

Technology Strategy Board

Driving Innovation



Resource Efficiency

Strategy 2009-2012

The vision of the Technology Strategy Board is for the UK to be a global leader in innovation and a magnet for innovative businesses, where technology is applied rapidly, effectively and sustainably to create wealth and enhance quality of life.

Our three-year organisational strategy is to drive innovation by **connecting** and **catalysing**. To achieve this we are focusing on three themes: challenge-led innovation, technology-inspired innovation and the innovation climate.

For more information on the overall strategy see **www.innovateuk.org**.

We have identified a number of application areas and technology areas on which to focus, and for which we are developing specific area strategies.

This document presents the strategy for the **Resource Efficiency** Application Area.

Foreword

The Technology Strategy Board aims to make the UK a global leader in innovation. Our job is to help ensure that the UK is in the forefront of innovation enabled by technology.

Our task is to *Connect and Catalyse*. As part of our challenge-led approach to innovation we treat societal and economic challenges of the future not just as threats but as opportunities for innovative solutions that enhance quality of life and increase wealth.

The world is changing. Globalisation, climate change and the growth of emerging economies present profound challenges to UK business sectors. Yet where there are challenges there are opportunities. Open access to global supply networks and emerging markets is easier than ever before; the highly skilled UK workforce, world class science base and open-market philosophy also put us in a strong position.

In this context the sustainable use of material resources is fundamental for achieving economic, societal, political and environmental benefits for the UK.

Opportunities to generate wealth through resource efficiency are not limited to one business sector but permeate the wider economy. We recognise the critical importance of lifecycle thinking, and the need to encourage innovation across multiple supply chains.

I welcome the importance accorded to materials security in this document. The low-carbon, resource-efficient economy will make use of a limited palette of high-tech materials. We need to pay particular attention to how we use these materials, recovering them efficiently at the end of a product's life, or using them less intensively to ensure that our technological options are not constrained.

This *Resource Efficiency Strategy* complements our other work supporting the low carbon agenda, such as the Low Impact Buildings and Low Carbon Vehicles Innovation Platforms. It also supports the broader environmental sustainability agenda. We fully recognise the magnitude of this challenge and look forward to working in partnership with key players to improve resource efficiency across a range of businesses, thus contributing to wealth creation in the UK.

Iain Gray

Chief Executive, Technology Strategy Board



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Executive summary

The issue of sustainability has attained unprecedented prominence on both national and international agendas, occupying the minds of businesses and governments as never before.

Globally, climate change is recognised as the most urgent environmental issue of our time. The *Stern Review of the Economics of Climate Change* set out a strong economic case for prompt action to tackle the effects of climate change, and the UK Government has been one of the first to act, with a range of measures that include the establishment of binding targets to cut carbon dioxide emissions under the Climate Change Act.

Reducing carbon dioxide emissions is not the only issue. Our growing population and improving standard of living mean that we will not be able to ensure access to the key resources our society is built on – whether it's food and water or minerals, metals and oil – if current trends in consumption continue. Governments and businesses are realising that solving this problem will provide major market opportunities, and that 'green' jobs and cleaner technologies can help us through the current economic difficulties, preparing for the prosperous UK industries of the future.

What is resource efficiency?

Resource efficiency is a broad area offering opportunities for innovation and wealth creation that permeate the wider economy. There is no resource efficiency sector *per se*, but a wide range of businesses and their supply chains responding to a common set of issues. Supporting these is a range of providers of products, processes and services, many of which form part of the traditional Environmental Goods & Services (EG&S) sector.

Resource efficiency has a key role to play in mitigating wider issues such as depletion of resources, environmental impact and materials security, and it also contributes significantly to the low-carbon economy. We have estimated the UK market value of this broad sector (see diagram) to be £50-75bn (see Appendix 4 for further details).

Our strategy

This strategy document sets out the Technology Strategy Board's approach to helping UK companies across a range of industry sectors to develop innovative solutions that add value, by embedding more reliability in the supply of material resources while reducing environmental impact. These solutions will be well-placed to generate competitive advantage and so wealth creation in the future.

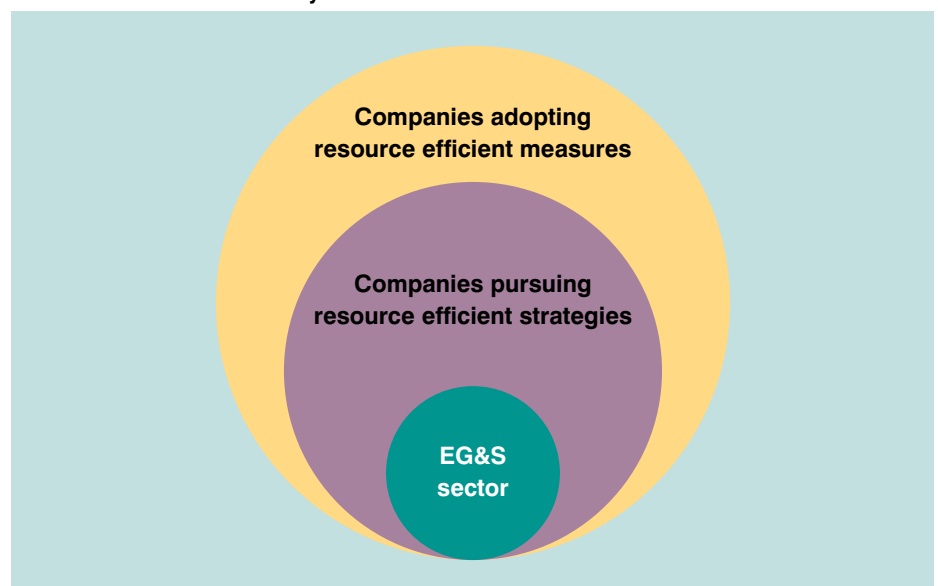
In the longer term, substantial improvements in resource efficiency will require a transition to (more) closed-loop

models of consumption, taking full account of the resource lifecycle. On a macro scale this implies the widespread adoption of principles of industrial ecology, and ultimately of a zero-waste model where all 'wastes' are eliminated or become raw materials for other uses.

We believe that the UK should:

- support the wider adoption of lifecycle thinking through the use of indicators and quantitative methods such as lifecycle assessment, embedded carbon and embedded water
- make greater use of its influence in product specification (at a business and European policy level) to reduce environmental impacts through global supply chains
- identify gaps in knowledge and data for fluxes of materials and the composition of waste streams, and work with bodies such as the International Panel for Sustainable Resource Management to address these.

Our view of resource efficiency sector - estimated market value £50-75bn



Our own investments and interventions in the resource efficiency arena will be guided by, and intended to promote, lifecycle thinking in patterns of resource use. We have identified **four broad approaches** that may be used to improve the efficient use of resources, at the same time reducing their environmental impact:

- substitute the use of at-risk materials or those that have a major environmental impact
- close the lifecycle loop to enable the same resource material to have multiple product lives
- dematerialise – reduce the total amount of material that needs to be used to deliver a consumer benefit
- reduce the amount of energy used over the lifecycle.

These approaches are underpinned by nine competences spanning the lifecycle:

- resource extraction
- bio-based materials
- design
- materials processing
- manufacturing
- service provision
- retail and distribution
- recycling
- disposal (waste and pollution management).

We have examined each of the four approaches in the context of these nine competences. Our initial assessment is that it is better to focus our investment on the four approaches, rather than target any of the nine competences specifically.

We recognise the importance of waste and pollution management as mitigation technologies, and will undertake focused activities in these areas where there is demonstrable benefit and market opportunity.

This strategy recommends actions for the Technology Strategy Board in five discrete areas:

Collaborative R&D

We will:

- run collaborative research and development competitions aimed at meeting specific challenges and appealing to a broad spectrum of business – spanning the four approaches and lifecycle areas described in this strategy
- consider a broader range of investment tools to encourage greater and more effective engagement with business. This could include feasibility and scoping studies for companies new to the field or with limited R&D experience.

Transferring knowledge and skills

There are many opportunities to generate wealth by working to transfer and share knowledge in the resource efficiency sector, ranging from tailoring techniques and processes to individual user needs, through to transferring knowledge and technology across sectors and along supply chains.

We will:

- create a new knowledge transfer network to stimulate the transfer of knowledge between businesses, academics and individuals. This will be formed by combining the Resource Efficiency and Environmental Knowledge Transfer Networks to provide focused support to those working in environmental sustainability
- support the formation of special interest groups, made up of businesses, academics and industry bodies, across a range of knowledge transfer networks to develop cross-sectoral activities in support of the work to address the challenges in the environmental sustainability area
- work with our partners delivering the knowledge transfer partnerships and through the knowledge transfer networks to increase the number and range of knowledge transfer partnerships in the resource efficiency sector.

Working with UK organisations

We recognise that resource efficiency is a broad area that permeates the wider economy. To support the development and deployment of innovations in resource efficiency we will need to engage with other organisations. These include:

- a range of businesses and sectors
- regional and national government (eg the Department for Environment, Food and Rural Affairs; the Department for Business, Innovation and Skills; devolved administrations; and regional development agencies)
- public bodies (eg the Environment Agency, Design Council and Carbon Trust)
- funders of fundamental research (eg the Natural Environment Research Council, Engineering and Physical Sciences Research Council, Biotechnology and Biological Sciences Research Council, and Economic and Social Research Council)
- agencies for market development (eg the Waste and Resources Action Programme).

We will:

- work with businesses, funding bodies and key organisations to identify those areas where the Technology Strategy Board can add most value, and to develop a delivery plan that provides a coordinated and effective response to the challenge to improve resource efficiency.

In particular, we will work with appropriate partners to identify and develop tools to support innovations such as:

- design and product conceptualisation
- changes in business models; for example, extending product lifetimes through the delivery of products as services
- understanding and accommodating human and business behaviours.

Working with international partners

There is broad scope to work with international partners, whether to inform and influence policy development, to share knowledge and best practice, or to participate in large-scale collaborative projects that span the supply chain.

In the short term we will:

- focus on Europe, including working through the new knowledge transfer network to identify opportunities for engagement.

Information gaps and measurement

We will:

- assess capacity in the UK to reduce the total amount of materials necessary to produce goods or deliver services
- work with other organisations such as the Natural Environment Research Council to address gaps in data and develop a framework to assess and prioritise reliability in the supply of raw materials and the global impact for materials that are important for UK business
- develop appropriate ways to measure resource efficiency and sustainability to assess and track activities within the area of environmental sustainability.

1. Scope

The Environmental Sustainability Application Area covers four broad areas:

- resource efficiency (including waste and pollution management, and energy from waste)
- energy efficiency
- water supply, sanitation and use
- the agrifood sector.

This document sets out our approach to the first of these four areas, while recognising that resource efficiency is closely related to the other areas.

We regard the following as separate application areas, and they are therefore excluded from the Environmental Sustainability Application Area:

- Energy Generation and Supply (including carbon abatement technologies, and carbon capture and storage) [1]
- Transport [2].

Similarly, many innovations that contribute to environmental sustainability are described in our other strategy documents. The principal areas of overlap are described in Appendix 1.

For the purposes of this document, we have used the following definitions:

- **Resource efficiency:** the delivery of benefit to the customer (industry or consumer) with the optimal use of material resource across the lifecycle of a product

- **Waste:** discarded end products or by-products that at the moment are not used in other products or processes. Waste streams (the flow of waste material from generation to treatment to final disposal) range in nature from inert materials to hazardous wastes. A cost is typically incurred to treat and/or dispose of them.

- **Pollution:** the impact of dispersed matter released to the environment during the production, use or disposal of goods or services. A cost is typically incurred to prevent or reduce the impacts of pollution.

These definitions are consistent with the 'waste hierarchy', a concept under which activities such as eliminating or minimising waste, reusing material and recycling are encouraged as being more desirable than disposing of waste and recovering energy. Managing waste and pollution may be viewed as necessary economic activities to compensate for using resources inefficiently.

2. Background and context

Environmental sustainability forms the seventh of the UN's eight Millennium Development Goals for 2015 [3]. Included within this goal is the objective to 'integrate the principles of sustainable development into country policies and programmes [and] reverse loss of environmental resources'.

The UN's fourth *Global Environmental Outlook* report (GEO4) provides a comprehensive assessment of the current state of the world's atmosphere, land, water and biodiversity [4]. While there has been some progress in addressing 'easier' environmental problems such as ozone-depleting chemicals, there remains a raft of substantive and persistent problems that threaten sustainable development. Many of these problems owe their origin in part to our inefficient use of resources.

The term 'ecological footprint' has been developed to describe humanity's demand on the Earth's ecosystems, in terms of the area of biologically productive land and sea required to provide the resources we use and to absorb our waste [5]. Globally our average ecological footprint has already reached 1.3 Earths (based on 2005 data), and if every person

on the planet were to adopt a North American lifestyle we would need five planet Earths. Environmental policymakers recognise that we are living beyond our planetary means, and that we need to move towards consumption and production patterns that are more in keeping with 'one planet living'.

The world's population, which stood at 6.7 billion in 2007, is forecast to reach 9 billion by 2050 [4] and then to stabilise or decline moderately. Per capita consumption is highest in the developed world but there is growing pressure from emerging economies. The most significant of these is China, which is expected to rival the US in terms of GDP by 2020 and to account for as much as a 22% of world GDP by 2030 [6]. The combination of population growth and increasing affluence has led to a dramatic increase in the rate of resource depletion, described in section 2.1.1.

