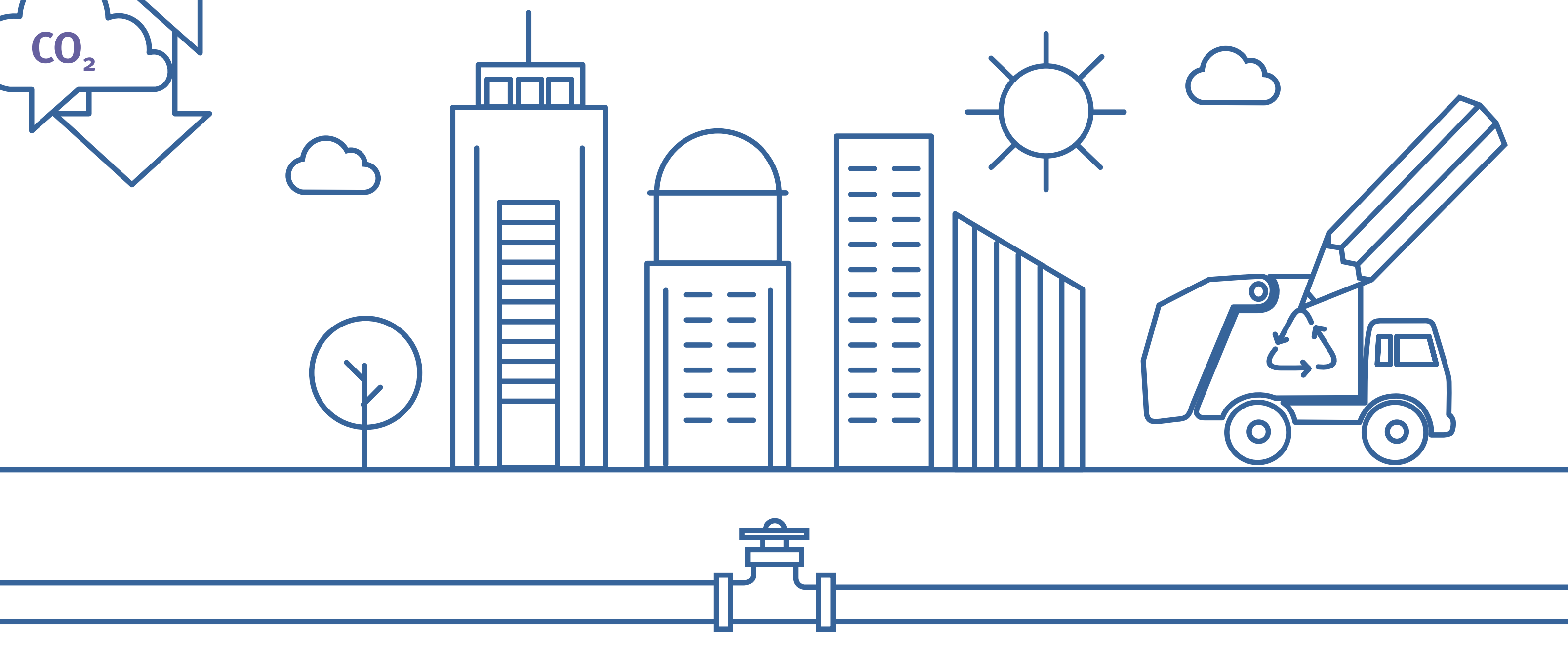
waste management in cities – including resource efficiency, the green economy, and the others listed under 'Options and technologies' on p153 – fundamentally alter the paradigms of waste, rendering predictions based on traditional thinking inaccurate. For this reason, 'scenario' approaches should be adopted. These use descriptions of a city operating in alternative, ideally radically different, ways in the far future. This releases thinking from the influence of current constraints, whether operational, financial or otherwise[28]. Future scenarios can be used to explore the possible consequences arising from an intervention if the city and the society that it supports changes from the present, and therefore makes it possible to design the intervention so that it brings about the desired benefits in the face of uncertainties[29]. Future scenario approaches are therefore able to test the resilience to future change of the policies, strategies and actions being taken today[2].

Cities are not the only segment of society that should adopt improved processes for the management of solid waste. But they have a unique potential to be sites of local experimentation and assessment, because they have distinct boundaries and forms of local autonomy and governance that make it easier to implement novel strategies for waste management. These factors make 'product as service' models particularly promising in cities[3]. As with other concepts, this approach must be translated into the local context of a city, along with changes to the relevant governance mechanisms. Yet the ideas of ownership of and joint responsibility for service provision in cities could provide a transformative step towards new citizen behaviours in relation to the efficiency and efficacy of service provision, including the reduction of waste.

We already know that sensor technologies can improve performance and efficiency in city systems, and could be employed beneficially to create 'smart' waste management systems. But taking a more holistic approach to waste management networks allows us to engineer 'truly smart' systems, in which changes to one system can bring about beneficial changes to the other systems it interacts with.

The author wishes to acknowledge the contributions to the ideas presented in the chapter of the iBUILD, Urban Futures and Liveable Cities research teams, and more specifically the contribution of Chris Bouch (Research Fellow, University of Birmingham) to the systems thinking and system maps.





This document is not a statement of government policy

CHAPTER 12:
Local Government

Councils across the UK have different recycling targets and statutory obligations, but they have all made huge progress over the past 15 years. Further gains could come from Extended Producer Responsibility schemes, which might be extended from packaging to other waste streams (such as food), in order to bring in the additional funding needed to achieve higher recycling rates. Meanwhile, directly charging households for waste services could spur beneficial changes in citizens' behaviour.

Lee Marshall, CEO of the Local Authority Recycling Advisory Committee

Local government involvement in the modern resource sector has its origins in public health issues. The rise of the urban population in Victorian Britain was not accompanied, at least initially, by the infrastructure needed to deal with the waste that these people were producing. The result was a rise in diseases such as cholera, smallpox and typhoid, prompting reformers to look at how the situation could be remedied. The first big step was the Public Health Act of 1848, but this only introduced voluntary public health measures; it wasn't until a revised Act in 1875 that local authorities were given duties in relation to wastes management.

Despite this drive coming from a public health rather than a resource-use angle, councils were still keen to keep resources in economic use. Organics and valuable materials like metal had thriving markets that also drew in private contractors, early forerunners of the big multinational waste companies that work for (and alongside) local authorities today. Over the years, the focus has moved from public health to resource efficiency, while the resources that local authorities collect from households has changed considerably: 'ash carts' have been replaced by 'multi compartment recycling vehicles', for example (see Chapter 4, Fig. 1).

The Environmental Protection Act 1990 governs the basics of local authority waste management today, laying out the requirements to collect and dispose of household waste free of charge. It also introduced key drivers for increasing recycling, the concept of recycling targets, and recycling plans. The legislation and policies within the act have been built on and enhanced largely through European-wide legislation and various guises of the EU Waste Framework Directive, which has introduced landfill bans, the concept of following the waste hierarchy, and the requirement to collect different materials separately.

Through all of these developments, waste collection is arguably the service that councils are most associated with and judged by. Perhaps this should not be a surprise, given that it is probably the only public service that reaches every household in the UK on a weekly basis.

Current and future local government involvement in waste services

In the past five years or so, the pressures on local government services have changed considerably, becoming very focused on the level of service that can be provided by a diminishing funding level. Waste services have not been able to escape this squeeze and local authorities have, in some areas, taken tough decisions to radically change the levels and manner in which residents' waste is managed.

While the basic duty to collect, treat and dispose of waste remains across the UK, the policy drivers diverge as a consequence of the devolution agenda across Wales, Scotland and Northern Ireland. This means that councils in England are aiming for a 50% recycling level by 2020 but with no statutory duty to meet it, while Scotland and Wales do have a statutory duty to reach targets of 70% by 2025. Separate food waste collections are thus commonplace in the devolved nations, assisted by funding from the devolved governments in pursuit of their policies, while the business case for implementation across England remains much more difficult to make. This is just one reason why we have seen recycling rates in Wales touch 58%, while in England they are around 45%.

However, given that in 2000 to 2001 recycling rates in England were just over 11%, we can also see that huge progress has been made. When compared to other EU member states, the UK as a whole has come further in a shorter space of time. During this period, local authorities have also grappled with fast paced issues such as market price and quality fluctuations, Compulsory Competitive Tendering regulations and changing material streams. When viewed against this backdrop of changing market environments and an evolving policy context, the increase in recycling rates across the UK is a significant achievement that local authorities should win credit for.

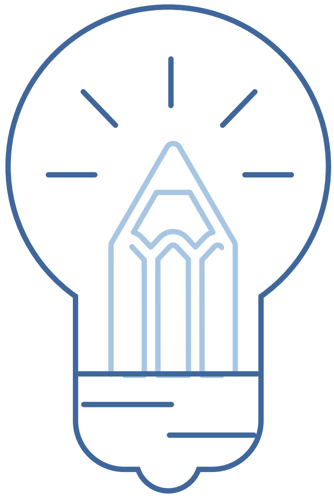
Local authorities continue to engage with government and other stakeholders to achieve continuous improvement, for example with the push to have more consistent collections (now expanding to look at consistency across design and reprocessing as well). There are differences in the ways that councils collect materials for recycling, largely linked to availability of local sorting facilities, end markets and the costs of collection. However, it is not the case that there are hundreds of distinct collection systems. WRAP group systems under three main headings in this area[1].

Two of the most visible changes to service provision are who provides the service, and how often it happens. Partnership working between local authorities has increased in recent years, in an effort to achieve economies of scale and efficiencies that protect or increase service provision to residents (see case study on p165). There are now several instances of two or three district councils working together with one set of officers to provide the same service across all their areas. There are also examples of this being done across whole county areas, notably in Somerset and Dorset where the partnership includes the county council responsible for the disposal of waste and the district councils responsible for the wastes that are collected.

These arrangements can take a lot of political will to progress, but have tended not to have gained a high profile or attracted comment from the general public.

The frequency of collections has been a much more contentious change to the way in which waste collections are being provided, and a clear indication of how councils are adapting to the new operating environment they face.

WRAP have undertaken studies[2] in the past that have shown that reducing the frequency of the residual waste collection increases the amount of resources captured for recycling, which is why the concept has been an option that local authorities have implemented in growing numbers. Where changes have occurred, it has sometimes been in the face of local and national opposition in the media, perhaps demonstrating that the reduction in public funding has been quicker than the public acceptance of its consequences. This can make the resource efficiency message, valid and important as it is, harder to get across to the general public.



What perhaps surprised people was the amount of **innovation** and **forward thinking** that was being undertaken by local authorities

Case Study

Waste collection in Newcastle-under-Lyme

Andrew Bird, Recycling and Waste Services Manager, Newcastle-under-Lyme borough council

Newcastle-under-Lyme is a waste collection authority located in Staffordshire. It is part of the wider Staffordshire Waste Partnership[1], an informal partnership involving all ten of the county's local authorities, nine waste collection authorities (WCAs), the waste disposal authority (Staffordshire county council), and the unitary authority of Stoke-on-Trent. They work together to provide cost-effective, quality services to the residents of Staffordshire.

The partnership developed a joint municipal waste strategy in 2004, entitled 'Zero waste to landfill by 2020', a target which it has now achieved. The vision was for each partner authority to achieve a recycling and composting rate of over 50%, and for the remainder of the waste to be dealt with at two energy-from-waste plants.

By 2009, the majority of the partner authorities were making good progress with their plans to reach the 50% target, but Newcastle-under-Lyme was lagging behind with a rate of 26%. The majority of other partner WCAs had introduced alternate weekly collections for residual and recycling/garden waste collections, but this was politically unacceptable to Newcastle-under-Lyme. In order to overcome this, a decision was made to look to introduce separate weekly collections of food waste, with dry recycling, garden, and residual waste collections being undertaken on a fortnightly basis.

This service was rolled out in 2010, with the authority procuring treatment of food waste through anaerobic digestion facilities, which at the time were limited in number. The dry recycling service was enhanced to include plastic bottles and card, but maintained a source-separated system, focusing on high quality (and therefore value) for the materials. Within a short period, the recycling and composting rate in Newcastle-under-Lyme rose to 52%.

In 2014, Newcastle-under-Lyme borough council started looking at options for revising its service, against the backdrop of needing to save around £0.5 million a year from its revenue budget. Thirteen options were modelled and considered before the council arrived at a final decision. As well as saving money, the council wanted to make recycling easier for residents, while maintaining the quality of materials collected.

The final decision was made to enhance the current service, retaining the source-separated system, but operating it weekly along with separate food waste, all collected using a single type of vehicle. Operation of the service has been bought back in-house, and the council has invested in building its own bulking and sorting facility, which means it can handle the recycling materials collected and then sell them directly to reprocessors. This is new territory for the authority, but maximising income is key to it making the necessary savings.

Initial indications are positive, with around a 30% increase in yields of dry recycling materials in the first month of the new operation. It is too early to predict whether this will be maintained, but the outlook is positive and a recycling rate well in excess of 56% is expected for this year.

Local government perspective on the European Commission's Circular Economy Package

The Circular Economy Package[3] is the latest drive from the EU to promote higher levels of recycling and better design of products to make them easier to repair and recycle. The broad aims of the package are to be applauded and welcomed, as most within the local government family want to see higher recycling levels and better resource efficiency. As with most things, though, the details of the package that have yet to be worked out will be crucial to its success, and will determine the impacts on local authorities.

While progress in England towards its current 50% recycling target has slowed, higher recycling rates in Wales and Scotland have been accompanied with directed funding in council recycling services in those countries. Local councils' spending on recycling has doubled since 2000, but government grant funding has fallen by 40% since 2010. Consequently, higher recycling targets will not be achieved if councils rely solely on further increases in government spending, and alternative funding methods will be needed if the UK is to adopt a 65% or 70% recycling target.

To reach a 70% recycling rate, virtually every household will have to recycle virtually all their packaging at the kerbside while also ensuring that larger items find their way to recycling routes through bulky collections and household waste recycling centres. They will also need to capture all their food waste separately. Given that local authorities have limited means to compel households to use the systems provided, there is still a reliance on the public to participate voluntarily in the recycling collection process. A recent report[4] in Wales highlighted how much recycling waste was still being placed in the residual container, suggesting that placing targets on local authorities will not achieve the desired end, and that a fundamental public behaviour change is needed instead.

There is also the issue of the cost of achieving these high levels of recycling. While increasing recycling obviously saves disposal costs, these savings in some instances may not always match the cost of collection. In two-tier areas (where one council is responsible for collection arrangements and costs, and a county council is responsible for treatment and disposal arrangements and costs), there may not be suitable methods of passing costs between the two, which just exaggerates the problems. To improve this situation, the Local Authority Recycling Advisory Committee (LARAC) and the National Association of Waste Disposal Officers (NAWDO) are working together and with others to look at ways to drive efficiencies for two-tier local government areas.

Elements within the package that aim to standardise how recycling rates are calculated make little difference to activities on the ground. They do, however, make learning lessons and exploring working practices from other European countries much more meaningful and useful. Adopting these standardised calculations may cause an apparent reduction in national recycling figures, depending on how the standard recycling calculation is reformed, but the potential benefits would outweigh this recalibration.

The circular economy proposals on Extended Producer Responsibility (EPR) is an area of particular interest to local authorities. This concept has the potential to bring in the additional funding needed to provide the comprehensive recycling services required to achieve higher recycling rates. The EPR concept states that the producer of a product remains

Recycling targets:

England
50%
by 2020

Wales & Scotland
70%
by 2025

For the past decade councils have been matching the **efficiency** and service levels of the **best private** sector operators

responsible for it after its initial use had finished – or, at least, responsible for funding the systems and infrastructures that ensure the materials embedded in that product are recovered and stay in economic use.

The UK has met its targets under existing Producer Responsibility obligations for packaging, using a system that has one of the lowest costs to producers in Europe. However, local authorities would argue that they have been covering some of these costs through the work they have done to expand kerbside collection systems, and that this diminishes the producers' responsibilities.[5] For example, Welsh local authorities spend nearly £250 million per year dealing with household waste. Approximately 20% of this is packaging, so public spending on packaging in Wales is £50 million. If this were scaled up across the UK, then spending would be in the region of £800 million per year. Yet the amount of funding made available through the sale of Packaging Recovery Notes (PRNs) is only £60 million per year, and not all of that finds its way to local authorities. So at present, producer responsibility for packaging receives substantial public funding.

Local authorities see the EPR concept as a potential means to redress this imbalance, pushing more of the costs back onto the producers and away from the public purse. Where the package is not clear is how EPR targets and household waste targets will complement each other and work together. An unintended consequence of the statutory nature of household waste targets in Wales is that local authorities will be putting resources into recycling packaging waste in order to avoid the potential fines that can be levied if they miss these targets. That could allow producers to lessen their commitment to recovering packaging, safe in the knowledge that local authorities will be increasing rates of packaging recycling to meet their targets. In other words, the producers will have no incentive to invest in household collection services in Wales. Local authorities need clear direction in the Circular Economy Package to ensure that targets on household waste do not override the concept of producer responsibility and put the onus back onto an already stretched public sector.

Best practice in local government

The waste management industry once regarded councils as inefficient, unresponsive and process driven. But this perception changed long ago, and for the past decade councils have been matching the efficiency and service levels of the best private sector operators, showing there is a place for both in the delivery of local services. A 2015 report that was commissioned by the Chartered Institution of Wastes Management (CIWM), supported by LARAC and NAWDO, and undertaken by consultant Ricardo Energy and Environment, looked at the impacts of austerity on councils' services, and how councils were responding to these challenges[6]. Inevitably, the councils had made cuts – but what perhaps surprised people was the amount of innovation and forward thinking that was being undertaken by local authorities in redesigning and improving residents' waste and recycling services.

As mentioned earlier, partnerships between local authorities have grown in recent years, demonstrating a willingness to put aside political differences to work for the greater good of local residents. Partnerships may be as simple as two neighbouring district councils in the same county sharing an officer resource, or could extend to a full scale realignment of complete waste services across a whole county, something that happened in Somerset, Dorset and Shropshire before it became a unitary authority.

A different example of partnership working occurs in Hertfordshire. While all the authorities in the county retain and operate their own collection services, they sell recyclable materials as a collective. This increases the tonnage of

Case Study

Waste disposal in Greater Manchester

John Enright, Head of Joint Working, Local Partnerships

In April 2009, the Greater Manchester Waste Disposal Authority (GMWDA) entered into a 25-year private finance initiative (PFI) contract with Viridor Laing (Greater Manchester) Ltd (VLGM). The contract involves £631 million of capital investment in new facilities for the sustainable management of about 1.1 million tonnes per year of waste collected by the local authority from 9 districts in Greater Manchester.

Under the contract, VLGM is responsible for constructing and operating 5 mechanical biological treatment (MBT) facilities using anaerobic digestion; 4 in-vessel compositing facilities; 1 materials recovery facility; 7 transfer loading stations; 20 household waste recycling centres (HWRCs); 1 combined heat and power thermal power station (TPS); and 4 visitor and education centres. The contract is guaranteed to achieve 75% diversion from landfill and 50% recycling rates by 2020, and GMWDA is working in partnership with VLGM to implement a long-term strategy that will exceed these targets. Through this partnership approach, landfill diversion rates in excess of 90% are potentially possible, giving environmental and financial benefits.

In 2011, GMWDA undertook a review of the 25 HWRCs provided under the contract, focusing on throughput versus design capacity; spatial distribution against population; customer surveys to determine travel distances; and a mapping exercise to identify any areas with insufficient capacity. As a consequence of this work, GMWDA decided to close 6 sites and construct 1 new facility in an area that did not have enough capacity. This exercise saved a net £600,000 per year in operating costs, and leaves us with 20 sites better able to meet the needs of our residents, whilst maximising recycling and diversion.

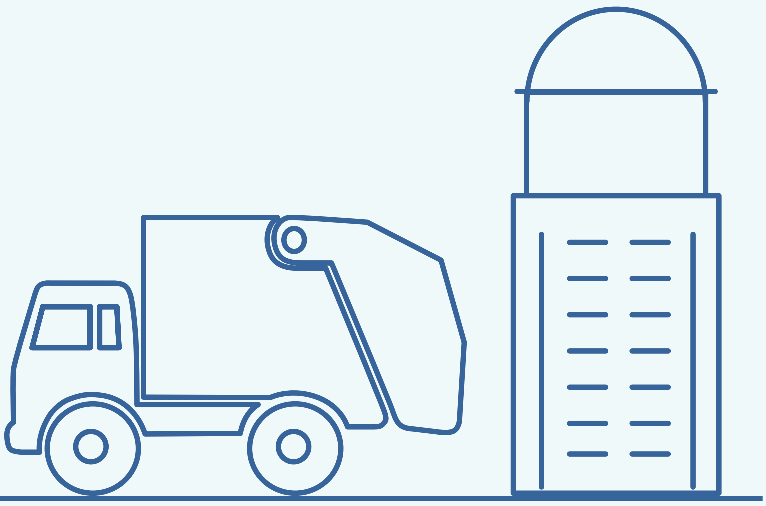
Reducing waste arisings has resulted in spare capacity being available in the residual waste stream facilities (both thermal and MBT facilities). GMWDA has therefore entered into agreements with a number of other local authorities to take some of their residual waste, making use of this capacity and generating an income stream. Over the last three years, roughly 200,000 tonnes of waste has been processed through the facilities under these arrangements, providing other authorities with access to modern, sustainable waste management facilities at a competitive rate and generating an income for GMWDA to help meet austerity targets.

Under the 2020 partnership vision with VLGM, the principal activity in 2015 to 2016 has been to identify waste streams destined for landfill that could have value recovered from them. Landfill costs are passed to GMWDA under the contract, so any additional tonnage diverted represents a saving to the authority. The partnership identified 60,000 tonnes to 90,000 tonnes of residual waste at HWRCs that was being landfilled directly. This material is now being processed by a shredder to create a fuel that can generate electricity and steam at the TPS, saving an estimated £3 million per year.

One of the key lessons learnt from this work

is that it is important to take a holistic 'cradle to grave' approach that looks at collections as well as disposal costs when considering options to change operations and reduce costs. A change in one area always affects the other, so waste collection authorities (WCAs) and waste disposal authorities (WDAs) must work closely together. Delivering savings requires all parties to have common purpose and aims, including the WDA, WCAs and contractors. This requires a long-term vision when considering options for savings, to avoid taking short-term decisions that have a negative impact on the ability to deliver sustainable waste management.

Waste collection is arguably the service that councils are most associated with and judged by



each material they can offer to the market, increasing their attractiveness to suppliers and improving their bargaining position. This results in a better price per tonne of material than if they had each marketed the material separately.

National conferences about waste have regular case studies showing how local authorities are innovating and changing their services, and local partnerships continue to support and highlight the advances that councils are making (see case study on p168).

Conclusions

A picture is emerging across the UK of different nations moving at different paces towards higher recycling levels. This is to be expected, given that waste policy is a devolved matter and has been for a number of years. It would be simplistic to suggest that all nations should adopt the practises and policies of the leader, as each nation faces a subtly different set of challenges and circumstances. For example, all councils in Scotland and Wales are unitary (meaning they control collection and disposal operations) whereas two-tier working is widespread in England.

That doesn't mean that certain policies and systems cannot be transferred. Comprehensive food waste collections in Wales have played a major role in pushing the recycling rate in the country close to 60%, and this success could be replicated elsewhere. However, this effort required a large financial investment, and each council must bear an ongoing cost, so it does not represent a cost saving in absolute terms.

Comprehensive food waste collections across England would go a long way to achieving the country's 50% recycling target. To facilitate this, the concept of EPR could be applied to food. This would enable funds to flow through to councils, and create a business case for separately collecting what is currently a low-value material. More should be done to support the energy generating aspects of anaerobic digestion (AD - see Chapter 6), which could reduce the fees that councils pay to AD plants to accept food waste (known as gate fees) and help to support the business case.

The different parts of the product design, use and disposal chain are still quite disparate, and true resource efficiency and circular economy thinking is not yet the norm. Some steps are being taken in this direction (see Chapter 10), but with so many industries and parties involved any progress in the future is likely to be made in small, incremental steps. From the perspective of local government, other areas where EPR could have near-term positive impacts include mattresses, paint and carpets (which currently end up at household recycling sites and are therefore a cost to the local authority and so divert resources from other services). While additional costs from this would result to business, they would fall to the source of those costs (the producer) and promote desired environmental and resource productivity outcomes.

There also needs to be some robust but constructive and opened-minded conversations across the sector regarding some potentially big policy areas. If councils expect more funding to come to their services through EPR then they should expect those providing that funding to want more involvement in the design and implementation of those services.

It is also the right time for the UK to explore radically different approaches as to how the costs of waste collection and disposal might be met and the impacts these might have on behaviours. Historically, the Landfill Tax (see Chapter 13) was a big driver in increasing recycling but in recent years the increases have tailed off. Equally, this Chapter has illustrated the significant funding challenges for local authorities. One approach worthy of further examination is direct charging of households for waste services. It could be argued that waste collection is a utility, and should therefore reflect other utility arrangements. Forms of direct charging are commonplace in a number of European countries and have been for a number of years (see Chapters 11, 13 and 14). The concept on a small scale has been around for some time in the UK for bulky waste items and is also being used to charge residents for garden waste collection services. The conversation about direct charging often focuses on the challenges and negative consequences (such as health and environmental risks that could arise from alternative forms of disposal), without seriously considering the potential it could have for improving citizen's behaviour towards their consumption and waste activities, and how the public sector recovers the costs of these services. Without a step change in consumer behaviour towards recycling, higher levels will not be achieved and sustained. Given that widespread charging for garden waste collections is already in place, a limited form of direct charging is already happening in the UK. If we are to extend that practice to other wastes, the key issue will be to decouple waste collection services from Council Tax.

If we restricted our view to the past two years, it would be easy to suggest that local authorities in England have not advanced the recycling and resource agenda. Over the past 15 years, however, they have taken large steps forward and driven a massive change in kerbside recycling services. The proposed Circular Economy Package is currently on the table, but with the UK set to leave the EU there is currently no clear view if it will form the cornerstone of the next 20 years of waste policy in the UK. It is therefore a crucial moment to look back at how the policy and delivery environment has changed since the Environmental Protection Act 1990, and reflect on how policy needs to evolve to make sure local authorities can continue to deliver the kind of positive change that has seen them take recycling levels from 3% to 45% across the UK during that time.

CHAPTER 13: National Government

Increasing resource productivity by reducing, reusing and recycling waste could contribute to economic growth and reduce environmental impacts. Three types of national-level policy options could achieve this: pricing and market-based approaches; regulatory approaches; and strategic approaches. This chapter offers detailed policy recommendations in each of these categories, supported by extensive evidence of what works from around the world.

Professor Paul Ekins and Dr Nick Hughes, Institute for Sustainable Resources, UCL

Introduction: why should policymakers be interested in resource productivity?

Resource productivity is a measure of the effectiveness with which an economy, or sector of the economy, generates added value from the use of resources. It can be expressed as the ratio of economic value (or output) to resource consumption (or input). Put simply, resource productivity amounts to getting more value out of the same, or less, resource input. From the perspective of the national-level policy maker, resource productivity is important for several reasons.