2.1 Trends and drivers

A range of drivers impinge on the issue of environmental sustainability, including environmental degradation and loss of biodiversity. In this strategy document

we outline the three drivers we consider most relevant to resource efficiency, and the opportunities it presents to generate wealth for the UK:

- resource depletion
- materials security
- climate change.

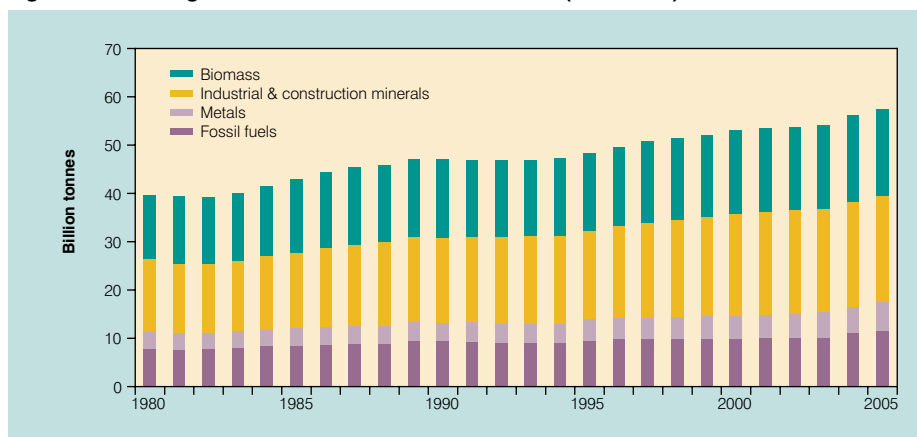
2.1.1 Resource depletion

Ever-increasing human activity means that we are depleting natural resources at an unprecedented rate. As Figure 1 shows, over the last 25 years the global extraction of natural resources has grown by 45%, from 40bn tonnes in 1980 to 58bn tonnes in 2005, and is forecast to reach 80bn tonnes by 2020 [7].

Asia's share in the amount of resources extracted globally has increased steadily, especially since the early 1990s, reflecting the increasing industrialisation of countries in that region. In China, the extraction of fossil fuels tripled from 1980 to 2005, and more recently there have been significant increases in resource extraction associated with the production of copper and other metals.

Such pronounced increases in demand have resulted, inevitably, in increases in the price of materials. Some metals reached prices as high as four times their previous level over the period 2002-08, and the price of oil peaked at \$145/barrel in mid-2008. Prices have since decreased dramatically as a result of the global economic downturn that started in late 2008, but in the long term price instability is a risk that will become increasingly important for many businesses in their strategic planning.

Figure 1 – Annual global extraction of natural resources (1980-2005)



Source: Sustainable Europe Research Institute

2.1.2 Materials security

Materials security is concerned with the ready access to raw materials at the time when they are needed, and is of fundamental importance economically.

A number of industrialised countries have recognised their critical dependence on particular raw materials and in some cases have implemented policies to mitigate this. For example, a Japanese Government agency, the Japanese Oil, Gas and Metals National Corporation, manages stockpiles of rare metals in co-operation with private companies to maintain stocks equivalent to 60 days' national consumption.

In the US, a 2008 preliminary report identified five materials that are highly critical and suggested a framework for assessing others [8]. In the same year, the European Commission (EC) adopted a communication proposing a Raw Materials Initiative [9]. The communication identified, as a priority, the need to work with Member States and stakeholders to develop a list of critical non-energy raw materials.

Two main components contribute to materials security:

- the absolute availability of that material (ie how much accessible material there is)
- the extent to which its supply might be restricted by bodies controlling access to it.

A variety of factors may contribute to a high level of materials insecurity, which may be based on 'material risk' or 'supply risk' (Table 1). A recent report, commissioned by the Resource Efficiency Knowledge Transfer Network (KTN), produced an approximate ranking of 69 elements and minerals according to these material risk and supply risk criteria [10].

Table 1 – Material risk and supply risk criteria

Material risk criteria	Supply risk criteria
<ul style="list-style-type: none"> ■ High global consumption levels ■ Lack of substitutability ■ Potential to contribute to global warming ■ Total requirement for the material 	<ul style="list-style-type: none"> ■ Scarcity ■ Monopoly supply ■ Political instability in key supplying regions ■ Vulnerability to the effects of climate change in key supplying regions

Materials security is a growing issue not only for precious metals such as gold, silver and some platinum group metals (palladium, platinum, rhodium and ruthenium), but also for more abundant metals such as cobalt and tin. There are concerns about the long-term availability of even common metals such as copper, nickel and zinc.

The potential impact of a reduced supply of raw materials can be appreciated by considering the range of applications, both current and potential, of these materials (Table 2). Many advanced consumer products rely on a range of 'hi-tech' materials (see table below) that are predominantly imported and may be at risk; some new environmental technologies that are important contributors to a low-carbon economy also require these materials. In some cases, these materials are produced as minor by-products of others (eg tellurium and rhenium), and it would be difficult to increase the supply to meet the significantly increased demand resulting from a new application. Future generations may not have ready access to these hi-tech materials, and may have to use a more limited palette of materials to develop new products.

Furthermore, the environmental impact associated with extracting these resources tends to increase over time as the most abundant reserves are exhausted and poorer ones start to be

exploited. For example, the concentration of copper in copper ore has decreased from approximately 12% in 1750 to less than 1% now. On a global scale the environmental impacts of the extractive industries include a significant contribution to climate change, with over 5% of global carbon dioxide (CO₂) emissions being attributed to mining, extraction and the production of primary metals (including steel) [11].

2.1.3 Climate change

Globally, climate change is recognised as being the most urgent environmental issue facing humankind. The European Union has proposed that the global temperature should not exceed an average of 2°C above pre-industrial temperatures [12]. In the UK, the 2008 Climate Change Act commits us to legally binding targets to reduce greenhouse gas emissions by at least 80% by 2050 and CO₂ by at least 26% by 2020, relative to a 1990 baseline.

A portfolio of approaches will be necessary to achieve these reductions and at the same time maintain a comparable economic output and standard of living. Low-carbon energy technologies and energy-efficient products (including transport) will be the most effective methods, but greater resource efficiency will also make a significant contribution.

Table 2 – Some hi-tech materials and their current/potential applications

Material	Current and potential applications
Palladium, platinum	Emissions prevention (eg catalytic converters), fuel cells and catalysts for chemical processes
Cobalt	High-performance alloys, rechargeable batteries and fuel cells
Silver	Advanced optics, solar cells, catalysis and nanotechnology (eg antimicrobial products)
Gold	Advanced optics
Rare earth elements (scandium, yttrium and the lanthanides)	Fuel cells, high-performance magnets and optoelectronics (eg lasers)
Indium	Liquid crystal displays, light-emitting diodes, photovoltaics, semiconductors, low-melting-point alloys and high-performance mirrors
Ruthenium	Hard disk drives and miniaturised components
Tantalum	Miniaturised components, in particular for mobile phones
Gallium	Semiconductors for optoelectronic devices (eg laser diodes and light-emitting diodes) and solar cells
Rhenium	High-performance alloys (eg for jet engine components) and catalysts
Tellurium	Metal alloys, semiconductors (eg phase memory chips and thermoelectric devices) and optical media (eg rewriteable CDs)

That contribution is expressed through the notion of 'embedded carbon', a concept that sums the energy inputs (in terms of their associated carbon dioxide emissions) for a product or material throughout its lifecycle. If that product or material is discarded after its first use, then those energy inputs will be incurred again to produce more of the same. Where there is an opportunity to extend the lifetime of the product and/or close the material loop – through recycling or service-based methods such as remanufacturing – the energy inputs are generally lower with the net result that less CO₂ is emitted per unit of service.

While we recognise the impact of embedded carbon in material resources, the focus of this strategy is on materials security and the environmental impact of resource efficiency. The embedded carbon benefits of resource efficiency complement programmes focusing on low-carbon technologies at the Technology Strategy Board, in particular the innovation platforms for Low Carbon Vehicles and Low Impact Buildings, and the Energy Generation and Supply Application Area.

2.2 Valuing sustainability

Historically, many people have regarded environmental technologies as a cost imposed on businesses. The recognition that sustainable products and processes have intrinsic value is a relatively recent development, but one that has gained considerable momentum.

One approach is to ascribe a value to goods and services that protect the ecosystem, such as climate regulation, water regulation and supply, and waste treatment. The value of the world's

ecosystem services was first estimated to be around US\$33trn in 1998, compared with the global gross national product of US\$18trn [13]. Economic activity depends largely on the availability of these ecosystem goods and services, yet often their value is not fully 'captured' by economic markets.

Various accounting methods have been developed that attempt to recognise the economic, societal and environmental aspects of sustainability. This has been referred to as 'full-cost accounting' or 'true-cost accounting' and the technique of taking all three aspects of sustainability into account is known as 'triple bottom line' reporting.

An expanding group of global leading companies, and many smaller ones, have embraced the principles of 'corporate social responsibility' in their strategic planning. A 2008 survey found that nearly 80% of the world's largest 250 companies are reporting on their social and environmental performance, compared with 50% in 2005 [14]. The UK's leading companies are particularly active, with 91% reporting on corporate social responsibility among the sample researched.

Among the broader business community, resource efficiency is increasingly being seen as a means to reduce costs, improve competitiveness and generate new commercial opportunities. A recent survey from the Engineering Employers' Federation shows that almost two-thirds of UK companies identified resource efficiency among their top three environmental concerns, with 'carbon emissions' cited by over two-fifths of companies [15].

2.3 Policy and regulation

Environmental market opportunities are heavily influenced by government policy and the regulatory and market mechanisms deployed to implement it. Policy targets worldwide are ambitious in terms of promoting resource efficiency and reduced CO₂ emissions.

Japan and South Korea are adopting the 'reduce, reuse and recycle' (3R) approach to move towards a 'Sound Material-Cycle Society'. Chinese policy advocates a 'circular economy' in which the 3R concept is combined with a closed-loop model for the manufacture of goods and delivery of services.

Closer to home, a large body of European policy relevant to resource efficiency illustrates the timeliness of this issue in political thinking. The EC is developing a 'Thematic Strategy on the Sustainable Use of Natural Resources', following the publication of the *Action Plan on Sustainable Consumption and Production* in July 2007 [16].

In the UK, a 2007 report by the Commission on Environmental Markets and Economic Performance (CEMEP) set out to advise the UK Government on how the UK could make the most of the potential economic benefits of the transition to a low-carbon, resource-efficient economy. Its recommendations included measures relating to environmental policy (eg better regulation and a credible long-term price for carbon), 'market pull' (eg the creation of lead markets), and 'supply push' (eg effective investment in new technologies and skills) [17].

While over-regulation impedes business, intelligent and well-signalled regulation enables businesses to make strategic decisions to address emerging environmental challenges and so develop a competitive edge. An increasing number of businesses have called for appropriate regulation to provide clarity in environmental markets [18].

Relevant UK policy documents and EU/UK legislation are presented in appendices 2 and 3 respectively.

2.3.1 Market incentives

Governments can employ a variety of levers to implement policy, either before or instead of regulations or legislation. These levers can encourage market development (eg environmental taxes and phase-out of non-compliant products) or market creation (eg procurement initiatives and environmental investment funds). Some examples of these are described below.

Landfill tax has been an effective way of encouraging more resource-efficient options for waste management. In the UK, the standard rate of landfill tax is £40 per tonne in the 2009-10 tax year and will increase by £8 per tonne each year to reach £72 per tonne in 2013-14. There are now around 450 landfill sites compared with 1,200 in 2001; the co-disposal of hazardous and non-hazardous wastes is banned, as are some waste streams such as whole and shredded tyres. The Landfill Allowance Trading Scheme and the corresponding Landfill Allowance Schemes in Scotland, Wales and Northern Ireland are 'cap and trade' schemes for biodegradable municipal solid waste, intended to reduce landfill disposal rates to 35% of 1995 levels by 2020.

Carbon pricing is another example of a cap and trade scheme, intended to accelerate the development of low-carbon technologies. For the EU Emissions Trading Scheme, each EU Member State Government sets emissions limits for all installations in their country covered by the scheme. Each installation is then allocated an allowance or cap, which can be met either by reducing emissions to below that level, or buying allowances from other participants in the EU emissions market which have achieved a surplus (by reducing emissions below their cap).

The price of carbon on the EU Emissions Trading Scheme was €10-30 per tonne of carbon dioxide equivalent (CO₂e) for much of 2007-09 [19]. The Confederation of British Industry (CBI) has estimated that in the future carbon will need to cost significantly more (peaking at €60-90 per tonne of CO₂e around 2020) to provide sufficient market impetus to bring about the introduction of new technologies to achieve the UK Government's goals to reduce CO₂ emissions [20].

Government procurement, amounting to over £220bn annually in the UK, is potentially a powerful lever to create a critical mass of demand for resource-efficient products in embryonic markets. The UK Government's Sustainable Procurement Task Force produced a national sustainable procurement action plan in 2006 [21]. The Treasury and the Department for Environment, Food and Rural Affairs (Defra) are working together to ensure that procurement supports sustainability through various targets, including an objective that by 2020 the Government estate should reduce its waste by 30,000 tonnes and recycle around 65,000 tonnes of waste.

Forward Commitment Procurement

has been proposed as a tool to stimulate environmental innovation. This entails the buyer specifying its future needs in advance and agreeing to buy a product that does not yet exist, provided it conforms to agreed levels of performance and cost [22]. The SBRI (Small Business Research Initiative) scheme, managed by the Technology Strategy Board, has been launched to encourage the use of Government research budgets to develop innovative products in a range of sectors.

3. The resource efficiency challenge

The global consumption of goods and services will increase as the world's population increases and more of its people enjoy a degree of affluence approaching that of the developed world. At the same time, the population of the developed world will continue to aspire to a high standard of living.

Meeting today's level of global demand is placing increasing stress on the environment and has resulted in significant environmental degradation, which so far has largely been confined to a local or regional scale. If current patterns of resource use do not change, these impacts will be greater and more widespread and, particularly in the case of climate change, are likely to be global in scale.

Higher demand globally is likely to be accompanied by higher and/or more volatile prices for raw materials. In the case of critical raw materials that are highly insecure, the lack of access may impede the development of new and existing commercial applications. In other cases, the imbalance between supply and demand may be relieved by exploiting

new, less abundant reserves, but this is likely to have a higher environmental impact than exploiting current reserves.

To ensure a sustainable future, radically different patterns of resource use will be needed. This presents both a major challenge, and a major opportunity for the UK to generate wealth.

The UK Government has signalled its intention to **make the transition to a low-carbon, resource-efficient economy**, using its extensive knowledge and skills base to the best effect.

A step-change improvement in resource efficiency and radically better use of waste streams have a key contribution to make to that competitive position.

The role of the **Technology Strategy Board** is to **invest effectively** to help ensure the UK gains a **leading position** in the **resource-efficient industries of the future**.

Our focus is on the supply-side aspects of the challenge to improve resource efficiency, as technological innovation has the greatest potential to reduce the impacts of production on resources. We recognise that it is equally important, however, to address demand-side issues, and will work with other organisations to understand how technology can contribute to reducing levels of consumption; for example, through extending product lifetimes through more durable and/or serviceable products. We also recognise that technological innovations may be subject to rebound and displacement effects, whereby an individual or society absorbs savings and replaces them with other activities that may be even more harmful to the environment.

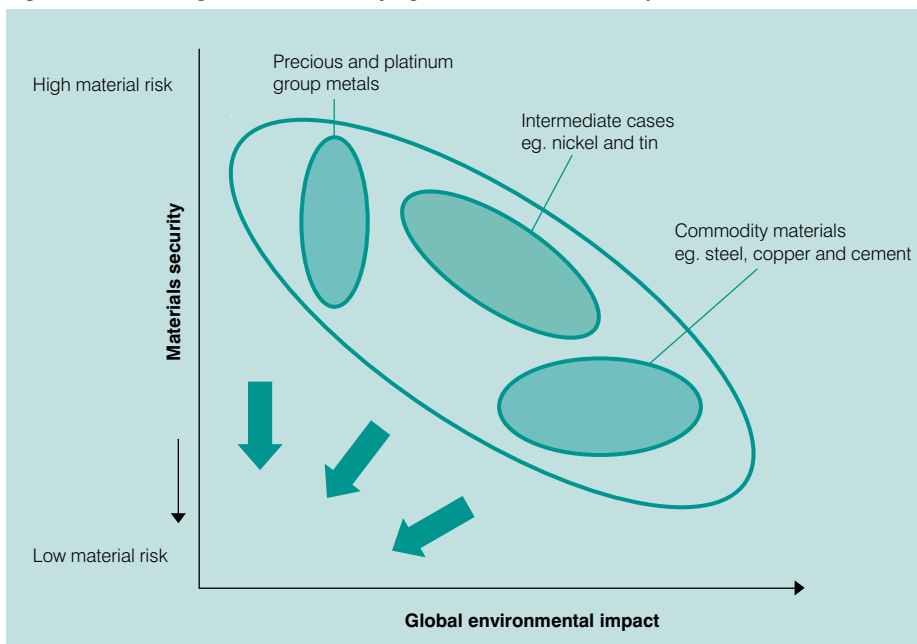
3.1 Our strategic approach

In prioritising the Technology Strategy Board's investments and activities in the resource efficiency sector, we seek to balance materials security and environmental impact to identify new opportunities to generate wealth for the UK. For this purpose, in some cases the carbon footprint may be a suitable proxy for assessing relative environmental impact; in others it is one of several contributors that need to be considered in combination.

Our strategic approach is represented schematically in Figure 2, which plots the security of materials against global environmental impact. We aim to improve the security and reduce the impact of materials by moving them away from high risk (top) and/or high impact (right), towards low risk and/or low impact (indicated by the arrows).

This picture is a simplification of the true situation, as both axes represent complex variables that depend on a range of factors. In some cases it will be clear which driver is most important.

Figure 2 – Balancing materials security against environmental impact



For example, materials security is the prevailing driver for a rare, poor-grade ore precious metal such as rhodium, which has a high environmental impact per kilo but is produced in small volumes (and therefore is less significant in global terms). In contrast, the global environmental impact is more important for commodity materials such as steel, copper and cement; these raw materials are distributed widely and abundantly, and processed on a large scale.

For intermediate cases, such as the metals nickel and tin, the situation is more complex. It may warrant further study to produce a framework that would enable factors for both materials security and global environmental impact to be assessed and weighted consistently. This framework could examine whether

CO₂ emissions are a good proxy for environmental impact, or whether the material risk is dominated by supply risk criteria, such as a limited number of suppliers.

In practice, individual materials will appear at several points on this diagram rather than at a single point, reflecting a range of sources and production methods. A material's position may move over time; for example, as technological innovations enable the exploitation of less abundant reserves that are geographically more dispersed. For example, at the moment the exploitation of bio-based resources would generally be considered low material risk and low environmental impact, but if these materials were to be produced on a large scale they might migrate to areas of concern.

3.2 Importance of lifecycle thinking

To use resources more efficiently it is essential to consider the lifecycle of the resource, which typically encompasses multiple product lifetimes. The opportunities to improve the resource efficiency and decrease the carbon intensity of products are not limited to a specific stage of the lifecycle, and improvements at one stage may have an adverse impact on another. The greatest benefits accrue by moving from a linear lifecycle (extract–consume–waste) to a closed-loop process, and there is a rich literature on approaches such as 'cradle-to-grave' or 'cradle-to-cradle' resource management [23].

Environmental Impact Analyser

The Environmental Impact Analyser is a tool to help businesses develop more sustainable products.

It was developed jointly by ICI Paints (Akzo Nobel), Forum for the Future and Carillion Building as part of a collaborative R&D project supported through our 'Zero emissions enterprise' competition.

ICI Paints has used the Analyser to launch a range of Dulux paint that has a significantly lower impact on the environment.

The Analyser assesses each stage in the lifecycle of a product and enables businesses to compare an existing product against a proposed new one, and to quantify the change in carbon, water and waste.

A key to the success of the Analyser is that its method is rigorous enough to be reliable but streamlined enough to be usable. It gives percentage savings compared to a specific baseline, not an absolute figure. A detailed lifecycle

analysis or carbon footprint would require a much larger investment of time and money than is often feasible.

The aim of the project was to identify the impacts arising across the lifecycle of paint – from the production of raw materials, to manufacturing, transport, use and final disposal. This work highlighted the production of raw materials at the stage that had the highest impact.

ICI Paints began investigating how to develop new paints from lower impact raw materials, but it needed to understand if this would achieve a sizeable improvement. The Analyser enabled ICI Paints to compare new paint formulations against its existing product and to quickly get meaningful answers about how well they reduced environmental impacts. For example, in the Dulux™ Trade range, new products have been developed that have 25–30% less embodied carbon and 49–84% fewer volatile organic compounds.



The Analyser has maximised the influence environmental considerations have had on decision-making, allowing ICI Paints to make informed choices based on quantitative evidence, and to communicate complex environmental issues in a clear way to the rest of the business and its customers.

A range of tools and techniques has been developed to understand and manage the inevitable trade-offs between different parts of the lifecycle. These tools range from qualitative rules of thumb through to fully quantitative analyses such as lifecycle assessment, which are conducted to a recognised international standard (ISO 14040:2006). Which tool is most suitable will depend on the needs of, and resources available to, the user, as well as the stage of the innovation cycle.

Figure 3 depicts a simplified resource lifecycle and four approaches to using resources more efficiently. Activities within the dashed box constitute the productive use of resources.

The four approaches are:

- **substitution**: using materials that are more secure and/or have a lower environmental impact
- **closing the lifecycle loop**: using the same material over multiple product lives
- **dematerialisation**: using less material to achieve the same benefits for consumers
- **reducing energy intensity**: achieving the same effect using less energy over a lifecycle.

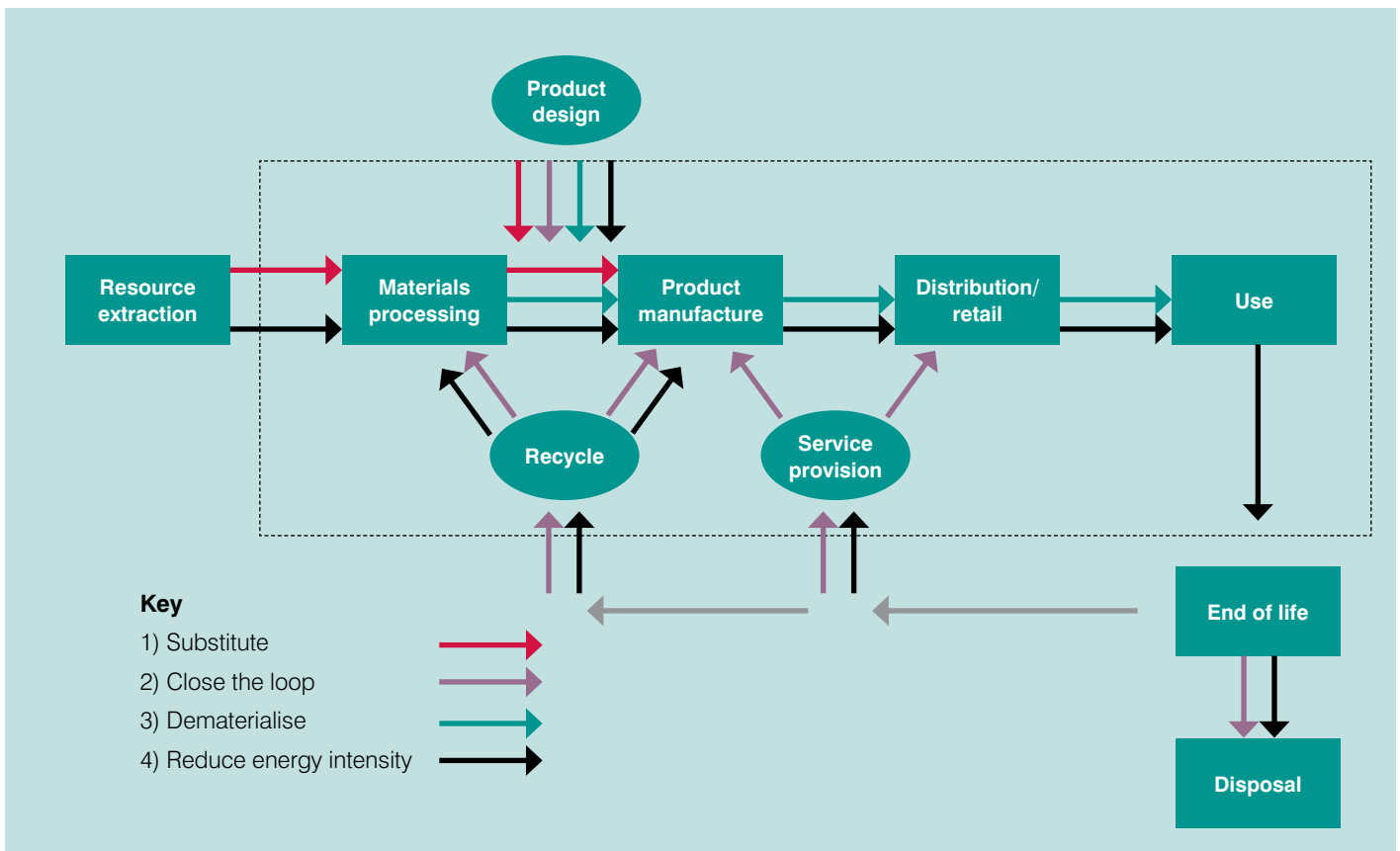
3.2.1 Substitution

Substitution may be applied at the level of the component, product or system; for example, by incorporating substances that have less impact on the environment or that are less hazardous, or by redesigning a component so that it requires fewer materials or steps to assemble.

At the component level, bio-based materials offer the benefit of locking up atmospheric CO₂ during the product lifetime, and, if sourced responsibly, may also present wider sustainability benefits. They can also form a 'closed loop' if they are composted or digested and returned to the land at the end of their life.