1. Contributing to economic growth

Increasing resource productivity increases the amount of wealth that can be generated from any given amount of resource – in other words, as with labour productivity, higher resource productivity contributes to wealth creation. Strong evidence for this assertion is provided by recent modelling for the International Resource Panel (IRP), an expert group of scientists founded by the United Nations Environment Programme (UNEP). It found that resource efficiency policies could boost GDP within G7 countries by 3% by 2050, compared to a business-as-usual scenario. For the world as a whole, the economic boost is even greater: up to 6% higher gross world product (GWP) by 2050, compared to business-as-usual[1].

For the UK specifically, increasing the resource productivity of the economy could have significant effects in creating new skilled jobs in industry. For a number of decades, the UK has become increasingly import-dependent in terms of resources, as its economic structure has shifted towards one of import-oriented service-based activities. Since the 1990s, the share of manufacturing in the UK's GDP has declined, while services have increased[2]. This has had mixed effects. In some areas, especially the south-east of England, the services and financial economy has thrived, contributing to job creation and growth. In other areas, especially those traditionally linked to manufacturing and heavy industry, unemployment rates still tend to be persistently and substantially higher than the UK average[3].

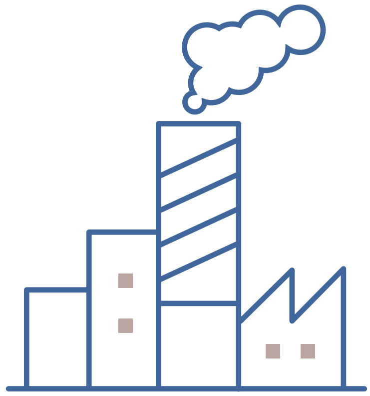
Resource productivity in the economy entails a shift away from simply importing products, and disposing of or exporting wastes. It involves retaining materials before they become wastes, and finding innovative ways of reusing them; as well as finding innovative ways to use fewer resources in the first place. Technologies such as 3D printing, practices such as eco-design and industrial symbiosis, and business models based around servicing, repair, remanufacturing and extended producer responsibility, are central to a resource productive economy, and all have the potential to create new jobs and reinvigorate the economy. Such new employment opportunities may be well correlated to the sectors and geographical regions currently experiencing highest unemployment, due to the good match between existing skill sets in areas of declining industry, and the skill sets required in new resource-productive jobs. As such the resource productive economy could create wider social benefits by redressing the structural imbalance of unemployment[3].

2. Resource availability

The availability and accessibility of different resources varies greatly. Some have large reserves, distributed across many global regions; in other cases, reserves are much less plentiful and under greater pressure. Access to some metals and minerals is further limited by the geographical concentration of economically recoverable reserves[4,5], and in the case of a vital resource such as water, in several regions of the world the rate of consumption exceeds the sustainable rate of renewal. Projections suggest that under business-as-usual conditions, overall global material resource demand will more than double by 2050 (ref. 1). Providing such quantities of resources may or may not entail absolute shortages of some resources, but the increasing challenges of delivering them through all the uncertainties of the business cycle would be very likely to lead to price spikes and volatility. A more resource-productive economy would not be as vulnerable to such price movements. Examples of resources and materials with particular availability concerns are water, land and biomass, with increasing uncertainties due to climate change; some metals, including those considered 'critical' due to growing demands and limited availability in nature, such as lithium and cobalt which are used in batteries[4,5]; and elements such as nitrogen and phosphorus that are important agricultural inputs[6,7].

3. Cost-effective greenhouse gas emissions reduction, and offsetting of other mitigation costs

The greenhouse gas (GHG) emissions generated during the production and manufacturing of products from resources and raw materials are substantial. Resource productivity has strong potential for cost-effective reduction of GHG emissions, especially when the GHG emissions of the whole resource lifecycle are considered. A clear example is the comparison of the production of recycled metals with metal produced from ores. For some metals, recycling can reduce energy demands by as much as 90%, compared to metal produced from ores, with this energy reduction typically resulting in a similarly substantial reduction in GHG emissions[1].



Resource productivity may thus provide an **important justification** for re-shoring in the UK some industrial and manufacturing activities

Of course, if GHG emissions are measured on a production basis, then increased resource-productive industrial activity in the UK that substitutes for imports may increase UK emissions, while reducing those in the exporting country. But global emissions will be reduced, which is what counts for climate change mitigation. Resource productivity may thus provide an important justification for re-shoring in the UK some industrial and manufacturing activities in a way that is consistent with global decarbonisation objectives, as well as having important socio-economic benefits that are discussed further below (see 'Strategic approaches' on p179).

Part of the same modelling exercise cited above shows the contribution that resource productivity could make to the climate agenda[8]. First, in comparison to a business-as-usual scenario, resource productivity policies alone would succeed in reducing global GHG emissions by 19% in 2050, even without specific climate-focused policies. When resource productivity policies are added to a scenario that already has stringent climate policies, the GHG reductions are further enhanced. Whereas a scenario with only climate-focused policies reduces GHG emissions by 56% from 2015 levels by 2050, adding resource productivity policies pushes the reduction to 63%.

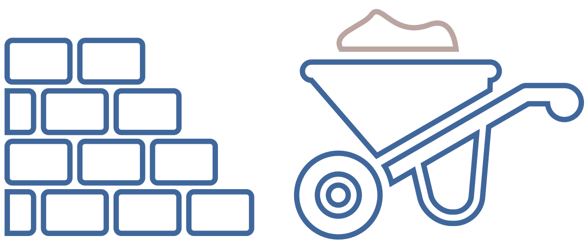
Furthermore, the modelling suggests that resource productivity policies could more than offset any costs associated with climate mitigation. Whereas the climate-policy-only scenario sees a GWP loss of 3.7% in 2050 compared to the business-as-usual scenario, the addition of resource productivity policies as well as climate policies sees GWP increased by 1.5% in relation to business-as-usual by 2050 (ref. 8).

4. Reduction in other environmental impacts

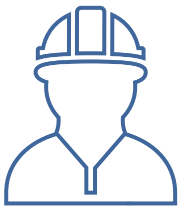
As well as GHG emissions, the use of resources produces other environmental impacts at every stage: extraction, production, use and disposal. These can include, depending on the resource: contamination of water and soil; destruction or degradation of productive land or ecological habitats; and airborne pollutants. The more productive use of resources is critical to enable humans to continue to extract and use resources, while reducing environmental impacts[1].

National-level policy approaches for resource productivity

Resource productivity policies as devolved to the local government level have been discussed in Chapter 12, and various other chapters have discussed the impacts of policies on particular sectors, for example household and municipal (Chapter 4) and industrial and commercial (Chapter 5). This section looks more broadly at national-level policy approaches to increasing resource productivity, with some examples of each type. It considers available national-level policy options in three categories[9]: pricing and market-based approaches; regulatory approaches; and strategic approaches. In each case, it draws on evidence of national-level policies implemented in the UK as well as in other countries.



An important economic driver of resource efficiency is the relative cost of **materials** and **labour**



Pricing and market-based approaches

1. Waste taxes and charges: The UK Landfill Tax, and pay-as-you-throw charges

The Landfill Tax was the UK's first explicitly environmental tax. The tax is charged at a 'standard rate' for waste that decays, such as household waste, which is known as active waste; and a 'lower rate' for inactive or inert waste, such as sand and concrete[10].

When first proposed by Kenneth Clarke, the Chancellor of the Exchequer at the time, in his budget of November 1994, it was suggested that the tax could be revenue-neutral, as corresponding reductions would be made in employer National Insurance contributions. In response to a consultation paper on the Landfill tax in 1995, local authorities expressed a number of concerns, including the lack of incentive the tax offered to householders to change their behaviour[11].

The Landfill Tax came into operation on 1 October 1996, at a standard rate of £7 per tonne and a lower rate of £2 per tonne. From 1 April 1999 the standard rate rose to £10, and an escalator of £1 per year was introduced for the subsequent 5 years.

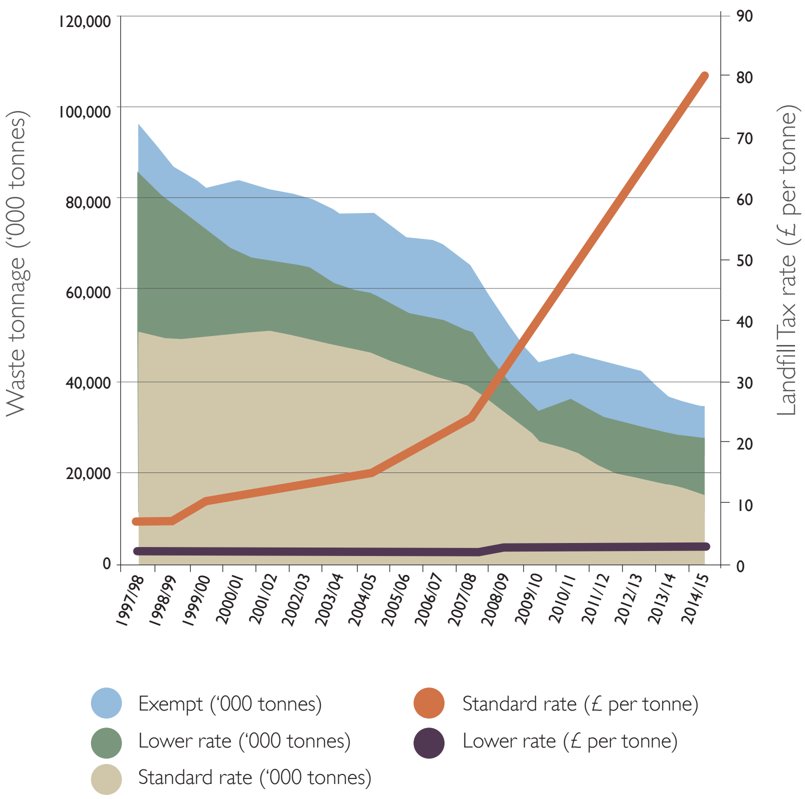
The government's 2002 pre-budget report promised to consult on a "revenue neutral" proposal to increase the escalator to £3 per tonne per year, towards a medium to long-term level of £35 per tonne[12]. In 2008, the escalator rose to £8 per tonne per year, with the lower rate rising for the first time, to £2.50. The Economic Secretary to the Treasury explained that the impact on local authorities of the increased cost was taken into account in the local government settlement, which included an annual increase in funding of 1% above inflation[12].

As shown in Fig. 1, the £8 escalator for standard waste was then maintained until 2014/15, when the standard rate reached £80 (with the lower rate still frozen at £2.50). Thereafter both rates have increased in line with inflation only. They currently stand at £84.40 per tonne (standard rate) and £2.65 per tonne (lower rate), raising more than £1 billion per year in revenue (see Fig. 2).

The landfill tax provides a strong incentive for local authorities to undertake separated waste

Figure 1: *Waste tonnage sent to landfill, and Landfill Tax rates.*

HMRC Tax and Duty Bulletins: https://www.uktradeinfo.com/Statistics/Pages/TaxAndDutyBulletins.aspx



collection and recycling from households. These issues are discussed further in Chapters 4 and 12. However, as noted numerous times during its development[11, 12], the Landfill Tax is not directly faced by householders. Whatever its effect on recycling by local authorities, it gives no direct incentives to householders to reduce their quantity of non-recyclable waste.

An alternative approach for household waste would be variable waste charging, also called pay-as-you-throw (PAYT) schemes. Under such schemes, households are charged for waste disposal on the basis of the weight or volume collected, providing a financial incentive to households to reduce their waste generation. Such schemes have been applied in many countries around the world, and they generally have a positive impact on waste prevention[13]. A review of studies from countries in the Organisation for Economic Co-operation and Development (OECD) found that variable waste charging "generally goes hand in hand with a 15-30% increase in recycling and a sharp fall in landfilling"[14]. Successful versions of variable waste charging have also been developed in Italy (see case study on p179).

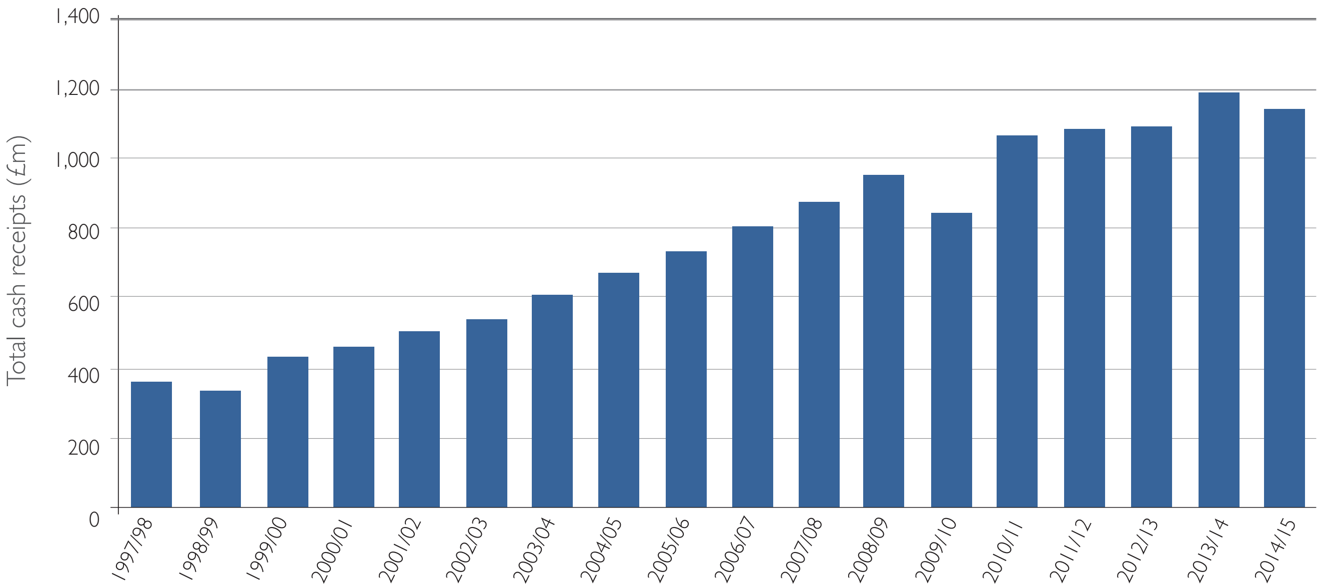
In the UK, however, local authorities (which are bound by the 2011 Localism Act) do not have the power to directly incentivise waste reduction, for example through PAYT schemes. Nevertheless, Blaby District Council in Leicestershire began a limited form of waste charging in 2001. The council provided residents with one 140 litre refuse bin and one similarly-sized recycling bin; residents were able to request additional refuse sacks or a larger refuse bin, but for a fee. Within the first year of the scheme, only 7% of households were renting a larger refuse bin or buying more refuse sacks, and it was reported that recycling collections had risen by 55% (ref. 17a). Also within the first year of the scheme, waste to landfill was reported to have been reduced by 3% (ref. 17b). Blaby District Council still operates this scheme, whereby households requiring greater refuse storage than the standard 140 litre bin incur a charge[17c]. Its recycling rate currently stands at around 49% (ref. 17d), which is higher than the UK average[17e]. The council has also recently received central government funding to run a three-year incentive scheme to reward households whose recycling bins are uncontaminated by non-recyclable refuse[17f].