Other substitution strategies include using multifunctional materials that enable products to be reformulated; and in the

Figure 3 – Simplified resource lifecycle and four ways to improve resource efficiency



field of catalysis, developing alternatives to materials whose supply is at risk, such as the platinum group metals.

Substitution can have profound implications for other lifecycle stages and the supply chain, and the impacts of these will need to be properly assessed. Impacts could include revalidation and qualification of manufacturing processes, or compromises in product performance and process efficiency; for example, poorer selectivity or a higher operating temperature for a non-platinum group metals catalyst. Other conflicts may occur at the end of the product's life; for example, bio-based plastic bottles and rigid packaging have poor compatibility with existing facilities to recycle high density polyethylene (HDPE) and polyethylene terephthalate (PET).

3.2.2 Closing the loop

Innovations for closing the product lifecycle loop take a range of forms but broadly comprise:

- recycling, remanufacturing and reuse
- eliminating dispersive losses of material during the lifecycle.

The main technological challenges relate to improving design for recycling, developing methods for processing large amounts of waste, and the identification, separation and recovery of high-value components from waste streams. Market development for products made from recycled materials and schemes that encourage consumers to change their behaviour also have an important role to play. A market opportunity exists to manage waste electrical and electronic

equipment (WEEE); this contains significant quantities of valuable or at-risk metals and materials within larger volumes of commodity or engineering plastics.

Design has an important contribution to make; for example, by taking into account the ease of remanufacture or repair during the specification process, and considering how compatible the materials are with the available infrastructure and recovery practices. Reverse logistics, the development of non-linear supply routes and waste management infrastructures, will also play a role in delivering extended producer obligations, whereby manufacturers assume some responsibility for the product at the end of its life. In some sectors this is driven by legislation such as the End-of-Life Vehicles Directive.

Carbon negative buildings (ModCell™)

Straw has been used as a construction material for centuries, providing super-insulation using renewable materials. Often used in 'eco-projects', it has never achieved widespread acceptance because the traditional hand-crafted approach cannot compete with conventional construction methods and materials for mainstream projects.

ModCell is tackling this problem by creating high-performance, high-tolerance, engineered straw bale panels that can be assembled to create low-energy 'passive' buildings using renewable, locally sourced, carbon sequestering materials. The technology was developed in part with the assistance of a collaborative R&D project, through our 'Design and manufacture of sustainable products' competition.

The ModCell panels are timber-framed, filled with straw bales and coated with a

protective lime render in a mobile Flying Factory™, close to the construction site to minimise transport miles. The panels have excellent fire resistance and acoustic properties, and have almost three times the insulating performance that is required by building regulations.

ModCell panels have already been used in commercial projects for offices and public buildings. ModCell has now developed a whole house based on ModCell panels. The prototype BaleHaus reduces the total energy needed for heating, cooling and appliances by over 50%, and the energy for heating by over 80%.

Because the natural materials used in ModCell panels sequester CO₂ during their working life, a typical BaleHaus



'banks' a net 22 tonnes of CO₂ after allowing for the energy used in manufacture and construction. This 'carbon credit' is enough to offset 10 years of BaleHaus energy needs using fossil fuels, and over 40 years if the energy is supplied from renewable, grid-based sources.

A BaleHaus home is designed to be dismantled, reused and recycled at the end of a typical 100+ year life.

www.modcell.co.uk

3.2.3 Dematerialisation

Dematerialisation is generally defined as the reduction of mass intensity or waste generation related to a unit of economic output. At the micro level it relates to decreasing the mass intensity per unit of service. It is based on the principle that reducing the amount of material contained in a product will reduce the amount of waste and pollution.

Dematerialisation is not a well-defined discipline but rather a convenient term for a range of approaches. Dematerialisation can be applied to products, systems and services, as the following examples show:

- liquid products can be reformulated into more concentrated forms (a product innovation)
- structural components can be made lighter – ‘light-weighting’ (a system innovation)
- car sharing may be supported in city centres (a service innovation).

With dematerialisation, the total mass of materials used to make a product is important, not just the weight of the final product. The ‘ecological rucksack’ – the amount of material moved to produce one kilogram of a material or product – is a powerful illustration of material intensity (Table 3).

In many product sectors dematerialisation occurs as products evolve, as technological innovations offer new ways to offer customer benefits. Dematerialisation can result in positive environmental change but aspects such as product durability, integrity, longevity and functionality need to be considered. For example, products should not have a shorter lifespan as a result of dematerialisation, and it should not be applied simply to create more disposable products.

REFLATED – from pixels into crystals

Liquid crystal displays (LCDs) are ubiquitous in modern life, appearing in everything from watches and mobile phones to laptops and televisions. Over 3 billion LCD devices were manufactured in 2006 including over 300 million large-area devices such as televisions and computer displays.

Each year millions of LCD screens go to waste in the UK alone – to landfill or incineration. Valuable materials are lost in this process, including indium (a metal in short supply), liquid crystals (which can cost more than gold) and high-quality glass.

REFLATED, a project funded under our ‘Zero emissions enterprise’ collaborative R&D competition, has been set up to demonstrate novel technologies for disassembling liquid crystal panels and integrating these with existing WEEE recycling systems. The consortium has developed a best practice guide, with Active Recycling Ltd offering an accredited training course for LCD recycling, and a pilot plant is under development to separate these three materials.



‘There is no doubt this is an increasing waste stream,’ said Arnold Black of C-Tech Innovation and director of the Resource Efficiency KTN. ‘Just take a trip to your nearest civic amenity site to see the piles of LCD TVs and monitors waiting to be scrapped. This project offers the prospect of a closed-loop process to recover the indium, which we believe will become economic when indium prices rise again. Most of the materials can be recovered – for example, the glass screens could be recycled into glass fibre where their inclusion in the ‘melt bath’ as a fluxing agent also lowers the energy cost.’

Approaches such as light-weighting need to address the whole system (‘right-weighting’) rather than focus on individual components, and impacts at the end of life such as recyclability need to be considered [24]. Significant benefits of dematerialisation are evident at the retail/distribution stage of the lifecycle, in terms of reduced transport costs and better use of valuable shelf space.

Table 3 – Ecological rucksack of some common materials

Material/product	Ecological rucksack (kg)
Rubber	5
Steel	21
Aluminium	85
Recycled aluminium	3.5
Gold	540,000
Diamond	53,000,000

3.2.4 Reducing energy intensity

Reduced energy costs in manufacturing and processing contribute directly to a company's bottom line. The prospect of high or volatile energy prices and the need to contribute to national carbon targets (governmental or sectoral) are further incentives to reduce energy consumption, which will require radical innovation across a range of production technologies.

There are opportunities for businesses to develop technologies and innovations that will reduce the amount of energy expended per unit of service or unit operation. These opportunities arise within three broad areas:

- point sources: large sites operating energy-intensive processes
- dispersed sources: emissions from common processes that have a large cumulative impact
- industrial ecology approaches to match heat sources and heat sinks, including small-scale combined heat and power (CHP).

Examples of point sources include resource extraction, primary metal manufacture and the chemical industries. Manufacturing cement is particularly energy intensive, accounting for as much as 5% of global CO₂ emissions produced by human activities. Many of these industries fall under the remit of the EU Energy Trading Scheme and as such required to pay a price for carbon emissions beyond an allocated cap.

Lighter glass packs

'ContainerLite' was an industrial collaborative project that aimed to reduce glass waste by exploring the most effective ways of light-weighting bottles and jars in conjunction with the supply chain. Consumer perception research by the Institute of Psychological Sciences at the University of Leeds aimed to understand perceptions of glass as a packaging material and to gauge sensitivity to weight changes. This enabled Coors, Burton on Trent, to lightweight its Grolsch bottle. The primary target to deliver weight savings of 7,400 tonnes (to which Grolsch alone contributed 4,500 tonnes, without affecting the overall shape or style), was achieved by the project's completion.

The secondary target, to work with glass manufacturers to gain an additional 30,000 tonnes of savings per annum within 12 months of the project's completion, also made significant progress. 'ContainerLite' was a Waste and Resource Action Programme (WRAP) funded project managed by the Packaging Materials Link.



Examples of processes contributing to emissions from dispersed sources include heating, cooling, transporting materials (including pumping of liquids), mixing and separation processes. There is scope for the introduction and development of technologies such as more efficient boilers, waste heat recovery and CHP, advanced process plant design and process control.

In the wider economy there are opportunities to reduce the amount of energy used in transport and logistics, as well as improving the efficiency of energy-using products. A recent report estimates that ICT equipment accounts for about 10% of the UK's total energy consumption [25].

4. Sector overview

There is no resource efficiency sector *per se*, but rather a wide range of businesses and their supply chains responding to a common set of issues.

This is summarised in Figure 4. The outer circle comprises all companies that are adopting resource-efficiency measures, which may be part of a broader programme such as improving manufacturing efficiency. A sub-set of these (the middle circle) are companies pursuing an explicit resource-efficiency or sustainability strategy.

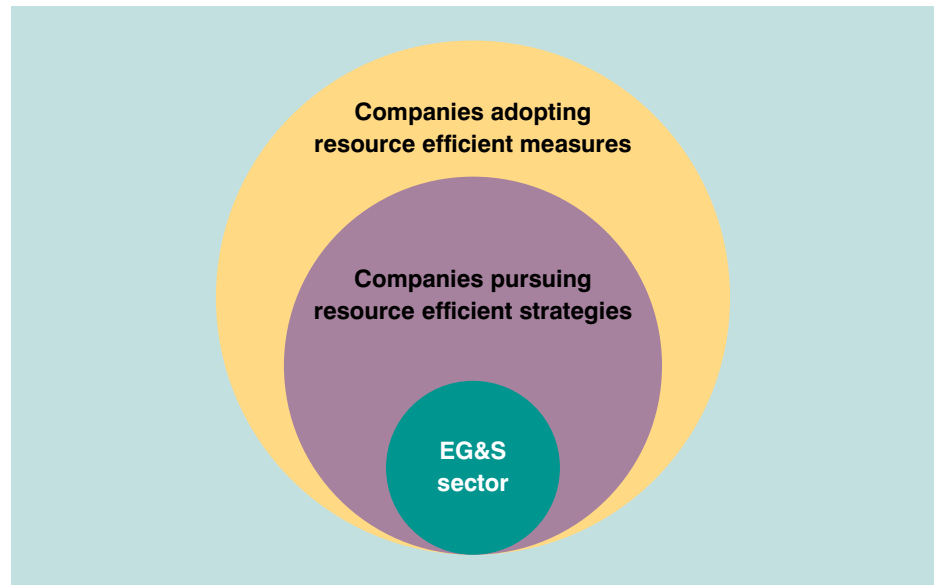
Supporting these is a range of providers of products and services including consulting and engineering firms (the inner circle). Many of these activities fall into the Environmental Goods and Services (EG&S) sector which is well-described and for which good market data exist.

The broad and pervasive nature of this sector has been recognised in several analyses: the CEMEP report [17] characterises the transition to a low-carbon, resource-efficient economy as a development that will 'stimulate the development of new business models, products and services, transform existing sectors of the economy and create entirely new industries'; and an Ernst & Young report states that 'green business' will affect the entire economy [26].

With this in mind, we estimate the UK resource efficiency sector to have a market value of around £50-75bn but it could be significantly larger depending on how the broader sector is defined. Evidence to support this estimate is presented in Appendix 4.

The market for resource-efficient products, processes and services is distinct from the cost benefits of deploying them. The latter is an important motivation for UK business, with the cost of waste disposal alone currently amounting to 4% of its annual turnover and set to rise to 6% with planned increases in landfill tax [27].

Figure 4 – Our view of the resource efficiency sector



A report commissioned by Defra estimated the benefits of 'low-cost/no-cost' resource efficiency measures (pay-back period less than one year) to range from £5.6bn to £7.4bn annually [28].

4.1 Market opportunities

4.1.1 Design

Businesses are recognising more and more the importance of design as a differentiator. In a 2007 survey of manufacturing companies, 55% saw design and development as one of their most important sources of competitive advantage in five years' time [29].

This shift in emphasis, coinciding with greater awareness of sustainability issues along the supply chain and on the part of the consumer, presents an opportunity for businesses to differentiate on the grounds of better performance, in terms of both functionality and environmental impact. An additional legislative driver will be provided by EU legislation in the form of the Energy Using Products Directive and the Eco-design Directive (in preparation).

Market opportunities include:

- making incremental improvements around an existing product
- designing and re-designing products based on a comprehensive assessment of the lifecycle
- designing new products incorporating radically new technologies that substantially improve resource efficiency
- integrating eco-design principles across a range of business activities.

4.1.2 Deriving value from biomass

The global market for biofuel feedstocks is expected to move from increasingly expensive first-generation feedstock (oil seed rape, palm oil and corn) to second and third-generation biofuels, which potentially are more efficient, both economically and in terms of resource use. Potential short-term constraints on market growth include the availability of feedstocks, competition with other uses for land (amenity, development and agriculture), and manufacturing capacity.

Other markets for bio-based materials include pharmaceutical ingredients, enzymes, biopolymers, packaging, composite materials and sustainable construction materials. A fuller treatment of opportunities for bioenergy and biofuels is provided in our strategy for the Energy Generation and Supply Application Area, and underpinning technologies are described in our strategy for the Biosciences Technology Area [30].