The Landfill Tax affects other sectors as well as households. In 2012, total UK waste generation was 200 million tonnes (Mt), spread across various sectors (see Fig. 3). The largest sectoral generator of waste was construction and demolition, which generated around 100Mt of waste. By excluding excavation waste – such as excavated soil, mineral waste and dredging spoils – this falls to about 45Mt, 87% of which was recovered. This exceeds the 2020 recovery target of 70% for construction and demolition waste under the EU Waste Framework Directive.

Figure 4 shows the split between quantities of waste sent to landfill compared to other final treatments, for different waste streams. A few of these waste streams stand out as having relatively large proportions and absolute quantities being sent to landfill. About 60% of the 'household and similar' waste stream, or

Figure 2: *Total cash receipts from Landfill Tax.*

HMRC Tax and Duty Bulletins: uktradeinfo.com/Statistics/Pages/TaxAndDutyBulletins.aspx

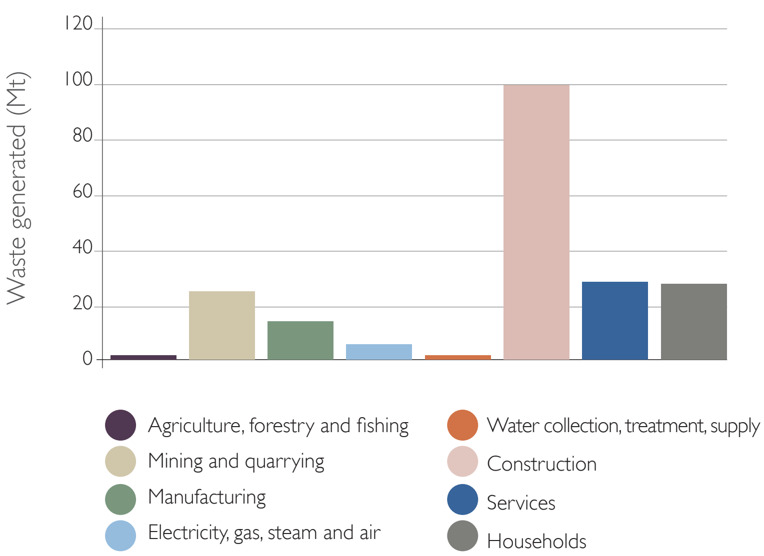


about 11Mt, is sent to landfill (this overlaps with, but is not directly equivalent to, the household sector shown in Figure 3). About 90% (10Mt) of 'sorting residues' – which includes residue waste from "mechanical sorting processes, refuse-derived fuels, non-composted residues from composting, etc"[19] – is sent to landfill. About 50% (18Mt) of soil waste, mostly excavation waste from construction and demolition, is sent to landfill. Though smaller in absolute quantities, high proportions – around 90% – of the wastes under the categories 'mineral wastes from waste treatment and stabilised waste', and 'combustion wastes', are sent to landfill. In absolute terms, the landfilled wastes under these categories are around 2Mt and 4Mt respectively. A more detailed statistical breakdown of the composition and origin of the waste that is still sent to landfill may be an important step to identifying measures to divert and reclaim such materials, including through creating "industrial symbiosis" synergies, joining up the material flows of different industries (see Chapter 11, case study on p157).

Other market based instruments can also affect the use and disposal of material resources. The UK's energy policy includes incentives to promote renewable and low carbon sources

Figure 3: *Total generation of waste in the UK by economic activity, 2012.*

Defra[18]



of energy. These include incentives, through the Feed-in-Tariff Contract for Difference (FIT CfD) regime to promote energy recovery from waste. Reclaiming energy from waste is clearly an effective way of avoiding waste going to landfill. However, it also prevents the recycling of any useful material that may have been present in the waste; and if incentives are not set at the right level, there is theoretically the possibility of creating incentives for the generation of waste, as an energy source, which may not be an efficient or effective way of reducing material consumption or carbon emissions. Hence the ongoing effect of the FIT-CfDs on waste generation and treatment should be monitored.

2. Aggregates taxes (or virgin material taxes)

Landfill taxes and other waste charges are taxes on waste at the point of disposal. Their direct incentive therefore is for the avoidance of landfill, and they do not necessarily incentivise more energy- and material-efficient practices moving further up the material management hierarchy (eg reduce, reuse). By comparison, a tax on virgin materials would theoretically have effects across the whole supply chain, and incentivise measures at every rung on the resource management hierarchy. In the UK there is an Aggregates Levy on sand, gravel and rock, whether dug from the ground, dredged from the sea in UK waters or imported[20]. UNEP envisages the application of just such extractive taxes across a range of materials, adjusted periodically according to increases in efficiency, to deliver revenue neutrality[21].

3. Rebalancing the cost of labour and materials

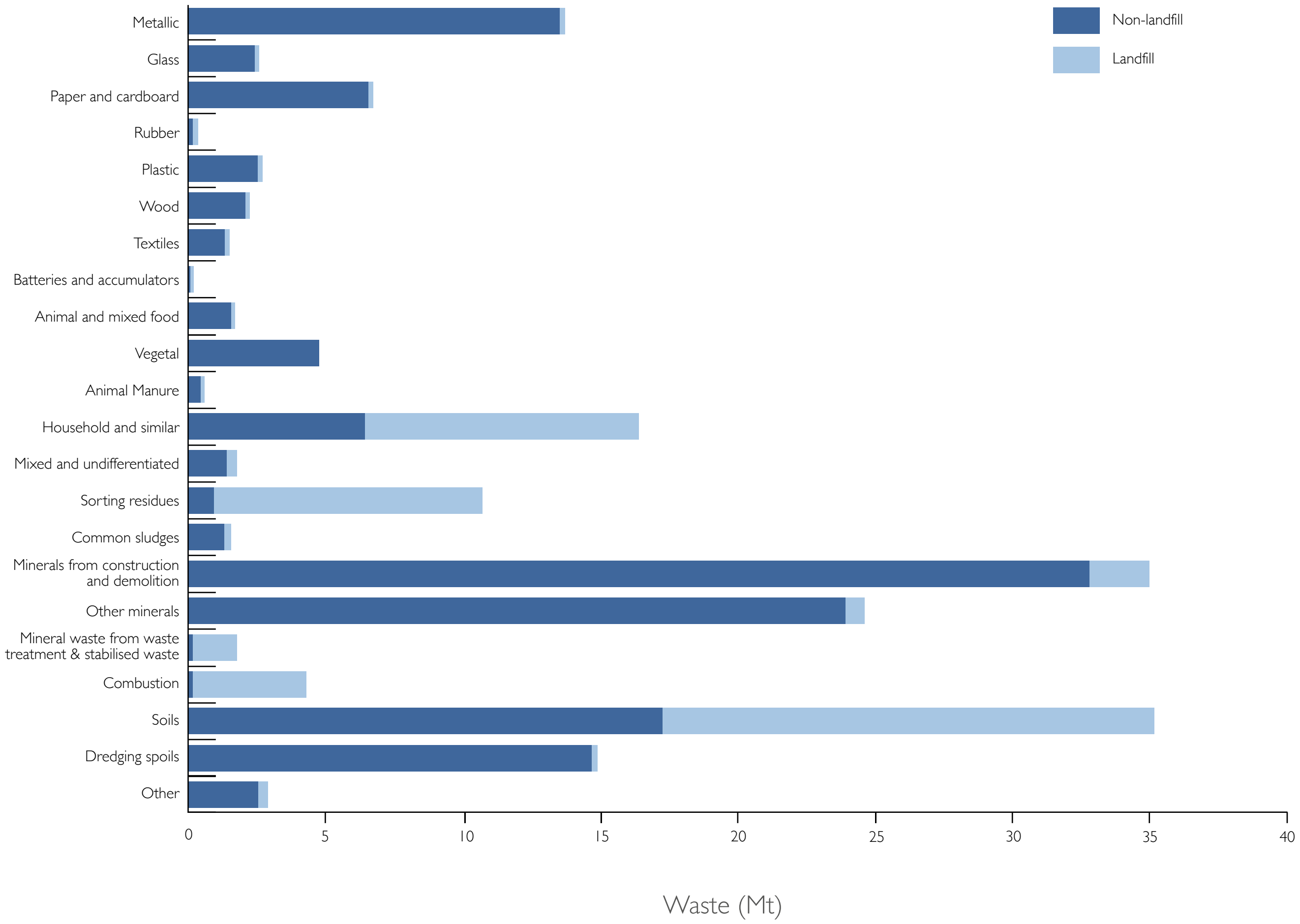
Recapturing the value of materials that would otherwise be disposed of as waste usually requires labour. Consequently, an important economic driver of resource efficiency is the relative cost of materials and labour. Resource efficiency and economic efficiency are not always aligned, and resource-inefficient behaviour can, sometimes, be more cost-effective than resource-efficient behaviour[1]. This can be the result of an economically rational calculus of the relative costs of materials, and of the labour that would be required to avoid wasting them[1, 21, 22a]. Therefore, national level policy measures that reduce labour costs relative to the cost of materials could help realign resource efficiency with economic efficiency. Examples of measures to reduce labour costs for resource productive activities could include reductions in employers' National Insurance contributions; or, as has recently been proposed in Sweden, cuts in the VAT charged on repair work, and tax rebates for the labour cost of repairs, which will significantly reduce the cost to consumers of repairing appliances[22b].

If reductions in labour costs are balanced against measures that increase costs of materials or of waste disposal, a combination of these approaches could promote resource efficiency in a way that was revenue-neutral for the government and for businesses. Indeed, Labour and Conservative governments invoked this principle as they introduced and subsequently increased the Landfill Tax. Compensatory reductions in employer National Insurance contributions were introduced to avoid increasing the tax burden on businesses, invoking the principle that the tax system should encourage work, and discourage environmental pollution[11].

4. Financing

Resource-efficient investments can often be inhibited because commercial banks are unable to finance projects with long-term payback periods. Government could potentially intervene to guarantee long-term loans, or to provide them directly, for example through the Green Investment Bank (GIB). There is a risk, however, that some more advanced material and resource efficiency concepts may fall outside of the GIB's current investment sectors. If the GIB is to remain the principal tool for long-term green investment, its potential for providing long-term financing for innovative resource efficiency projects would be enhanced if it were involved in government-led strategic reviews of future resource productivity technologies and growing industry sectors, in order to ensure that emerging but promising technologies and sectors were not missed. This could be undertaken in tandem with the Government's proposed new Industrial Strategy.

Figure 4: *Total waste sent to final treatment (landfill vs. non-landfill) by type of waste material, 2012 (Mt).*



5. Consumer information

One of the barriers to pro-environmental or resource-efficient behaviour is the lack of information that would enable people to make such decisions. One response to this in the consumer area has been the emergence of labels and certification schemes. However, the proliferation of different consumer labelling schemes, each with slightly different criteria, may be counter-productive. As is made clear by the guidance from the Department for Environment, Food and Rural Affairs (Defra) on environmental claims and labels, a wide range of voluntary and mandatory environmental claims and labelling schemes are in operation, relating to a variety of products including food, timber, paints, aerosols, cleaning products and electrical products[23], frequently asserting different pro-environmental qualities. As noted in Chapter 9, citizens are "overwhelmed by the volume of choice and information they are exposed to, and marketer's relentless efforts to 'engage' with them"[24]. Defra's guidance states that "environmental claims and labels must be credible to consumers, clearly understood, and genuinely reflect a benefit to the environment". Defra is not responsible for enforcing the accuracy of claims in environmental labels – that lies with a range of other bodies, including local authority Trading Standards Services and the Advertising Standards Authority[23] – but there may be a role for government to step in and facilitate a more uniform certification approach, beyond the existing Defra guidance.

Regulatory approaches

In some cases, regulations may inadvertently be providing a barrier to increased resource efficiency. In such cases, the amendment and reform of regulations would increase resource efficiency.

1. Regulations for remanufacturing

One example is in the case of remanufacturing. It involves the disassembly of product components and their remanufacture into modules or products with 'as new' qualities. As a relatively new concept, the regulations concerning design, sales and disposal of products were not created with an awareness of the possibility of remanufacturing, and thus in some cases work against it. For example, materials once classified as waste may be prohibited from re-entering product supply chains. Clearly, the original framing of such regulations has important justifications, for example to avoid amplifying contaminants in the food chain, or to avoid the production of goods from materials whose safety performance has been compromised. However, such regulations mean that warranties and safety guarantees may in some cases not be achieved by remanufactured products, despite the fact they are designed to 'as new' specifications[25]. Amendments to such regulations that allow remanufactured products to achieve the same warranties as new products, provided of course that they meet the same strict safety performance criteria, would do much to improve the prospects for remanufacturing industries.