4.1.3 Resource efficiency services

One of the strongest recent trends in UK manufacturing has been the blurring of the traditional division between manufacturing products and providing services. A similar trend is observed in other sectors, where a move to a service-based business model is seen as a way to capture greater added value from a company's knowledge base and also to build longer, closer relationships with customers to generate longer-term revenue streams. At the same time the traditional environmental services sector is changing its focus from 'end-of-pipe' issues to providing more integrated services and developing new products and services.

Market opportunities include:

- inventory management and advice
- end-of-life value recovery such as remanufacturing
- ICT-based services for collecting, analysing and sharing data
- new distribution channels for recycled/reused goods
- new forms of contractual arrangement (eg leasing rather than sale of goods).

Companies are more aware of the benefits of using resources more efficiently, but there is still scope to improve the understanding and take-up of managing resources across various business sectors. The wider opportunity is for companies to fully integrate these considerations into their business management.

4.1.4 Energy from waste

Energy from waste (EfW) is the generic term for a range of technologies that extract the energy stored in waste materials into useful forms such as fuel, heat and/or electricity. It has been estimated that these could contribute as much as 17% of all UK electricity consumed by 2020 [31].

EfW is the largest source of renewable energy (30%) in the UK, comprising 1.5% of total electrical generation capacity. It complements other renewable technologies by providing a backload of generation capacity irrespective of the ambient conditions. Market barriers include obtaining acceptance and

planning approval as well as structural issues; for example, how can efficient CHP systems be connected to, and effectively used by, the local infrastructure, or how can biogas be injected into the grid. There are also opportunities for small-scale in-house technologies, such as CHP or anaerobic digestion, to treat waste on-site.

As Table 4 shows, the Environmental KTN has estimated that for EfW to deliver the targets for 2020 set out in Defra's 2007 *Waste Strategy*, a capital expenditure of over £15bn will be needed, and the potential annual market will approach £2bn [32].

Table 4 – Potential market for EfW technologies in the UK

	Number of new plants needed	Potential annual market	Total capacity outlay
Biological anaerobic digestion	288	£400m	£1.44bn
Thermal treatments gasification/pyrolysis/mass burn incineration	180	£1.57bn	£13.6bn
Total biological and thermal treatment	468	£1.97bn	£15.04bn

Source: *The Business Case for Energy from Waste 2007*, Environmental KTN

5. UK capability

5.1 Underpinning competences

A range of competences will need to be mobilised by businesses to contribute to the four approaches set out in section 3.1. Figure 5 summarises these nine competences and outlines some of the technologies and innovations that support them.

In this section, each of the stages is rated against the Technology Strategy Board's four criteria for investment (see below). The ratings of low, medium or high reflect the fit with these criteria. At a higher level, we have rated innovations in resource efficiency high in terms of timeliness and impact, and also in terms of the Technology Strategy Board providing added value.

Technology Strategy Board's criteria for investment:

- Does the UK have the capability to develop and exploit the technology?
- Is there a large market opportunity?
- Is the idea ready?
- Can the Technology Strategy Board make a difference?

5.1.1 Resource extraction

Fit against criteria for investment	
UK capability	High
Global opportunity	High
Timeliness & impact	High
Added value	Medium

The total value of annual mined production worldwide is around US\$450bn, with US\$200bn of this being attributed to coal/lignite, US\$150bn to metals (and gems), and US\$100bn to industrial minerals and aggregates [33]. Exploration budgets for non-ferrous metals totalled \$12.6bn in 2008, and for ferrous metals \$10bn in 2007 [34].

Much extraction of primary resources now takes place overseas, but historically many global extractive industry companies were established in the UK and they maintain a strong commercial or technical presence here to this day.

The value of UK construction and industrial minerals production 2007 was £29.09bn, including production of primary aggregates of over 220 million tonnes [35].

The sector broadly comprises the extraction of energy sources, construction minerals, industrial products and metals. The environmental and societal impacts of the extractive industries tend to be large, wide-ranging and long-term owing to their scale and nature of operation. A small improvement in efficiency can make a substantial difference in terms of environmental and economic performance. The sector has been an early mover in developing sustainability strategies; for example, benchmarking performance using recognised reporting frameworks such as the Global Reporting Initiative [36].

5.1.2 Bio-based products

Fit against criteria for investment	
UK capability	Medium
Global opportunity	High
Timeliness & impact	High
Added value	Medium

The UK has good capability in developing bio-based materials and products from agricultural and forestry renewable feedstocks and others (for example, incorporating CO₂ and methane into chemical feedstocks). While the UK has limited manufacturing capability for bioplastics, it has relevant expertise in compounding and processing plastics, and also in manufacturing composites.

Bio-based products are estimated to account for 10% of global chemical sales by 2010 (\$125bn) rising to \$250bn in 2020 [37]. One source estimates that a third of all chemicals and materials will be produced from biological sources by 2030 [38].

Biotechnology is seen as being pivotal to the European economy and a growth sector for the UK [39]. Broader competencies will be required, in particular drawing on the strengths of the UK chemicals industry and science base to exploit high-value products, or to work with a wider range of feedstocks, including cellulose biomass. New supply chains will need to be constructed to do this effectively, bringing together partners from sectors such as the food, agricultural and chemicals industries with the emerging science base.

Exploiting biological feedstocks on a large scale will have implications regarding sustainability, and in particular may compete for land that is now used for agriculture or habitat. A lifecycle assessment of bioplastics suggests they generally present advantages over their petrochemical counterparts [40], but for biofuels the evidence is less clear cut [41].

Figure 5 – Technologies that support the stages of a product lifecycle

Competence	Substitute	Close the loop	Dematerialise	Reduce energy intensity	Supporting technologies or innovations
Resource extraction	L	M	L	H	Separation technologies Low-energy mechanical processing Selective hydrometallurgical, electro-winning and extraction processes
Bio-based materials	H	L	L	M	Novel biochemical and chemical approaches for biomass processing Separation and purification technologies Bio-based additives and modified materials to extend technical characteristics such as heat resistance and mechanical strength Technologies for biofuels/biorefineries
Design	H	H	H	H	Ecodesign Lifecycle assessment, lifecycle tools and techniques, predictive modelling Systems thinking/integration Design for disassembly/reuse/recycle/remanufacture Computer simulation of material properties Digital technologies for design, knowledge management (product data representation and exchange and lower-cost prototyping)
Materials processing	M	M	L	H	Processes for lightweight materials and structures, including composites and hybrids Smart and multifunctional materials, nanomaterials Surface modification and coating technologies
Manufacturing	M	L	M	H	Particulate engineering, near-net shape manufacturing Process intensification Atom-efficient and cleaner chemical technologies, lean manufacturing Distributed manufacture and mass customisation techniques Remanufacturing Advanced automation and control systems
Service provision	L	H	H	L	Development of new business models to support delivery of product service systems Asset condition monitoring for inspection, maintenance or repair
Retail and distribution	L	M	M	L	Global logistics and supply chain management Responsible sourcing protocols Consumer engagement and communications Product labelling (eg ecolabel)
Recycling	M	H	M	M	Advanced joining and breaking technologies Sorting and segregation technologies Closed-loop service models Market development for products made from recycled materials
Disposal (waste and pollution management)	M	-ve	L	M	EfW technologies and anaerobic digestion, incineration with CHP, gasification, pyrolysis Technologies that are economic at smaller scale/more tolerant of heterogeneous waste compositions Hazardous waste treatment technologies Site investigation, risk assessment, management and prevention technologies

5.1.3 Design

Fit against criteria for investment	
UK capability	Medium
Global opportunity	Medium
Timeliness & impact	High
Added value	High

The UK is home to several internationally-recognised design and architectural practices, noted for their iconic products. The design industry employs 62,000 people in the UK, delivering services to the value of £7bn (fee-based income and turnover) [42].

There is a strong science base for lifecycle assessment, design tools and other environmental impact assessment methodologies. Some larger companies across a range of businesses have in-house capability, and external practitioners also provide support as part of the £750m environmental consultancy services sector. The Design Council’s ‘Designing Demand’ programme provides a way of introducing design to industrial environments.

The design stage correlates most strongly with all four approaches to the challenge to use resources more efficiently. As much as 70-80% of the environmental impact of a product – and a similar proportion of its costs – is locked in at the design stage. Tools and techniques have been developed to help integrate eco-design principles in the design process, from simple rules of thumb and hierarchies of materials and processes, through to software that incorporates the latest environmental data about materials and components.

However, barriers exist to improving resource efficiency at the design stage. Many designers work on a contract basis to a customer’s specifications, and there may be limited opportunity to discuss making modifications. Assessing the lifecycle and supply chain adds considerable complexity, and time may not have been scheduled to allow for this. What is more, the various parties may not share a common technical vocabulary.

5.1.4 Materials processing

Fit against criteria for investment	
UK capability	High
Global opportunity	High
Timeliness & impact	High
Added value	High

Businesses in the UK that produce and process materials have an annual turnover of around £200bn. The supply, primary production and processing of raw materials contribute around £25bn GVA to the UK each year. UK industrial capability for materials processing spans a range of materials from metals (ferrous, aluminium and titanium) and commodities (glass, plastics, paper and paper board) to high-value materials (polymer matrix composites, ceramics and fibres).

Our *Advanced Materials Strategy* [43] identified the areas of energy, sustainability and high-value markets as priorities for investment in high-added-value products and services. Within the area of sustainability, we recommended a focus on transport, construction and the ‘reduce, reuse and recycle’ agenda.

5.1.5 Manufacturing

Fit against criteria for investment	
UK capability	High
Global opportunity	High
Timeliness & impact	High
Added value	High

The UK is the world’s sixth largest manufacturer by GVA. Manufacturing contributes £150bn to the UK economy and accounts for 50-55% of exports, many of which are high-technology goods. Productivity has increased by 50% since 1970, and the sector accounts for 75% of business R&D [44].

Our *High Value Manufacturing Strategy* identified nine technologies that support the four pillars of manufacturing innovation (products, processes, service systems and value systems) [45]. Many of these technologies contribute to the UK’s capability for resource efficiency, including:

- resource efficient and sustainable processes
- disposal and recycling
- whole life planning
- design and innovation process
- collaboration within extended operations and resulting in global value networks.

Remanufacturing is a significant if not prominent sector in the UK, with an estimated market value of £5bn in 2004 [46]. The economic and environmental benefits of remanufacturing can be substantial. A report on innovation in environmental services [47] cites the

example of construction and mining equipment manufacturer Caterpillar, which has found that remanufactured components such as diesel engines can have 85% lower energy costs and 60% lower materials costs than their new counterparts. The reprocessing of 'end-of-first-life' vehicles and components is now a significant activity at its site in Shrewsbury.

Remanufacturing accounts for a small percentage of manufacturing turnover, but growth should be stimulated in specific product areas by legislation that places responsibility on producers, such as the End-of-Life Vehicles Directive. Higher-value remanufacturing market opportunities often involve a strong knowledge transfer component and may well entail a service-based business model for example through condition monitoring or inspection/ servicing after an agreed period of use.

5.1.6 Service provision

Fit against criteria for investment	
UK capability	Medium
Global opportunity	High
Timeliness & impact	High
Added value	High

Over two-thirds of manufacturers now offer services on the back of production, compared with 50% in 2007 [48]. Approximately 18% of UK manufacturers now offer a whole-life service package to customers, from design and development through to end-of-life.

The broader service sector accounts for over 75% of the UK economy. Sustainability, more specifically aspects relating to resource efficiency, has been identified as a common driver for innovation in five service sectors (retail, logistics, construction, environmental services and internet delivered content) that jointly account for 25% of UK GVA. Capability for service innovation does not rest solely in R&D expenditure but more in intangibles such as developing closer communication with customers and up the supply chain.

5.1.7 Retail and distribution

Fit against criteria for investment	
UK capability	High
Global opportunity	High
Timeliness & impact	High
Added value	Medium

UK retail sales were £278bn in 2008, of which sales by predominantly food stores were over £127bn. The retail sector generated almost 8% of GDP and provided employment for over 2.8 million people, as at the end of September 2008 [49].

Retailers represent the front line in terms of engaging with consumers and they also exert a powerful influence over the logistics and supply chain. They are faced with both an opportunity to differentiate brands and also a challenge to reduce complex arguments for sustainability to a simple message for frequently time-poor consumers.

Some retailers have published ambitious, high-profile sustainability strategies while others prefer a lower-key, step-by-step approach. Approaches range from pro-actively introducing minimum sustainability standards in some product categories on behalf of the customer, to providing information on a range of indicators to inform consumer choice.

Freight and logistics is a significant industry sector, contributing £75bn to the UK economy and employing 2.3 million people across 190,000 companies [50]. The transport of goods has increased as supply chains have lengthened in the increasingly global economy.

5.1.8 Recycling

Fit against criteria for investment	
UK capability	Medium
Global opportunity	High
Timeliness & impact	High
Added value	Medium

The global recycling industry processes more than 500m tonnes of waste annually, employs over 1.5m people and has an annual turnover of approximately \$200bn [51]. The UK recycling industry has a turnover of over £6bn, of which metals recycling accounts for approximately two-thirds.

The recycling of pre-consumer (industrial) waste is significant but data for this are not widely available. Recovery and recycling of scrap are widely implemented as good

manufacturing practice. There are opportunities elsewhere in the supply chain; for example, 40% of recycled packaging plastics are plastic films recovered from wholesale and distribution activities, with transit and secondary packaging accounting for a further 10% [52].

Recycling of post-consumer waste has increased steadily over the last decade, from below 10% in 2000 to an average household recycling rate that is now over 35%. There is a strong policy driver to increase this further, with national targets to recycle and compost 40% of household waste by 2010 and 50% by 2020 [27].

The traditional reliance on landfill has meant that the UK has been slow to develop the infrastructure to process secondary materials. Major capital expenditure items are frequently sourced from overseas, and recovered materials are often exported as there is insufficient capacity to treat them in the UK. However, there are promising signs of growing capability: some small and medium-sized enterprises are developing and applying technologies; an increasing number of expert university groups [47]; and organisations such as WRAP are developing the market.

5.1.9 Disposal (waste and pollution management)

Fit against criteria for investment	
UK capability	High
Global opportunity	High
Timeliness & impact	Medium
Added value	Medium

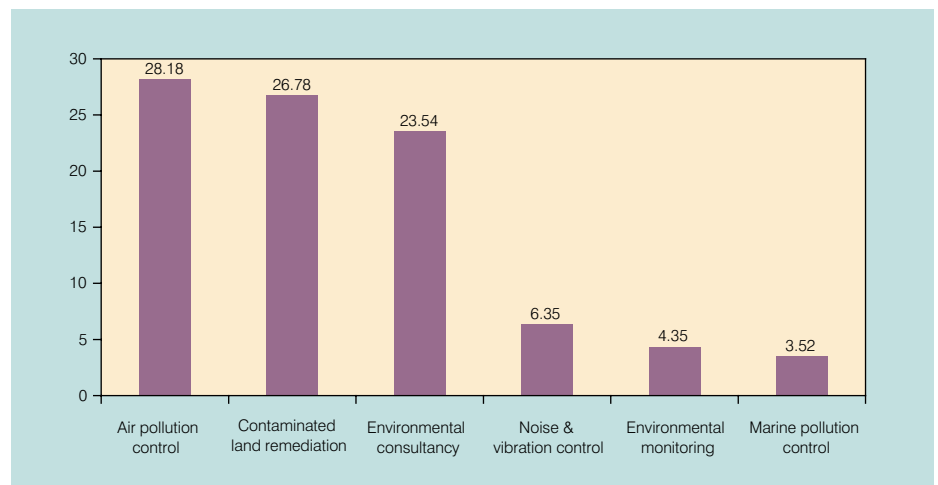
Waste management in the UK is a significant sector with over 3,000 companies employing over 70,000 people [47]. Six large companies dominate the delivery of waste management services, and many companies in the sector are integrated waste management firms that offer a range of services including domestic and private collection, treatment, recycling, composting, energy-from-waste and landfill. Several smaller technology providers offer expertise in areas such as anaerobic digestion, pyrolysis and plasma treatment.

The global waste management market (excluding recycling and recovery) has been estimated to be worth over £140bn [51]. A total of 2.12bn tonnes of waste were generated in 2007, and this is set to increase significantly, driven by growing incomes and expectations in the emerging economies. The amount of waste generated by China already exceeds that of the US and is expected to double to around 500m tonnes by 2030 [53].

The UK needs to invest substantially in waste management infrastructure over the next 20 years to meet its 2013 and 2020 landfill obligations; it needs an estimated 9m tonnes of processing capacity for municipal solid waste alone [54]. This would require capital expenditure of around £5-6bn to achieve the 2013 target for municipal solid waste and a further £4-5bn to achieve the 2020 target, set out in the Government's *Waste Strategy* [27].

The global secondary EG&S markets (excluding water and wastewater treatment, waste management, recovery and recycling) are valued at £92.72bn, with the largest sectors being air pollution control, contaminated land remediation and environmental consultancy (Figure 6) [46]. The UK has good capability in each of these three sectors, with strengths in contaminated land remediation, in particular for site investigation, risk assessment, and management and prevention technologies. An internationally-active consultancy sector is supported by a strong UK academic base.

Figure 6 – Global secondary EG&S markets (£bn)



Source: Innovas Solutions, commissioned by BERR (2009) *Low Carbon & Environmental Goods & Services: an Industry Analysis*. See also Appendix 4 for UK market data

5.2 Cross-cutting issues

5.2.1 Human and business behaviours

People's buying habits and attitudes to consumption are influenced by many factors, and consumers can find it difficult to trade strongly marketed short-term considerations such as convenience and ready availability for longer-term considerations such as durability, recyclability and wider environmental impacts. Conversely, products that are strongly marketed on their 'green' credentials are unlikely to be adopted by the mass market if they are not comparable in terms of performance and price.

Better information and product labelling have a role to play, and more proactive consumers may turn to third-party validation of product claims. There is some evidence that increased consumer awareness is being translated into improved environmental performance across a range of products [55].

Behavioural factors can be important in other areas such as a preference to own a product rather than purchase a service, and reluctance to separate waste for recycling. Eco-efficient buildings frequently operate significantly below their design specification because people use heating, cooling and appliances in a way that was not designed for.

Many business models are based on selling large volumes of materials or goods, and may be predicated on generating regular sales through in-built product obsolescence or fashion. Modifying products so that they last longer, or introducing a closed model to allow recovery of the material resource will require a challenging shift in business behaviour.

5.2.2 Measurement and standards

Measurement and standards have an important role to play in stimulating innovation and enabling individuals and organisations to make the best decision. CEMEP has recommended using 'dynamic' standards which specify performance beyond that of current products to drive improvements in resource efficiency, particularly at the EU level [17]. Product standards can be particularly effective when linked to procurement policy, where the default option might otherwise be to replace like for like rather than specify more efficient alternatives.

The ISO 14001, ISO 14004 and BS 8555 standards relate to the development and integration of environmental management systems, and are supported by a raft of standards on auditing, labelling, environmental performance evaluation, lifecycle assessment, environmental communications, and greenhouse gas management. ISO 14062 provides guidelines on integrating environmental aspects into product design and development, but at the moment it offers guidance only and may not be used for certification.

Recent developments include the publication of BS EN 62304 and IEC 62430 (ecodesign of electrical and electronic components), and the UK-based PAS 2050, a publicly available specification that encourages consistency when assessing lifecycle greenhouse gas emissions of goods and services. A series of publicly available specifications focusing on waste and recycling are now being developed.

Further opportunities to develop measurement and standards to support innovative technologies include:

- measurement technologies for determining the properties of materials and processes
- modelling tools for designing more resource and energy-efficient products

- better methods to determine the level and nature of contaminants in a variety of (mixed) material streams
- methods for quickly determining the composition of materials (linked to sorting technologies)
- measures and definitions for biodegradable products
- methods and systems for storing and retrieving information about the components and materials used in complex products
- methods for monitoring the condition and structural health of products during their extended lifetime.

5.3 UK landscape and funding

The UK business support landscape for innovation in resource efficiency, and the Technology Strategy Board's position within it, are summarised in Figure 7. During the early stages of the technology development process, at technology readiness levels (TRLs) 1-2 [56], a range of research council programmes and projects contribute to the knowledge base and academic capability in the area of resource efficiency; the work of the Engineering and Physical Sciences Research Council (EPSRC), Natural Environment Research Council (NERC), Biotechnology and Biological Sciences Research Council (BBSRC) and the Economic and Social Research Council (ESRC) is particularly relevant (Table 5).

Priority areas for the EPSRC [57] are 'Energy' and 'Nanoscience through engineering to application', and with other research councils it has identified 'Living with environmental change' as an area for support. NERC's strategy [58] includes three priority areas of interest: 'Sustainable use of natural resources', 'Environment, pollution and human health' and 'Technologies'. The BBSRC [59] has 'Bioscience for industry' as a priority science area, which includes bioprocessing, bioremediation and renewable biological

sources of industrial materials. The ESRC has identified 'Energy, the environment and climate change' as a key research challenge for the social sciences [60]. Table 5 lists major programmes relevant to resource efficiency in which research councils participate, in some cases jointly with other organisations such as the Carbon Trust.

The Carbon Trust is a private, independent company set up by the UK Government with a broad remit to accelerate the move to a low-carbon economy, working with business and the public sector to reduce carbon emissions. It supports activities across the spectrum of the innovation chain including providing grants for R&D; strategic and business development advice to start-up companies; funding to overcome barriers to commercialisation; and technical expertise and venture capital investment for low-carbon businesses. It does not focus specifically on resource efficiency but many of the activities it supports benefit resource efficiency.

Important business support programmes administered through the Carbon Trust include the Enhanced Capital Allowance scheme and grant-funded programmes. The Carbon Trust's Applied Research Programme is open to UK businesses and research institutions, and supports the development and commercialisation of technology with the potential to reduce UK CO₂ emissions with grants of up to £250,000.

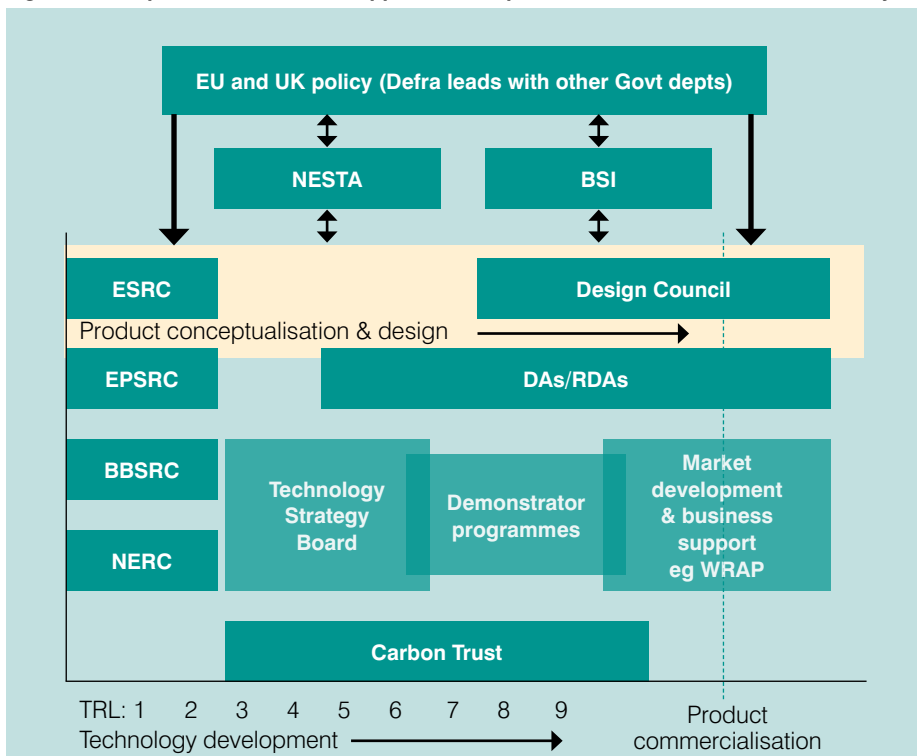
Defra's Business Resource Efficiency and Waste (BREW) programme has played an important role in the resource efficiency and waste minimisation arena. This programme was started in April 2005, and in the period up to March 2008 financed £284m support to businesses through a range of agencies and organisations to encourage more sustainable behaviour. In April 2008 BREW activities were amalgamated with other Defra funding schemes, and around £155m was allocated to support existing BREW activities for year four of the programme.

Since March 2009 WRAP has coordinated business support for resource efficiency in England, and provides a one-stop-shop to help businesses, organisations and households. The organisations incorporated into this programme include:

- the National Industrial Symbiosis Programme (NISP)
- Envirowise
- the Centre for Remanufacturing and Reuse
- the Construction Resources and Waste Platform
- Action Sustainability
- BREW

The devolved administrations (DAs) and nine English regional development agencies (RDAs) support activities that contribute to the resource efficiency agenda, including collaborative R&D (grants and innovation vouchers), market development (such as for recycled materials) and wider forms of business support. While they don't provide specialist advice, organisations like Business Link play an important role in disseminating best practice and case studies to engage a wider range of businesses.

Figure 7 – Simplified UK business support landscape for innovation in resource efficiency



5.4 International programmes and funding

The EC adopted the Environmental Technologies Action Plan to cover activities that promote eco-innovation and the use of environmental technologies. The action plan aims to boost the development and use of environmental technologies to make European companies more competitive, and to help overcome the many barriers that historically have hindered progress in this area. There are three priority areas: getting from research to markets; improving market conditions; and acting globally.