2. Extended producer responsibility

In the UK, producer responsibility legislation places a responsibility on businesses for the end-of-life environmental impact of packaging, electrical and electronic equipment (EEE), batteries and vehicles[26]. These regulations could be extended to include more businesses and products, with higher requirements. So-called extended producer responsibility (EPR) seeks to make the manufacturer responsible for the entire lifecycle of the product, especially the take-back, recycling and final disposal of the product at the end of its use-life[27]. The responsibility can be either physical or financial (as with the Packaging Recovery Note (PRN) scheme in the UK[28]) and can be undertaken individually by the original manufacturer of the product, collectively by a group of manufacturers, or by third parties. A number of EPR schemes have been introduced around the world, especially in Japan, Canada and Europe, where current EPR schemes cover packaging, batteries, electric and electronic equipment and vehicles.

EPR regulations might stimulate a number of innovative responses from producers. In leasing or service-based business models, producers sell the services from products over their lifetime, rather than the products themselves. Producers might try to incentivise consumers to return end-of-life products to them by charging a fee when the product was sold which would be returned to the consumer when the product was returned when its life was over, similar to deposit-refund schemes which are in place for drinks bottles in a number of countries. The treatment of end-of-life vehicles (ELVs) comes closest to this philosophy at the present time, as according to the EU ELVs Directive (2000/53/EC) auto-manufacturers are required to take back their ELVs and recover a minimum of 95% of their materials, with 85% being reused or recycled, and the remaining 10% able to go to energy recovery.

3. Ecodesign

Although design itself consumes only about 15% of the resources of the manufacturing processes, the European Commission estimates that more than 80% of the lifecycle environmental impact of a product is typically determined at the design stage. Ecodesign, or design for the environment (DfE), integrates environmental considerations into the design of products and processes with the aim of reducing their lifecycle environmental impacts, and this approach could make a significant impact on resource productivity. The EU Ecodesign Directive (2009/125/EC) provides

The resource productive economy could create **wider social benefits** by redressing the structural imbalance of unemployment

Pay as you throw, Italian style

Paul Ekins and Nick Hughes, Institute for Sustainable Resources, UCL

The advocacy group Zero Waste Europe has highlighted two case studies from different regions of northern Italy. In the town of Capannori and the city of Treviso, rates of domestic waste segregation for recycling now exceed 80%. In both areas, residents segregate their recyclable waste into multiple streams. They are incentivised by pay-as-you-throw systems, which charge them according to the weight of non-recyclable waste. Incentives are also provided in both municipalities to encourage composting. Transparency and communication are considered to be crucial to the success of the schemes. In Capannori, residents were extensively consulted and provided with information prior to the introduction of the measures; and in Treviso, an online database allows residents to track what waste has been collected from them and to understand how their charges have been calculated[15, 16].

the framework for setting ecodesign standards for a range of energy-related products.

Successful regulation will also depend on the ability to measure and set standards on identifiable resource productivity indicators. For example, Environmental Product Declarations (EPDs) use lifecycle analysis to provide verifiable information of the environmental impacts of a product, including raw material extraction, energy use, air, soil and water emissions/discharges, water use and waste generation. As a development of EPDs, 'product passports' would also contain relevant information regarding the material composition of the product; its upgradeability; the replaceability of important components by users; and information on the efficient use and proper disposal of the product, such as dismantling and recycling instructions, and the toxicity of materials. This would greatly facilitate the reuse or remanufacturing of the product at the end of its use life.

4. Driving future performance, supporting commercial research and development, and scale-up

Regulation can also be an important way of driving future innovation, by providing producers with a clear signal as to what future performance requirements will be. An example of this type of approach is Japan's Top Runner scheme, which is concerned with energy efficiency and has successfully driven up design standards across a range of consumer product groups[29].

5. Food chain regulation

In the area of food waste, regulations could be developed to inhibit commercial practices that tend to generate waste. These could include preventing excessive cosmetic standards that cause large amounts of discards, and promoting 'whole crop purchasing' (see Chapter 6). The public sector could set an example in these areas through its procurement policies (as discussed under 'Green public procurement' on p183).

Strategic approaches

1. Industrial strategy: skills, training, research and development, and coordination

Chapter 10 explored the different kinds of jobs and businesses that could be generated through a transition to a more resource-productive economy. The jobs required to bring about many aspects of resource productivity may in some cases require new skills, and in other cases may build on existing skill bases from previous industries.

UK manufacturing has been declining for decades. In 1990, manufacturing contributed 19% of UK economic output; by 2014 this had fallen to 9%. Services, meanwhile, grew from 67% of output in 1990, to 80% in 2014 (ref. 2). Notwithstanding overall economic growth during this period, this kind of economic restructuring has led to uneven impacts. The regions of the country where industry and manufacturing had traditionally been strong, for example, have been amongst those worst hit by unemployment[3].

In 2011, the government published a 'Plan for Growth' which noted the decline in output and jobs in manufacturing, and stated an objective to "achieve strong, sustainable and balanced growth that is more evenly shared across the country and between industries"[30]. The document described numerous measures, including reductions in corporation tax and further tax relief to small businesses. However, in addition to such measures, constructing an industrial strategy around the aim of making the UK a leader in resource productivity could stimulate jobs and growth. Increased resource productivity could have positive employment benefits, especially in sectors currently most affected by unemployment[3]. For example, remanufacturing activities could logically be sited in areas of existing or historic manufacturing, where unemployment tends to be higher as a result of the decline in those sectors.

A Foresight report for the Government Office for Science, 'The Future of Manufacturing', identifies four key features of this future[31]. Manufacturing will be more responsive and closer to customers, with digital technologies allowing mass personalisation and distributed production. There will be new global market opportunities from emerging economies, but also potential for some 're-shoring' of UK manufacturing, as shown by the examples of several companies that have returned some or all operations to the UK, for diverse reasons including quality control, reduction of carbon footprint, and the marketing power of a 'made in Britain' brand. There will be increasing focus on the sustainability of products, both due to national and international regulations, as well as consumer-pull. All these characteristics could promote resource productivity and a more 'circular' economy in the UK – and in so doing generate medium- and high-skilled employment opportunities[3].

The report makes a number of recommendations including: the importance of developing and training a skilled workforce; the potential for 'phoenix industries' (declining industries whose skill bases can still be used to seed newly emerging industries); the significant role that government can play in assisting industries and supply chains by supporting co-location and manufacturing regions; the importance of 'patient capital' (ie financial support that is not tied to a requirement for high returns in the short term) to support long-term investment; the importance of research and development in new technologies; the value of well-designed regulation to incentivise product and process efficiency; support for new business models based on reuse, remanufacturing; and 'servitisation' models.

Existing government programmes include the Advanced Manufacturing Supply Chain Initiative, which was launched in 2012 to help facilitate potential supply chain partners to co-locate in the UK; and the High Value Manufacturing Catapult Centre[32]. Co-ordinating activities such as these should be continued and expanded.

2. Facilitating industrial symbiosis

The classic definition of industrial symbiosis is that it "engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products"[33] (see Chapter 11, case study on page 157).

Kalundborg in Denmark is considered the paradigmatic model of a geographically-specific industrial symbiosis network[34]. This concept is also at the heart of Japan's Eco-Town programme, which has led to the establishment of 26 eco-towns across the country. In the Kawasaki Eco-Town, for example, plastic is recycled for use in blast furnaces, for concrete formwork and for ammonia production; polyethylene terephthalate (PET) plastics are recycled to produce other PET products; and paper is also recycled. As well as reducing material waste, the industrial symbiosis strategy in Kawasaki has been estimated to have reduced lifecycle carbon emissions by 13.77%, mainly from iron and steel, cement and paper manufacture[35].

As a result of government subsidies, 61 recycling facilities have been established across Japan's 26 eco-towns, with a combined capacity of nearly 2 million tonnes of waste per year. And for every government-subsidised recycling plant, a further 1.5 plants were built by the private sector without subsidy[36]. This suggests that government actions to establish an industrial symbiosis ecosystem can act as a springboard for further private sector-led development of environmental industries. Industrial symbiosis is also well established in other Asian countries, including China[37–39] and Korea[40]. An alternative approach is the geographically dispersed facilitated industrial network, of which an example was the UK's National Industrial Symbiosis Programme (NISP) (see case study on page 182).

Potential future opportunities for industrial symbiosis in the UK might be identified through careful analysis of data on material resource flows through industries, including which materials are disposed of in landfill; which are used for energy recovery; and, of the materials captured for recycling, how much is recycled and reused within the UK, as opposed to exported to other countries (see Chapter 2).

3. Green public procurement

Green Public Procurement (GPP) is a process whereby public authorities seek to procure goods, services and works with the same function but a reduced environmental impact throughout their lifecycle. As just one example, a recent study estimated that the UK could save up to £40.7 million as well as reducing CO_2 emissions and waste management costs if the proposed Government Buying Standards for furniture were applied by all central government departments and executive agencies[43]. Similar cost, carbon and materials savings are likely to be available across many procurement areas.

Government procurement can also be a key tool for driving future innovation, by setting ambitious future standards. A government advisory group, the Environmental Innovation Advisory Group (EIAG), developed the concept of 'forward commitment procurement' in its first report of 2006 (ref. 44). The report argues:

"R&D is relatively cheap and leads to many prototypes but all too frequently these do not make it to market because the uncertainty of future sales makes it too risky to invest in expensive demonstration and scaling-up. Investment at this high-risk stage only makes sense in the context of a commercial opportunity that may not be visible, or attainable to a supplier without good supply chain management by those further up the value chain. The Government is uniquely placed to make this opportunity both visible and credible through its procurement activities."

The proposed process would therefore be that a public sector body would offer to buy "in the future a product or service that delivers specified performance levels including environmental benefits at a defined volume and at a cost it can afford". If the performance standards are met at the defined future year, the procurer would buy in bulk, giving the technology developer the certainty of revenue reward needed to justify investment and scale up. At around the time of this report, the EIAG was working with procurers including the HM Prison Service, London Fire and Emergency Planning Authority, the Environment Agency and local authorities, to demonstrate the approach in practice.

Case Study

The National Industrial Symbiosis Programme

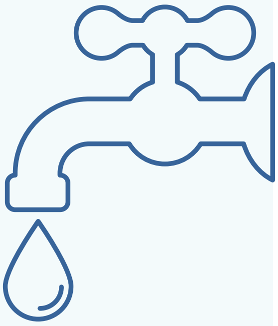
Paul Ekins and Nick Hughes, Institute for Sustainable Resources, UCL

The UK's National Industrial Symbiosis Programme (NISP) was funded by Defra over five years between 2005 and 2009. The programme reduced landfill, CO_2 emissions, and the use of water and virgin materials at well below £1 per tonne; it also reduced costs and generated extra sales for businesses, saved and created jobs, and raised more than three times as much government revenue as it was given in public subsidy (see Table 1). The NISP outputs were independently verified, and take no account of any benefits from changes in business culture or awareness of resource use that are not directly related to NISP-initiated programmes.

These outcomes were the result of a sophisticated business-led (but publically facilitated and funded) programme. It combined an innovative, networked IT system; an emphasis on innovation that involved close collaboration with the relevant Knowledge Transfer Network of the Technology Strategy Board; a strategic focus and delivery plan at the regional level, at the time

Table 1: *Environmental and economic benefits from NISP in millions of tonnes (Mt) of waste and millions of pounds (£m), April 2005-March 2010. The data show that every £0.31 of government investment produced £1 of extra government revenue, a fiscal multiplier of 3.2. The 5-year total assumes NISP contribution to savings of only 60%, but persistence of savings to subsequent years, declining by 20% per year. Public investment of £27.7 million over 5 years is assumed to be split equally between 5 environmental categories (ie £5.5 million per category). Author calculation from NISP data*[41]

	Simple 5-year total	Cumulative over 5 years	Value for money (Public investment/ unit output)
Environmental benefits			
Landfill diverted (Mt)	7.0	12.6	0.44 (£/t)
CO_2 reduction (Mt)	6.0	10.8	0.51 (£/t)
Virgin materials saved (Mt)	9.7	17.5	0.32 (£/t)
Hazardous materials reduced (Mt)	0.36	0.7	7.9 (£/t)
Water saved (Mt)	9.6	17.2	0.32 (£/t)
Economic benefits			
Extra sales (£m)	176	317	0.087 (£/£)
Costs saved (£m)	156	281	0.099 (£/£)
Extra government revenue (£m)		89	0.31 (£/£)
Private investment (£m)	131		
Jobs created	3683		
Jobs saved	5087		



coordinated though the Regional Development Agencies (RDAs); and a relationship with the regulator, the Environment Agency, which not only gave access to information about the nature and location of materials that could be turned from wastes to resources, but also was extremely helpful in clarifying the relevant regulations to businesses.

It was on the basis of these sorts of insights and results that the European Resource Efficiency Platform (EREP) recommended that industrial symbiosis should be facilitated at an EU level. A recent study estimated that scaling up industrial symbiosis programmes across the EU could generate more than €3 billion in sales and cost savings, and 45 million tonnes of CO_2 reduction (5% of Europe's annual reduction target for 2020 (ref. 42)). Facilitated industrial symbiosis programmes based on the NISP model are now spreading outside Europe and are already well established in, among other countries, Brazil, China, Mexico, South Africa and Turkey.

Conclusions: Public policy for increased resource productivity

There are several strong arguments in favour of increasing resource productivity:

- Underpinning economic growth, by providing a general macroeconomic stimulus
- Job creation in industrial and manufacturing sectors
- Increased resilience to resource price volatility or possible future resource scarcity
- Cost-effective reduction of GHG emissions
- Reduction in other environmental impacts

However, markets do not necessarily achieve the full cost-effective potential of resource productivity by themselves. National-level policy has an important role to play in helping to achieve this potential. Having studied three categories of national-level policy making, we can offer the following recommendations for policies that would increase resource productivity.