The Seventh Framework Programme (FP7) supports the theme of 'Environment (including climate change)' within its

Table 5 – Major research council programmes in the resource efficiency sector

Programme	Sponsor(s)	Comments
Sustainable Urban Environment	EPSRC	£32m programme in two phases to establish clusters examining diverse sustainability issues in the urban environment
Sustainable Technologies Programme	ESRC	Policy-relevant research on the social and economic processes that shape, foster or inhibit more sustainable technologies
Cultures of Consumption	ESRC	£5m multidisciplinary programme on the changing nature of consumption
Waste for the World	ESRC	£3m collaborative project examining global patterns in the movement, management and trade in wastes
SUPERGEN	EPSRC, BBSRC, NERC, Carbon Trust	£32m multidisciplinary initiative in sustainable power generation that includes a component dedicated to biomass and bioenergy research
Rural Economy and Land Use	ESRC, BBSRC, NERC, Scottish Executive, Defra	£24m programme to investigate the social, economic, environmental and technological challenges faced by rural areas
Living with Environmental Change	UK research councils, national, regional, local government departments and agencies	Interdisciplinary research and policy partnership to tackle environmental change

programme on cooperation, and has earmarked €1.9bn to fund activities in this area for the duration of FP7. Research areas include the sustainable management of resources, and environmental technologies. The FP7 theme 'Nanosciences, nanotechnologies, materials and new production technologies' includes resource-efficient and cleaner production processes.

The Competitiveness and Innovation Framework Programme has a budget of €3,621bn from 2007 to 2013 distributed between three programmes. The Entrepreneurship and Innovation Programme supports eco-innovation, and the Intelligent Energy Europe programme supports energy efficiency technologies.

The Life+ programme supports projects linked to nature conservation, environmental technology and communicating environmental matters. It has a budget of €1.7bn for the period 2007-2013.

Support for environmental and eco-innovation projects is also provided through the Eureka and Eurostars programmes. Euroenviron is a pan-European R&D network, established under the Eureka initiative, with the aim to promote and facilitate Europe-wide 'market driven, collaborative, environmental R&D projects'.

There is significant coordination of national and regional research programmes through ERA-NET actions such as:

- SKEP (scientific knowledge for environmental protection): a consortium of funders of environmental research, led by the Environment Agency
- SUSPRISE (sustainable enterprise): coordination of national sustainability programmes, joint development and use of new sustainable technologies
- ERA-IB: industrial biotechnology
- ERABUILD: sustainable construction and operation of buildings
- SNOWMAN (sustainable management of soil and groundwater under the pressure of soil pollution and soil contamination): contaminated land management.

Several regional or pan-European networks promote eco-innovation, including the European Partners for the Environment and the Enterprise Europe Network.

In a global context the activities of several organisations are relevant, including:

- OECD: sustainable development is recognised as a cross-cutting issue for the OECD programme. The organisation conducts specific projects including sustainability assessments and approaches for measuring sustainable development. The OECD has published a review of international initiatives on sustainable resource management [61].
- United Nations Environmental Programme (UNEP): it has established initiatives on the use of natural resources, cleaner production, lifecycle management, and recently set up the International Panel for Sustainable Resource Management.

6. Technology Strategy Board activity to date

We have held five collaborative R&D competitions with a specific focus on resource efficiency since 2004, representing a Technology Strategy Board investment of over £33m across 59 projects. Many of these projects deliver benefits in other areas such as energy efficiency and intensity of water use. Funding for these competitions was provided through the BREW programme.

The competition areas were:

- waste minimisation and management
- the zero emissions enterprise (two competitions)
- design and manufacture of sustainable products
- remediation of contaminated land.

Many other collaborative R&D competitions have had a significant resource efficiency component, recognising the importance of sustainability as a driver across all application and technology areas. Recent examples of this are the 'Sustainable materials and products' and 'High value manufacturing' collaborative R&D competitions, which together represent an investment of over £25m.

Two of the five innovation platforms that we sponsor have a strong environmental sustainability component: Low Carbon Vehicles and Low Impact Buildings. The focus of the Low Impact Buildings Innovation Platform is to reduce the energy and water intensity of new and existing housing stock.

We have sponsored activities to share and transfer knowledge about resource efficiency. The Resource Efficiency and Environment KTNs have jointly led these activities, which have complemented those of national programmes funded through BREW to promote best practice (Envirowise, WRAP) and knowledge transfer (National Industrial Symbiosis Programme). Other KTNs, often working jointly, have developed projects or special interest groups relating to resource efficiency. One example is FROPTOP [62], a joint special interest group between the Bioscience for Business and Chemistry Innovation KTNs to develop the business case for platform chemicals and high-value products derived from biomass.

In total, 138 knowledge transfer partnerships were completed in the EG&S sector between 2003 and 2007, increasing annual profits before tax to participating companies by more than £280m. This is a significant contribution to UK capability in a sector that historically has suffered from a shortage in skilled personnel.

7. Resource Efficiency Strategy

This document aligns our Resource Efficiency Strategy with our higher-level strategy and priorities. This strategy should be viewed in the context of the UK's overarching strategy on sustainable development [63], and incorporates issues raised in key policy documents such as the CEMEP report [17], Government waste strategies [27], and the UK's Sustainable Consumption and Production Programme [64].

Resource efficiency has a key role to play in mitigating wider problems such as depletion of resources, environmental impact and materials security, and it also contributes significantly to the low-carbon economy. In the longer term, substantial improvements in resource efficiency will require a transition to (more) closed-loop models of consumption, taking full account of the resource lifecycle. On a macro scale this implies the widespread adoption of principles of industrial ecology, a discipline which seeks to improve the sustainability of industrial systems by analogy with biological systems. Ultimately this implies adoption of a zero-waste model whereby all 'wastes' are eliminated or become raw materials for other processes.

This picture is consistent with recommendations made in the policy documents above. We have also identified key actions at a national level that will help accelerate the pace of innovation in resource efficiency.

We believe the UK should:

- support the wider adoption of lifecycle thinking through the use of indicators and quantitative methods such as lifecycle assessment, embedded carbon and embedded water

- make greater use of its influence in product specification (at a business and European policy level) to reduce environmental impacts through global supply chains
- identify gaps in knowledge and data for fluxes of materials and the composition of waste streams, and work with bodies such as the International Panel for Sustainable Resource Management to address these.

Our strategy recognises the importance of both materials security and the impact on the environment of extracting and using resources. Our analysis shows that either or both of these factors will lead to constraints in market growth if current trends in economic development and resource use continue. Innovations that avoid or mitigate these constraints will be a source of future wealth and competitive advantage for the UK.

The Technology Strategy Board will:

- invest in four approaches to improve the efficient use of resources:
 - substitute the use of at-risk materials or those that have a major environmental impact
 - close the lifecycle loop to enable the same resource material to have multiple product lives
 - dematerialise – reduce the amount of material that needs to be used to deliver a consumer benefit
 - reduce the amount of energy used over the lifecycle.
- recognise the importance of waste and pollution management as mitigation technologies, and undertake focused activities in those areas where there is demonstrable benefit and market opportunity.

We have assessed the opportunity in each of these approaches by considering the UK's capability across nine contributing areas, described in section 5.1, that broadly span the resource lifecycle. Our initial assessment is that our investment is best focused on the four approaches, rather than targeting any of the nine areas specifically.

In addition, there are multiple and substantive overlaps with other Technology Strategy Board programmes and activities, which are shown in Appendix 1. We will build on these links and develop new ones; for example, in support of new innovation platforms such as sustainable agrifood.

7.1 Collaborative R&D

Collaborative research projects have been effective in the resource efficiency area, particularly by supporting organisations for which environmental issues figure prominently in their strategic thinking. There is an opportunity to cast the net wider, to engage both a broader section of this community and others who are in the process of incorporating resource efficiency at a strategic level.

We will:

- run collaborative R&D competitions aimed at meeting specific challenges and that appeal to a broad spectrum of businesses; these competitions will span the four approaches and lifecycle areas described in this strategy
- consider a broader range of investment tools to encourage greater and more effective engagement with businesses. These could include feasibility and scoping studies for companies new to the field or with limited R&D experience.

7.2 Transferring knowledge and skills

The diffuse and pervasive nature of the resource efficiency sector means that there are many opportunities to generate wealth by working to transfer and share knowledge. These range from developing new technologies to tailoring techniques and processes to individual user needs, and transferring knowledge and technology across sectors and along supply chains.

We will:

- create a new knowledge transfer network to stimulate the transfer of knowledge between businesses, academics and individuals. This will be formed by combining the Resource Efficiency and Environmental KTNs to provide focused support to those working in environmental sustainability
- support the formation of special interest groups, made up of businesses, academics and industry bodies, across a range of KTNs to develop cross-sectoral activities in support of the work to address the challenges in the environmental sustainability area
- work with our partners delivering the knowledge transfer partnerships and through the KTNs to increase the number and range of knowledge transfer partnerships in the resource efficiency sector.

7.3 Working with UK organisations

We recognise that resource efficiency is a broad area that permeates the wider economy. To support the development and deployment of innovations in resource efficiency we will need to work with other organisations. These include:

- a range of businesses and sectors regional and national Government (eg Defra; the Department for Business, Innovation and Skills; DAs and RDAs) public bodies (eg the Environment Agency, Design Council and Carbon Trust) funders of fundamental research (eg NERC, EPSRC, BBSRC and ESRC) and agencies for market development (eg WRAP).

We will:

- work with businesses, funding bodies and key organisations to identify those areas where the Technology Strategy Board can add most value, and to develop a delivery plan that provides a coordinated and effective response to the challenge to improve resource efficiency.

In particular, we will work with appropriate partners to identify and develop mechanisms to support innovations such as:

- design and product conceptualisation
- changes in business models; for example, extending product lifetimes through the delivery of products as services
- understanding and accommodating human and business behaviours.

7.4 Working with international partners

There is broad scope to work with international partners, whether to inform and influence development of policy, to transfer knowledge and best practice, or to participate in large-scale collaborative projects that span the supply chain.

In the short term we will:

- focus on Europe, including working through the new KTN to identify opportunities for engagement.

7.5 Information gaps and measurement

Much information is available, however there are gaps in market data and in the understanding of UK capability in some sub-sectors. Our response to the challenge to improve resource efficiency will need to be assessed in terms of improved environmental performance as well as by economic indicators.

We will:

- assess capacity in the UK to reduce the total amount of materials necessary to produce goods or deliver services
- work with other organisations such as NERC to address gaps in data and develop a framework to assess and prioritise reliability in the supply of raw materials and the global impact for materials that are important for UK businesses
- develop appropriate ways to measure resource efficiency and sustainability to assess and track activities within the area of environmental sustainability.

Appendix 1– Links to other application and technology areas and innovation platforms

Technology areas	Areas of cross-over
Advanced Materials	<ul style="list-style-type: none"> ■ Bio-based materials and composites ■ Biodegradable and recyclable materials ■ Lower energy materials processing ■ Smart materials and surface modification technologies
High Value Manufacturing	<ul style="list-style-type: none"> ■ Modelling of whole-life manufacturing costs (and impacts) ■ Design for environment ■ Processes for optimal end-of-life fate (including remanufacture and recycling) ■ Near-net and additive manufacturing methods ■ Light-weighting of components and systems ■ Low-carbon manufacturing processes
Nanotechnology	<ul style="list-style-type: none"> ■ Nanocomposites/particles (eg for lightweight structural reinforcement or to impart functionality such as flame retardancy and barrier properties) ■ Electrical storage applications (rechargeable batteries and supercapacitors) ■ Nanostructured materials for the catalytic treatment of pollutants
Biosciences	<ul style="list-style-type: none"> ■ Bioremediation and clean-up technologies ■ Biosensor and monitoring technologies ■ Bioprocessing and anaerobic digestion ■ Bioscience and biotechnology for bio-based materials, platform chemicals and value-added products ■ Self-repairing structural materials ■ Environmental sensors
Electronics, Photonics & Electrical Systems	<ul style="list-style-type: none"> ■ Sensors, monitoring and imaging applications ■ Low energy products ■ Energy storage and microgeneration ■ Component and hardware design for easier recycling
ICT	<ul style="list-style-type: none"> ■ Decision support tools ■ Systems for resource and carbon accounting

Application area	Areas of cross-over
Energy Generation & Supply	<ul style="list-style-type: none"> ■ Energy from waste and biofuels
Creative Industries	<ul style="list-style-type: none"> ■ Design, marketing and communications
Transport (including aerospace)	<ul style="list-style-type: none"> ■ End-of-life producer responsibilities ■ Light-weighting and composite materials

Innovation platform	Areas of cross-over
Low Carbon Vehicles	<ul style="list-style-type: none"> ■ Light-weighting and end-of-life considerations
Low Impact Buildings	<ul style="list-style-type: none"> ■ Sustainable construction materials, recyclable construction materials ■ Improved construction methods to reduce waste
Sustainable Agrifood	<ul style="list-style-type: none"> ■ Crop nutrition & management, waste reduction and management, greenhouse gas reduction methodologies

Appendix 2 – UK Government policy documents

Document	Overview	Fit with resource efficiency strategy
<i>Securing the Future – the UK Sustainable Development Strategy</i> (2005) [63]	Agreement of five principles for sustainable development across UK Government; identification of four agreed priority areas and indicators for sustainable development.	Articulates the UK's aspiration to 'one planet living'. The priority areas include sustainable consumption and production, natural resource protection, and environmental enhancement.
<i>CEMEP report</i> (2007) [17]	Independent commission set up after the <i>Stern Review</i> to make recommendations to Government to help the UK exploit the opportunities from the transition to a low-carbon, resource-efficient economy.	Recognises the pervasive nature of resource efficiency opportunities throughout the wider economy. The recommendations include: exploring the scope for the greater use of dynamic performance standards and the need for coordination of innovation support, including linking R&D support to procurement opportunities.
<i>Building a Low Carbon Economy: Unlocking Innovation and Skills</i> (2008)	Government response to the CEMEP report, outlined how Government is implementing the CEMEP recommendations through a range of initiatives and strategies including the Science and Innovation White Paper (<i>Innovation Nation</i>), the Enterprise White Paper (<i>Unlocking the UK's Talent</i>) and the Climate Change Bill.	Identifies the four key challenges to implementing CEMEP recommendations: Government needs to set a long-term policy framework; policy must positively support innovation; the economy and our workforce need the right skills; and the process will involve partnership working.
<i>Waste Strategy for England 2007</i> See also: <i>Draft Waste Strategy 2009-2050: Towards Zero Waste</i> (consultation completed) Scotland's Zero Waste Plan (consultation underway) <i>Towards Resource Management, Department of the Environment Ireland</i> (2006)	Key objectives to: <ul style="list-style-type: none"> ■ decouple waste generation from economic growth ■ meet and exceed Landfill Directive targets for biodegradable municipal waste ■ increase diversion from landfill of non-municipal waste and secure better integration of treatment of municipal and non-municipal waste ■ secure necessary investment in waste management infrastructure ■ gain the maximum environmental benefit from that investment. 	A portfolio of actions and targets broadly based on the waste hierarchy will stimulate demand for resource-efficient goods and services. Measures include: <ul style="list-style-type: none"> ■ incentives to reduce, reuse and recycle waste, and recover energy from waste ■ regulatory reform to drive the reduction of waste and diversion from landfill ■ target action on materials, products and sectors with the greatest scope for improving environmental and economic outcomes ■ stimulating markets for recovered materials and investment in waste management infrastructure.