1. Pricing and market-based approaches

The cost of materials and of disposing of waste, compared to the cost of the work required to use less material or create less waste, is a crucial calculus in determining to what extent resource productivity is pursued. Public policy can change the relative costs of materials, waste disposal and labour, to ensure that increased resource productivity is better aligned with economic efficiency and business profitability.

The Landfill Tax is an important environmental tax that has had a clear impact on increasing resource productivity, mainly through increasing recycling rates. However, the Landfill Tax does not directly incentivise households to reduce the quantity of waste they generate. In fact, waste collection and disposal for households continues to be financed through taxation, irrespective of the weight and volume generated by particular households. This effectively results in waste-intensive households being subsidised by those that try to reduce and recycle their waste. It is economically inefficient, unfair, and provides no encouragement or incentive for households to engage more sustainably with their waste.

The economic policy instrument that has been effectively employed by a number of countries to address this situation is to charge people for the weight or volume of waste they generate, through so-called 'Pay-As-You-Throw' (PAYT) schemes, examples of which are briefly described in the case study on page 174. The success of such schemes depends critically on their design, such as ensuring effective communication and transparency as to the reasons for the charges and the measures that can be taken by householders to reduce or avoid them. It could also be emphasised that the charges are replacing unfair and regressive taxation, rather than adding new costs. Such communications measures are likely to be critical features to support householders in adjusting their behaviour in the desired direction – thereby avoiding the charge, rather than paying more and continuing to generate waste.

Once appropriate price signals are in place, a whole range of supplementary policy instruments may be introduced as a further stimulus to waste reduction and recycling. These include composting incentives, explanations about the economic and environmental benefits of reducing landfill, and various options of re-use and repair as well as recycling, including through the use of online communication channels. Deploying these instruments alongside one another as part of a package can reduce overall waste collection and disposal costs, and make it easier to dispose of waste responsibly, thereby helping to avoid environmentally harmful disposal of waste outside proper waste pathways.

A second issue with the Landfill Tax is that it is a tax on waste disposal, and therefore does not have a direct effect on activities further up the supply chain of a product, from material extraction through manufacturing and assembly. Increased resource productivity in supply chains could be stimulated by extending the aggregates tax to cover more materials, and raising it gradually and transparently, in a similar manner to that pursued with the Landfill Tax.

The impacts of these pricing measures would be enhanced – offering greater competitive advantages from increased resource efficiency – if corresponding measures were undertaken to reduce the cost of labour, aiming as far as possible for revenue neutrality. Measures could include reductions in employer National Insurance contributions, and reductions in VAT or tax rebates on the labour costs of resource productive activities, such as the repairing of appliances.

Pro-environmental consumer choices can also be supported by well-articulated consumer information, and the government should ensure that such information is consistent, transparent and trustworthy.

The government should find ways to make patient financing available, to support resource productive investments that have a long payback time. Financing strategies should be coordinated with the government's long-term industrial strategy and technology horizon scanning, to ensure that promising but emerging technologies and sectors are not left out.

In combination, these measures would increase the costs of resource consumption and wastage, while decreasing the costs of the labour required to use resources more efficiently, and reducing investment barriers to resource-productive innovations. Overall, they would provide a strong stimulus towards resource productivity.

2. Regulatory approaches

Regulations are also important structures that influence the behaviour of firms and individuals. It is worthwhile examining regulations to ensure that they encourage, and do not obstruct, resource productivity.

Regulations surrounding waste product standards and warranties should be re-examined to ensure that they do not inhibit remanufacturing. This should not compromise safety and other standards. Regulations should reflect that it is possible to meet such standards using remanufactured components.

Producer responsibility regulations should be extended to make producers responsible for the full material lifecycle of their products. This would include ensuring that packaging was easily recyclable; that there were incentives for products to be collected at the end of their lives; and that they can be disassembled for easy repair, or for recovery and recycling of their parts.

Data from developing product passports and

EPDs would enable resource productivity targets to be set for product groups. These should be set using the Top Runner approach, with clear standards for future performance set in advance.

It may also be possible to use regulation to discourage certain wasteful commercial practices, for example the rejection of edible food at the farm gate for aesthetic reasons.

It is sometimes perceived that increasing regulations will lead directly to increased costs for businesses and consumers. This can of course be the case. However there are various potentially countervailing effects, which should also be considered.

First, it should be recalled that even if costs are increased in the short term in one particular part of the material chain, this is often simply an internalisation of an externality which had previously been paid for in some form in another part of the chain. For example, if extended producer responsibility regulations impose costs upon the producer of a product due to the requirement to reclaim end of life materials, they nonetheless avoid the costs that were previously paid by local authorities (and by extension households through council taxes) for the end of life disposal of the materials.

Second, there is evidence that, even without accounting for externalities, environmental legislation can sometimes lead directly to innovation and productivity improvement. Again, to take the example of EPR, such regulations could stimulate producers to develop more resource-light design of their products and packaging as a means of reducing their exposure to end of life recovery costs – the resource-light designs could result in reduced costs compared to the pre-regulation designs, generating a productivity benefit for the firm.

Finally, from a macroeconomic perspective, there is evidence from economy-wide modelling studies that resource efficiency measures can lead to increased economic productivity, as discussed in the introduction to this chapter.

3. Strategic approaches

To move beyond purely incremental improvements in resource productivity would require substantial reorganisation of the way materials move through the economy. This in turn requires reorganisation of infrastructure, and coordination between various actors in the public and private sector who may not necessarily have histories of collaboration. National government clearly has a strategic coordinating role to play, bringing actors together and facilitating the building of new relationships, supply chains and infrastructures.

To move beyond purely incremental **improvements in resource productivity** would require **substantial reorganisation** of the way **materials move through the economy**

There is evidence from both the UK and other countries that industrial symbiosis programmes can provide significant economic and environmental gains. The government should explore the potential for a new national industrial symbiosis programme, taking relevant learning from previous versions (see case study on page 182), and applying it in the current context. There would be potential for such a programme to include material flows in the commercial and agricultural sectors, as well as industry.

Clear data should be generated on what material and waste flows are actually taking place, so that possibilities for symbiotic material flows can be identified. The government should review the need for data on material and waste flows, to en sure that potential reuse and recycling loops can be identified and capitalised on through its strategic activities.

The government has recently launched a consultation on developing an industrial strategy. This is a welcome development, and can be taken as an opportunity to consider how the medium- and long-term employment opportunities that could be generated by a more resource-productive economy, in areas such as remanufacturing and eco-design, can best be realised. Key elements of the strategy are likely to include skills training and re-training programmes to help provide the necessary work forces that will deliver a more resource-productive economy. A related research and development programme should support the development and scale up of promising new technologies that will enhance resource productivity, and the financing mechanisms to enable investments in such technologies should also be considered.

The government should also lead the way in stimulating demand for resource efficient products and supply chains, through the use of green forward commitment procurement.

CHAPTER 14:
International exemplars

The change from a linear to a circular economy is taking place at a different pace, and with differing emphasis, around the world. Given the increasingly globalised nature of the waste basiness, international collaboration is becoming ever more important. The UK can learn from international best practice in strategic planning, waste prevention, materials recycling, the treatment of organic waste, and the opportunities for exploiting the resources in residual waste.

Jeff Cooper, Editor-in-Chief of Waste and Resource Management, Past President of the Chartered Institution of Wastes Management, and Former President of the International Solid Waste Association.

Three main themes run through this chapter:

1. The UK needs to look to the future, in order to address how changes in society, our built environment and technology will influence resource use and waste management, from collection through processing to final treatment options. In particular, it should consider the impact of the 'Fourth Industrial Revolution', driven by computer-controlled manufacturing, the Internet of Things, cloud computing and other innovations.
2. We must improve the attitudes and behaviour of businesses and the wider community regarding waste management, reinforcing and building on the progress the UK has already made to ensure that we fully exploit the opportunities for waste prevention and future resource utility from waste recovery.
3. Every aspect of our resource use and waste management should be examined by businesses of every size and structure in order to maximise the UK's resource resilience.

The circular economy aims to utilise the maximum value of resources, and keep them in use for as long as possible, through waste prevention; reusing, recycling and recovering resources from waste to produce secondary raw materials; and treating the residual waste stream from these processes through energy recovery and other means.

The change from a linear to a circular economy is taking place at a different pace and with differing emphasis around the world, largely in response to national and international environmental policies to reduce landfill and greenhouse gas emissions. Although there have been resource shocks caused by restricted access to raw materials and energy – such as the oil shortages of the 1970s – there has been no long-standing limitation on the ability of the economy to function adequately, albeit with minor disruptions to the life of some citizens. The generation of increasing quantities of secondary raw materials, and the search for markets for them, has therefore been more of a by-product of concern about the environmental consequences of increasing resource use and waste generation, as well as rising carbon emissions.

There are different policy and technological responses to the challenges of moving towards a more circular economy. For example, countries place differing emphasis on 'cascading' materials: repeatedly using a resource at decreasing quality until, after several recycling cycles, energy is finally recovered from residual waste. Moreover, some materials are more easily reused or recycled than others, because they do not have the added challenges of containing hazardous substances, or being a complicated mixture of materials (metals, plastics and resins) that are difficult to recover.

Meanwhile, the waste industry is moving away from managing waste to landfill and towards managing waste for energy production; and further, to managing waste in a closed-loop economy. Some members of the Organisation for Economic Co-operation and Development (OECD) – Denmark, the Netherlands, Japan, and Sweden, for example – now landfill less than 12% of their waste, and are efficient at generating energy from waste. This group of countries is now moving on to cascade other resources. A second group of OECD countries – including UK, US, and Ireland – are more dependent on landfill, but they are moving large volumes of materials to alternative treatment systems, as well as exporting materials to other countries because of the lack of infrastructure to utilise them at home. A third group of OECD countries – including Greece and Poland – are still focused on landfill, but are now beginning to explore reuse and recovery (see Fig. 1).

These changes are also being seen in major international waste companies, including Veolia Environment and Sita Environment, as they change their emphasis from waste management to recycling and recovery.

Given the UK's current position in its journey to a closed-loop economy, there is scope for it to learn from countries that are further along the road, with respect to new technical processes; reusing and recycling of materials not currently recovered; and methods used to influence corporate and social behaviour to support these changes. There is also scope to learn from models that bring together representatives of different industries, which is increasingly necessary if waste is to be minimised from the design stage, and if markets are to be found for secondary raw materials.

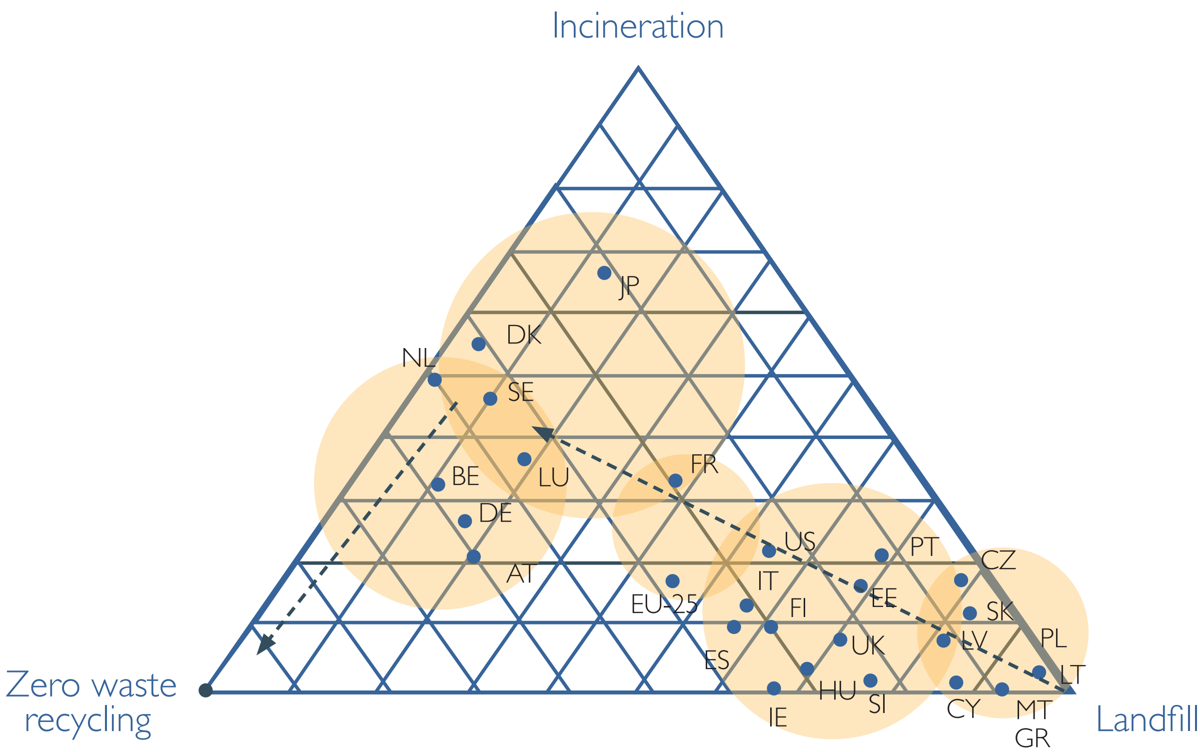


Figure 1: *Moving from landfill towards waste recovery and recycling. Countries such as Denmark (DK), the Netherlands (NL) and Sweden (SE) landfill very little of their waste; the UK, US and France (FR) are moving towards alternative treatments; while others including Greece (GR) and Poland (PL) send almost all their waste to landfill.*

Source: ISWA (ref. 1)

52

Number of UK recyclable packaging compliance schemes

For international comparisons to be useful, we need access to data and comparable systems for measurement (see Chapter 2). Advances in information technology now enable the waste management sector to access real-time, accurate data. In a 2015 report on the circular economy, the International Solid Waste Association (ISWA) suggested that innovations such as the smart grid, used in the electricity supply industry, need to be mirrored in the waste industry[2]. Real-time data systems for recyclable waste are emerging in South Korea, Australia, Japan and across the European Union. The ISWA report states that such systems need to be international in their application, and will require public-private commercial partnerships in order to be successful and to support the emergence of commodity markets for secondary raw materials. Therefore, strengthening the UK edoc system to provide information about waste being sent for recovery and final disposal might be warranted (see Chapter 2).

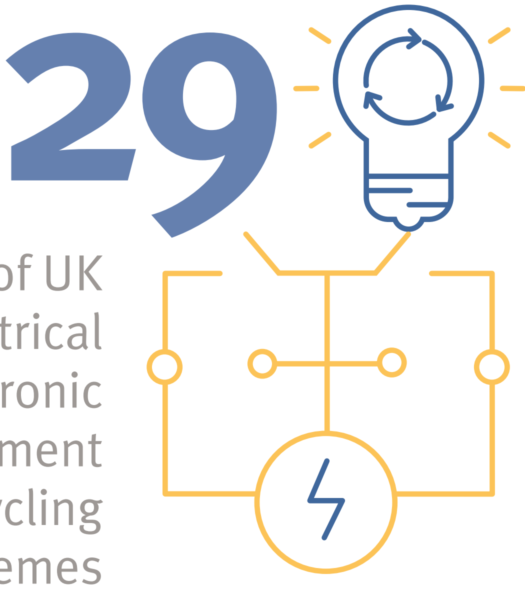
One of the difficulties in evaluating the efficacy of international waste practices lies in the measurements of effectiveness and the definitions of waste. There is great difficulty in comparing countries' data regarding waste generation levels, both for particular types of waste and their levels of recycling achievement. The most recent and comprehensive international assessment of waste generation levels was provided in the 2015 UNEP publication 'Global Waste Management Outlook'[3], based on research provided by ISWA. These approaches reflect the economic, political and social contexts of each country, as well as historical preferences for particular types of waste practices. This means that it is difficult to accurately predict growth in waste arisings and changes in its composition.

International trade

The UK has an open economy that allows a greater degree of international trade in goods and services than many other countries. While there are concerns about the loss of materials through exports of waste, in a globalised economic system it is difficult to ensure that materials are reutilised within a single country or single trading bloc, such as the EU.

The UK benefits from easy access to goods, services, raw materials and energy sources from the global trading system, but globalisation has also helped to bolster purchasing decisions that place short-term use ahead of longevity and sustainability. When selecting materials and composites, designers are under no economic pressure to consider the end-of-life costs to recover the raw materials that their products contain. Instead, increased recovery costs are simply passed on to society.

At the same time, there is an opportunity to export processed waste to markets outside the UK. ISWA's 2015 report cites OECD research showing that the current market for secondary raw materials is already worth $200 billion and estimated at 700 million to 800 million tonnes per year[4]. It is dominated by recovered metals (nearly 50% by value) and paper (recovered paper makes up over 50% of the global paper market)[5]. The recovery and utilisation of recovered paper has increased in recent decades in developed economies, a trend that reflects the increasing supply of recovered paper and board from recycling collection schemes. However, this often leaves a surplus that can only be utilised productively outside the UK, rendering export to other countries the most viable option. Internationally, the dominant exporters are the US, Japan, UK, the Netherlands, France and Germany. The demand for this material comes from the major importers, mainly China. Overall the quantity



Number of UK waste electrical and electronic equipment recycling schemes

traded trans-nationally has more than doubled since 2000, a trend that is expected to continue[6].

Opportunities are growing for the recovery and reuse of plastics, electronic waste and textiles. As more secondary raw materials are produced, this increases the flows of plastics, paper and electronics, as well as refuse-derived fuels (RDF) and solid recovered fuels (SRF). These materials are often moving from western countries to the growing manufacturing centres across the world, and to where capacity exists for energy production from waste. For example, an increasing proportion of recovered plastics are being sent to China[6], the dominant destination for recovered plastics, and its demand for scrap plastics has consistently grown over the past 10 to 20 years. ISWA cites evidence that the Indian plastics conversion sector is growing rapidly, and is likely to become a strong market for recovered plastic polymers of good quality, including PP (polypropylene)[7]. Despite these factors, the report assesses the overall information on markets, and the mechanisms for the effective trade of waste plastics, to be poor.

However, it cannot be assumed that these materials will always have an external market. For example, Chinese customs authorities introduced 'Green Fence' controls in 2013 to exclude imports of contaminated recyclables, in order to ensure the quality of reclaimed paper and plastics. ISWA notes that China, in particular, is seeking to become more self-sufficient in generating these materials, and its imports of low-quality grades of mixed papers will start to decrease[7]. Therefore, as the UK increasingly has to compete with other countries for access to markets in newly industrialised countries that would like these raw materials, there will be a need to place more emphasis on quality, even if such materials are effectively being subsidised. Indeed, many of the issues leading to a poorly-functioning market for secondary materials link back to quality.

The markets for all secondary materials are subject to greater volatility in pricing than primary raw materials. Examining the recent data for paper and plastics shows that the volatility for these secondary materials is between three to nine times greater than for the primary raw materials (see Fig. 2). This exacerbates the difficulties that all businesses in the system face, from collection through sorting, processing to reprocessing.

Developing a secure reverse logistics solution for waste – either for reutilisation domestically, or for export – is therefore a pre-requisite for the future. Most importantly, there needs to be a fundamental shift in the attitude and behaviour of individuals and industries so that as much care is taken as possible in separating waste initially, and in ensuring it remains uncontaminated during the reverse logistics system that moves it to final reprocessing, in order to ensure the quality of the product.

One of the difficulties that much of the UK faces is that waste collections of recyclable materials from households, and often from commercial premises, are co-mingled and then sorted at a materials recovery facility (MRF). Co-mingled collection of recoverable waste from households is common practice in the US, and the UK adopted this approach – albeit with a composition that has more than twice the proportion of glass (10%) than the US[8]. Broken glass affects the output quality from most UK MRFs for paper and plastics. In contrast, other European countries require consumers to take glass products to local bottle banks.

ISWA states[2] that secondary raw material commodity markets are largely immature and lack: agreed global standards; effective dispute resolution procedures; data and information flows on secondary raw materials; and effective

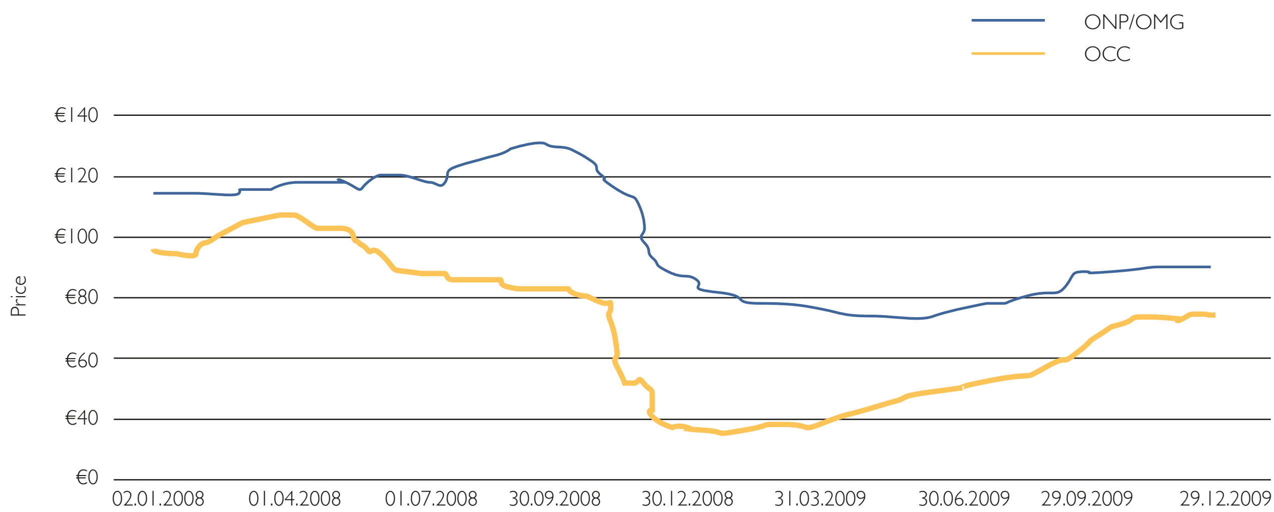


Figure 2: Recovered paper price fluctuations in Europe 2008 to 2009 – old newspapers and old magazines (ONP/OMG), and old corrugated containers (OCC).

Source: FOEX Indexes Ltd 2015, from ISWA (ref. 7)

price management risk strategies. Such immature markets are not places where participants will have confidence to buy without seeing the materials, or without having close working relationships with the seller. More needs to be done to create mature markets for materials, like the London Metal Exchange for scrap metals.

Learning from international best practice

Drawing on international experience in moving closer to a closed loop economy can be beneficial for the UK, providing there is a clear understanding of which practices are in need of improvement, and of their economic, political and social context. In addition, there may be a need to support and provide incentives to encourage the adjustments that will be necessary to introduce such international best practice effectively into existing arrangements.

An effective closed-loop system for waste minimisation and recycling is one that maximises the potential for sound resource management at every opportunity, and which adopts a cascade approach for reuse, recycling and resource recovery. The hierarchy adopted for exploring best practice examples with a closed-loop system is as follows:

1. Effective strategic planning for waste prevention, reuse of waste and resource recovery
2. Effective practice in waste prevention
3. Effective practice in reuse, recycling and resource recovery using a cascade model approach. As a concept, cascading originates with bio-based materials such as wood. At present, the cascading of plastics is not far developed, and there is room for further improvement. Iron could undergo a cascade utilisation, with some restrictions (the material is degraded by contamination with other metals, and the cascade does not end with incineration). Scientific and technical challenges such as material deterioration and the presence of hazardous substances, along with the need for investment to facilitate technological advances, may mean that it is not possible to fully close the loop. In those cases, the life of materials can be extended through effective practice in materials recycling, and through effective practice in treatment of organic waste.

Number of UK schemes for battery recycling

4. Effective practice in the treatment of residual waste. Circular flows will always have a residual waste stream because of market conditions, available technologies and/or social barriers. This residual waste stream needs to be treated as an important energy resource, but also as potential source of chemicals. This requires an assessment of the resource potential from residual waste, as well as effective practice in recovery of treatment residues.

Where United Kingdom waste minimisation and recycling practice is deemed to be below optimum efficiency and effectiveness, there could be merit in examining and learning lessons from current international practice. This section therefore presents some of the current best practice examples, while acknowledging both the difficulties in evaluation of effectiveness explained earlier, and the need to make judgements about what constitutes best practice based on accepted professional standards. The research and evaluation carried out by ISWA and its professional working groups (particularly the Recycling and Waste Minimisation Working Group) is therefore an important source evidence.

Best practice in strategic planning

Effective waste prevention measures are key to resource efficiency and the circular economy, and there is a need for consistent long-term policy, along with legal and fiscal frameworks to support sustainable resource management. With waste prevention being at the top of the resource management hierarchy, it is important that this aspect is emphasised in future plans for the UK's economy. Examples of where such best practice can be found internationally include South Korea, a country that in its response to the global financial crisis of 2008 decided to re-orientate its economic strategy. South Korea adopted a 'National Strategy for Green Growth 2009-2050'[9], putting environment and sustainability at the heart of its future industrial policy. The strategy aims to:

- Promote eco-friendly new growth opportunities
- Enhance peoples' quality of life
- Contribute to international efforts to combat climate change

South Korea also established a Presidential Commission on Green Growth in 2009, and enacted a Framework Act on Low Carbon Green Growth in 2010. The government spends about 2% of GDP on Green Growth programmes and projects.

The Netherlands changed its waste strategy into a 'resource strategy'. It also promotes green growth to generate economic growth while reducing pollution, ensuring efficient use of resources and maintaining natural assets. In addition, investment, competition and innovation in greener technologies helped to stimulate new economic opportunities. By 2009, all environmental efficiency indicators for emissions and waste in the Netherlands had improved compared with 2000. Austria has also adopted a waste management strategy that is based on a strict application of the resource management hierarchy.

In the field of demolition waste recycling, Denmark has a strict approach. Planning controls ensure maximum resource re-utilisation of the components and materials from buildings due for demolition. Sweden also uses planning controls to ensure potentially hazardous wastes are removed from such buildings, thereby ensuring that the materials obtained for reuse are not going to cause any future risk.

Best practice in waste prevention

A key aspect of waste prevention is to engage at the design stage, prior to manufacture. This engagement could be to secure:

- Design for long service life
- Design so the product is easy to repair
- Avoidance of toxic substances in the product
- Design for recycling
- Opportunities for components and materials within the waste stream to be designed into new products and retained in the remanufacturing of products
- Opportunities to displace primary raw materials and primary manufactured components
- Design accommodating safe final sinks for unusable materials

However, such changes must also demonstrably improve sustainability, and ISWA can offer advice on the availability of and specification of secondary raw materials[4, 7].

There are examples where industry has taken the lead in waste prevention because of the need to be able to control decisions in the supply chain. For example, vehicle manufacturer BMW sends all of its scrap metals and plastics to the original suppliers, and has procedures for the disassembly of its end-of-life vehicles (ELVs) that maximise the potential for reuse of parts and components, and for recycling materials.

Economic incentives are more limited at the household level, which means that it is a huge challenge to make households more resource efficient. Examples of best practice include the Netherlands, which has a 70% household waste recycling target and an extensive series of pilot programmes challenging families to progress towards zero waste generation. This programme has been funded by the government and is administered through the Royal Dutch Waste Management Association (NVRD).

Several municipalities in the Netherlands have decided to change their waste management system to collect only recyclable wastes from each household, requiring householders to deliver their residual wastes to central collection points. This was first undertaken on a pilot basis in part of the city of Zwolle, with the intention of rolling it out to the whole city. It is an increasingly popular model in other Dutch municipalities, with collected recyclables usually including: organic waste, paper and cardboard, and packaging waste (plastic, cartons and metals)[10]. Consumers are still expected to take their glass containers to local bottle banks. The residual waste and glass are usually deposited into underground refuse storage (URS) containers. These have small feed tubes, with waste dropping down into a 3-5m^3 steel container that can be hoisted out and emptied into a truck. In the UK, the London Borough of Tower Hamlets has pioneered this system since 2000, and Lambeth and Newham have recently followed suit. In the Netherlands, this system has often been introduced as an alternative to adopting pay-as-you-throw (PAYT – see Chapter 13).

Economic incentives are more limited at the household level, which means that it is a huge challenge to make **households more resource efficient**

A further development of sophisticated collection is the use of vacuum collection systems, which are more commonly used in other European countries and Japan. In the UK there is currently only one example, in a residential development in Wembley (see Chapter 11, case study on p161). These systems can be used to collect different segregated waste streams, as well as residual waste, and can be retrofitted into highly developed urban areas (eg the historic core of Copenhagen, and a 1970s development in Valencia, Spain).

Best practice in materials recycling

The main driver for recycling in the UK is avoiding the cost of landfill tax, plus a limited contribution from the extended producer responsibility (EPR) system for packaging. In the UK, EPR only indirectly benefits municipalities because there are many competing packaging waste compliance schemes. Unlike many other European countries, most states in the US, and provinces in Canada, which have a wider range of goods subject to EPR, the UK has adopted only the 4 EPR systems required by the EU. This covers packaging, waste electrical and electronic equipment (WEEE), ELVs and batteries.

In total, the UK has 52 packaging compliance schemes (plus the opportunity for individual company compliance): 29 for WEEE, 2 for ELVs and 5 for batteries. These competing compliance schemes give client companies a low-cost way of providing evidence that they have reached their combined recycling and recovery targets, especially for packaging. They do this by purchasing PRNs (packaging waste recovery notes) and their export equivalent, PERNs (packaging export recovery notes) from UK-based reprocessors and exporters (see Chapter 10). The packaging waste is predominantly recovered from commercial and industrial sources, and therefore the collection of packaging waste by local authorities is not supported by compliance schemes – it is only incidental, through the value of the material to a reprocessor such as a cardboard production mill. This system of competition for evidence of compliance was subsequently carried over to the WEEE system, but with even greater complexity: it involves designated collection facilities (DCFs), which are mainly household waste and recycling centres; approved authorised treatment facilities (AATFs); and UK reprocessors and exporters.

In other EU member states there are a variety of approaches to reclaim packaging waste, but most provide significantly greater support to municipalities that are instrumental in the earliest stages of collecting segregated packaging waste from households. Although the single national compliance schemes adopted initially in most EU countries now have an element of competition to meet the EU's competition requirements, the total number of those schemes is still less than for the UK alone.

There would be benefit in adopting an approach to use more money for promotional efforts to influence consumers to separate their waste more carefully. But with competition, it is difficult to justify such expenditure without some form of regulatory requirement. Examples of where such best practice can be found include Belgium with its Fost Plus packaging recovery system, which is often cited as a leader in the field. Fost Plus provides a national strategic approach to the recovery of packaging in collaboration with both municipalities and industry throughout both the packaging chain and the reverse logistics system from consumer to reprocessing. It also provides both promotion of the packaging waste recovery systems and feedback to consumers with regard to their contribution, which further reinforces their separation of recyclables.

Several EU member states, South Australia and several US states (along with companies operating there) also run deposit systems for beverage containers and other items, such as electrical and electronic equipment. Norway, for example, has developed a 21st century approach to beverage containers with a refundable deposit. The country has roughly 3,700 reverse vending machines (RVMs) that scan the barcode of PET (polyethylene terephthalate) bottles and aluminium cans, and then provide refunds to consumers – along with a wealth of information to Infinitum, the company running the system. It assesses the refunds for each individual type of packaging and generates promotional materials when a particular type of beverage container is achieving a lower return rate[11].

Best practice in the treatment of organic waste

Collection schemes for garden/green waste have been established widely across OECD countries[12]. A wide range of receptacles are used including wheeled bins, reusable PP bags, skips and road containers. Collection periods vary widely, especially for household collections.

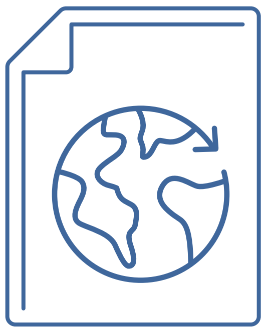
Consumers generate a massive quantity of food waste at a variety of locations, and many countries have launched campaigns to focus attention on reducing avoidable waste. The UK's Waste and Resources Action Programme (WRAP) has played a leading role in this internationally. At present, the methodologies used for treating this waste rely on either physical processing or biological treatment. The main challenges relate to improving capture rates and delivering clean, homogeneous organic wastes. For food wastes that cannot be prevented or redistributed, separate collection schemes have been widely established, especially in Europe. In 2012, for example, Milan launched a scheme to collect organic waste and use it to deliver compost and energy. By 2014, the city was collecting food waste from all households. Residential and commercial food waste is collected separately, diverting 135,000 tonnes per year from incineration to produce 18,000 tonnes of compost for agriculture; and capturing bio-methane to generate 12.8 megawatts of electricity that powers a nearby plastic reprocessing plant. To reinforce the transition to organics recovery, Italy also banned the use of non-biodegradable plastic bags in 2010, in order to improve the quality of its composting treatment operations.

Resource potential from residual waste

Within the UK, England has energy recovery plants and is constructing more, but 3 million tonnes of RDF and SRF is still being exported every year. A wide range of technologies could extract value from this residual waste, both for further resource use and especially as an energy source. Beyond the most commonly used method of incineration for heat and/or electricity generation, there are several other options, including:

- Waste vegetable oils to produce bio-diesel (see Chapter 6)

50%



Proportion of global paper market accounted for by recycled paper

- Anaerobic digestion of organic wastes
- Utilisation of landfill gas for a variety of options
- Processing of the organic fraction of residual waste for chemicals and fuels
- Depolymerising plastics waste to produce chemical feedstocks and energy products
- Gasification of residual waste for gases and liquid fuels

The easiest and most commercially successful option to date has been the use of landfill gas, which is generated by the natural biodegradation of organic wastes in a landfill site. The gas can be used to produce electricity on site or transported to nearby markets, such as brick kilns or for horticultural use. In a minority of cases, the gas has been processed to feed it into local gas distribution grids. The gas can also be used to power vehicles, especially for buses in Sweden, for example. This type of procedure is a positive by-product of the need to trap and treat the methane and other greenhouse gases entrained in landfill gas for environmental protection. Other options for turning waste into materials or energy products require more investment and have a potentially lower rate of return.

The organic fraction averages two-thirds of household and commercial waste, and around the world there are a number of projects and potential applications to extract chemicals or fibrous materials for energy. In the UK, there has been an agreement between the Danish company DONG Energy and Novozymes to build a plant in Northwich, Cheshire, which will recycle 120,000 tonnes per year of household waste and covert the remainder to biogas using enzymes. Other initiatives in the UK and elsewhere in Europe are at earlier stages of development.

Depolymerisation of plastic waste has been undertaken in several countries, including the UK, with mixed success. The most ambitious schemes are those to generate flows of gases which can then be recombined to create chemical feedstocks for plastics manufacture, while the majority are mainly concerned with producing substitute or synthetic diesel fuel. These include projects and proposals from

The organic fraction averages **two-thirds** of household and commercial waste

Swindon company Recycling Technologies, which aims to convert residual plastics waste to energy or a mixed plastic feedstock, depending on the composition of the waste (see Chapter 4, case study on p59).

In its least ambitious mode, the gasification of waste provides a gas flow that can be used as an energy source for a boiler to generate electricity and/or heat, as an alternative to direct incineration of waste for the same purposes. More ambitious options include the production of synthetic or substitute natural gas to be fed into the local gas grid system[13]. A more ambitious proposal from British Airways and US company Solena Fuels, which aimed to use gasification to convert 600,000 tonnes of residual waste per year into jet fuel, bio-diesel and renewable energy, was halted when the price of oil dropped dramatically in 2014. Pyrolysis is one method of gasification that has the potential to produce fuels in the form of solid char, liquid fuel and gas, usually through flash pyrolysis[14].

Effective practice in recovery of treatment residues

Most incinerator plants in the UK have either on-site, or more usually off-site, facilities that can separate ferrous and non-ferrous metals from incinerator bottom ash (IBA), and then process the rest of the IBA to produce secondary aggregates.

More sophisticated processing of incinerator residues could remove a greater proportion of metal content, as is done in Switzerland. One option is to use a dry IBA-handling solution, to maximise the recovery of metals (wet IBA picks up 30% minerals contamination from chemical reactions). In addition, dry processing makes it easier to extract smaller fractions of metal (less than 5mm) that are neglected by current processing methods. A further option used in Switzerland is to recover the 13% of metals that are incorporated in fly ash. An incinerator with a capacity of 200,000 tonnes per year would have a zinc fly ash content of 350 tonnes, and 170 tonnes of this is recoverable, plus smaller amounts of lead and copper, although the latter mainly comes from IBA.

Advances in **information technology** now enable the waste management sector to access real-time, **accurate data**

International collaboration

ISWA has an important role in bringing together practitioners and researchers from all sectors of industry to share knowledge and best practice. It achieves this through its publications, congresses and Beacon conferences, as well as the activities of its task forces and working groups. It also has a role in building skills to equip those working in the sector for the changes from a waste to a resource management industry. Co-operation with nationally-based professional bodies and other organisations will also be necessary to increase training and development capacity.

Other platforms that bring key people together include the G7 Alliance on Resource Efficiency, which was created after the G7 summit in 2015 as a forum to exchange and promote best practices, foster innovation and create information networks that include businesses and other stakeholders in the public sector, research institutions, academia, consumer groups and civil society. The Ellen MacArthur Foundation's CE 100 platform brings together 90 companies, including waste management companies, to accelerate the transition to a circular economy.

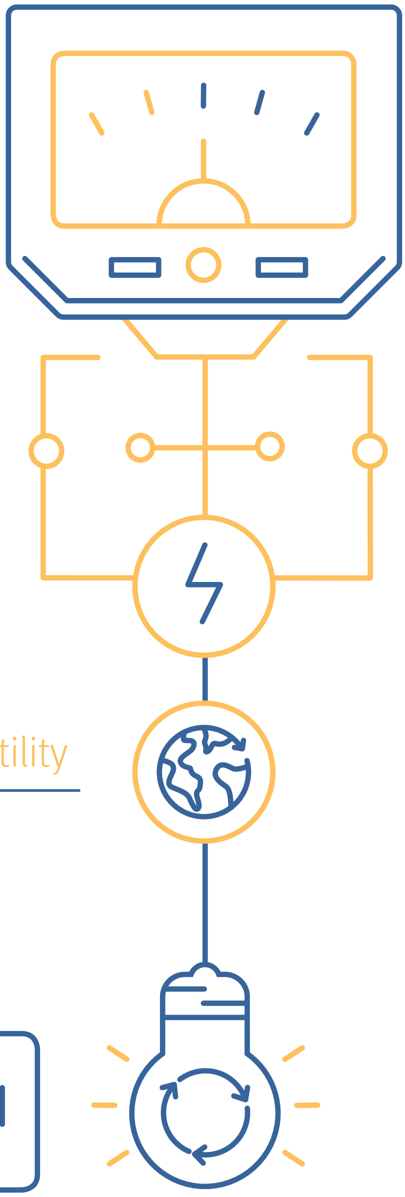
Given the nature of international markets, any effective interventions to support innovation in the design phase require mechanisms to facilitate interaction between waste professionals, designers and manufacturers at an international level, so that they can explore solutions for manufacturing products with sustainable materials management in mind.

Such a forum could also be a means of disseminating information and research findings on the recyclability of materials. ISWA suggests that key partners in this process will be organisations such as the European Innovation Partnership on Raw Materials (Resources), which aims to establish five new secondary sources of raw materials, fund 64 new business start ups and optimise recycling and material chains for end-of-life products[2].

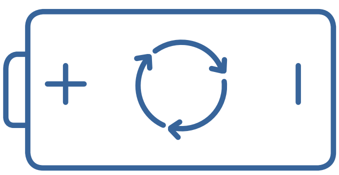
Continuing collaboration with the OECD countries allows access to forward thinking on a range of environmental issues, especially the role of environmental taxation and regulatory frameworks, many of which will have benefit for the UK's resource efficiency. For example, many countries are now using the OECD green growth indicators to measure their progress towards greater resource management.

Conclusions

While pioneering work has been undertaken locally and nationally in the UK, there are lessons to be learnt from overseas practices. Britain has a proven track record of innovation, and perhaps it should now utilise the advances that the Fourth Industrial Revolution offers. There is a need for all businesses to adopt a long-term strategy for maximising resource utility, in whatever part of the production and distribution system they function. Local communities and their elected leaders and municipal managers can improve both the local environment and resource recovery by empowering their citizens to manage their wastes more effectively. Regarding waste as a resource stream that can generate new business opportunities and create jobs will make the UK economy more resilient in the testing times that lie ahead.



> There is a need for **all businesses** to adopt a long-term strategy for **maximising** resource utility



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