Document	Overview	Fit with resource efficiency strategy
<p>Low Carbon Industrial Strategy: A Vision (2009)</p> <p>LCIS Budget Delivery Plan (2009)</p> <p>Low Carbon Industrial Strategy (2009)</p> <p>Low Carbon Transition Plan (2009)</p>	<p>This series of strategy documents identifies a number of key areas where Government could play an active role in the move to low carbon, including making the UK the best place in the world to locate and grow low-carbon business; making the UK the best place to develop, manufacture and use low carbon vehicles; and putting in place energy infrastructure for the UK's low carbon future – in renewable, nuclear and carbon capture and storage.</p> <p>Measures announced in the 2009 Budget enable an additional £10.4bn of low carbon sector and energy investment over three years, securing new jobs and new business, and placing the UK at the forefront of a worldwide low-carbon recovery.</p>	<p>These documents describe how the low-carbon economy will change our industrial landscape, supply chains and the way we work and consume, and recognise that businesses and consumers can benefit from significant savings through energy and resource-efficient measures.</p> <p>Measures in the Budget include money to support energy and resource efficiency in businesses, public buildings and households over the next two years, and a continued increase in the standard rate of landfill tax by £8 per tonne on 1 April each year from 2011 to 2013, to reduce landfill in a sustainable way by encouraging further investment into alternative waste management options.</p>
<p>Towards a Low Carbon Economy – Economic Evidence and Analysis</p> <p>BIS Economics Paper #1 (2009)</p>	<p>Sets out the economic rationale for the Low Carbon Industrial Strategy; the evidence and conclusions from recent research on the UK's strengths; and how UK businesses are already responding to the challenge of climate change.</p>	<p>Recognises energy and resource efficiency as key contributors to a low-carbon economy. Describes the pivotal role that innovation, skills, finance, consumer demand and key sectors will have in developing a low-carbon economy in the UK.</p>
<p><i>Building Britain's Future: New Industry, New Jobs</i> (2009)</p>	<p>Identifies key areas where Government action can have most impact: investing in growth to speed recovery; and building manufacturing and services essential to ensure British people and businesses can compete successfully for the jobs of the future.</p>	<p>Aims to create the best possible conditions in which UK businesses can thrive, removing barriers to success and offering targeted support to unlock new potential in existing and new technologies. Inherent links to resource efficiency.</p>
<p>Ecosystems Approach Action Plan (2008)</p>	<p>Sets out actions to enable Defra, key partners and stakeholders to work together to apply an ecosystem approach to conserving, managing and enhancing the natural environment in England, ensuring that the value of ecosystem services is fully reflected in decision-making.</p>	<p>Encourages a holistic approach to policy-making and delivery, with the focus on maintaining healthy ecosystems and ecosystem services.</p>

Document	Overview	Fit with resource efficiency strategy
<p>IB 2025: Maximising UK Opportunities from Industrial Biotechnology in a Low Carbon Economy (May 2009) and Government Response (June 2009)</p>	<p>Report of the Industrial Biotechnology Innovation & Growth team (IB-IGT) focusing on how best the UK may benefit from opportunities in the market for renewable chemicals and low-carbon manufacturing. The IB-IG recommends actions in five areas:</p> <ul style="list-style-type: none"> ■ improve the connectivity of UK industrial biotechnology activities to grasp the necessary opportunities ■ de-risk access to new products and technologies ■ accelerate the innovation and knowledge transfer process ■ retain and develop the necessary interdisciplinary talent in science and management ■ create a 'public' and 'business' environment that supports industrial biotechnology. 	<p>The Government response recognises the important role of industrial biotechnology in a low-carbon economy and recommends activities for the Technology Strategy Board and others in support of this goal.</p>
<p><i>Making the Most of Packaging</i> (2009)</p>	<p>The overall aim of the UK Government's packaging strategy is to minimise the environmental impact of packaging, without compromising its ability to protect the product. To make this happen, Government will work with delivery bodies and industry so that in 10 years' time packaging is designed to use as little material as will do the job, and with reusability, recyclability or recovery in mind. The strategy also sets out plans to improve the recycling of packaging waste, particularly glass, plastics and aluminium, with a focus on the household waste stream and on quality.</p>	<p>Recommendations include measures in:</p> <ul style="list-style-type: none"> ■ ecodesign ■ refillable and reusable packaging to meet consumer needs to revitalise the refillables market ■ recyclability including closed-loop recycling; the relative merits of weight – and carbon-based targets ■ bio-based packaging for co-degradation of packaging and food waste ■ improved performance and functionality of packaging in the supply chain which can deliver efficiency and environmental impact benefits.

Appendix 3 – EU/UK legislation relevant to the resource efficiency sector

Legislation	Type	Status	Relevance to resource efficiency strategy
Batteries and Accumulators Directive	EU	Effective May 2009. Battery/accumulator producers (over a 1 tonne UK sales threshold) required to provide for the collection, treatment, recycling and disposal of waste batteries through a Battery Compliance Scheme.	Driver for closed-loop approach to battery manufacture and/or recycling infrastructure.
Climate Change Act	UK	Effective November 2008. Main provisions include legally binding carbon emissions reduction targets and setting of national carbon budgets.	Encourages development of lower energy-intensity processes across range of sectors.
Renewable Energy Directive	EU	Sets legally binding target of 20% use of renewable across all energy types; target of 10% renewable transport fuels by 2020 replaces 2003 Biofuels Directive.	Driver for the substitution of oil-derived fuels.
End-of-Life (ELV) Vehicles Directive	EU	Effective 2003. Places stricter environmental standards on ELV sites. Provides for free final disposal of the vehicle from 2007, the costs of this take-back system being borne largely or solely by vehicle manufacturers and importers.	Driver for closed-loop approach to vehicle design and manufacture.
Energy Using Products Directive	EU	Enacted into UK law August 2007. A proposal is being considered to extend the scope of the Directive to include products not consuming energy during use but having an indirect impact on energy consumption.	Driver for wider adoption of eco-design.
Environmental Liabilities Directive	EU	Effective 2009. Aims to reduce damage to certain categories of 'environmental damage'.	Driver for pollution management technologies, particularly to safeguard/clean up water pollution and land contamination.
Proposed Directive for Industrial Emissions	EU	A proposal was adopted by the EC in 2007 that would recast seven existing directives into a single legislative instrument. The directives recast in this proposal include Integrated Pollution Prevention and Control, the Waste Incineration Directive, and the Solvents Emissions Directive.	Includes provisions such as the application of best available techniques to reduce industrial emissions, which should stimulate growth for the pollution control market, in particular air pollution control technologies.

Legislation	Type	Status	Relevance to resource efficiency strategy
Landfill Directive	EU	Effective 2004. UK landfill tax (April 2009) at £40/tonne, rising by £8/tonne/year to £72/tonne in 2013-14. Requirement to pre-treat all wastes before landfill; ban of co-disposal of domestic and hazardous waste.	The objective is to reduce mass and hazards presented by waste, with a corresponding increase in recycling and recovery.
Registration, Evaluation, Authorisation and Restriction of Chemical Substances (REACH)	EU	Requirement to provide range of data for estimated 30,000 chemical substances. The pre-registration phase has elapsed and is now entering the compulsory registration phase.	Recovered waste materials are eligible for REACH registration, with the exception of compost, biogas and anaerobic digestate. Legislation provides mechanism to substitute highest risk materials.
Restriction of Hazardous Substances Directive (ROSH)	EU	Effective July 2006.	Aims to phase out use of lead, mercury, cadmium, hexavalent chromium and certain polybrominated compounds.
Waste Electrical and Electronic Equipment (WEEE) Directive	EU	Enacted into UK law January 2008. Places responsibility on producers for financing the collection, treatment, and recovery of waste electrical equipment.	Will stimulate technologies for the reuse and recycling of a range of electronics wastes in 10 product categories.
Waste Framework Directive (revised)	EU	Entered into force December 2008; to be transposed into UK law by December 2010.	Establishes waste hierarchy as a priority order which should be deviated from when it is justified by lifecycle thinking. Greater emphasis placed on prevention; end-of-waste criteria for a range of materials (starting with metals) should assist in market development for recycled materials.
Energy Services Directive	EU	Effective April 2006. Intended to enhance the cost-effective improvement of energy end-use efficiency. The Directive applies to providers of energy-efficiency measures, energy distributors, distribution system operators and retail energy sales companies, and all energy users except those involved with the EU carbon emissions trading scheme.	Driver for improvements in energy efficiency across a broad range of sectors.
Soil Framework Directive	EU	Under consideration.	Could generate significantly higher levels of demand for contaminated land remediation over a 25-year period.

Appendix 4 – Resource efficiency market valuation

It is not possible to accurately estimate the market for resource-efficient products, processes and services but the following indicate a UK market value of around £50-75bn. Key market data are highlighted in bold; however, there are many other contributions, and these figures do not represent the total market.

Good data exist for the traditional EG&S sector, with a recent report valuing the UK market at **£22.3bn** (Figure 8) [51].

The same report valued the renewable energy sector at £31.1bn, and the emerging low-carbon sector at £53.3bn. It estimated the total value of the low carbon and environmental goods and services market at £107bn.

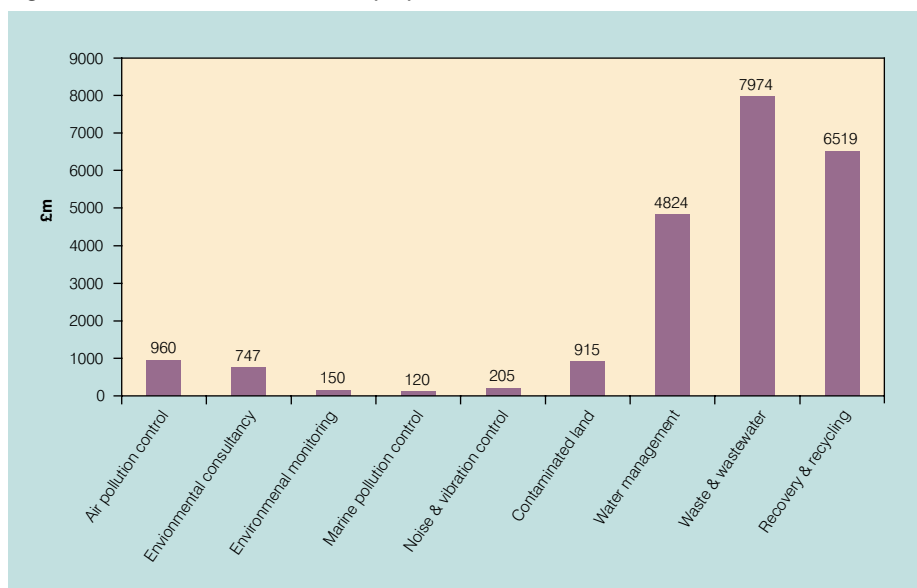
Within the emerging low carbon sector, several sub-sectors were described that overlap significantly with the resource efficiency sector:

- alternative fuels: **£18.6bn**
- energy management: **£2.6bn**
- building technologies: **£13.0bn**

The manufacturing sector will be a significant contributor of resource-efficient products and processes. The following provide an indication of the likely contribution:

- UK manufacturing accounts for 15% of GVA, or £150bn each year. Typical product renewal cycles in the UK manufacturing sector are around three or four years. If one-quarter of these enable significant resource/energy efficiency improvements, then this would imply the UK market for resource-efficient products is around **£9-13bn**
- £15bn is invested in UK manufacturing each year [65]. As much as 50% of this may contribute to environmental sustainability (eg improved resource efficiency, energy efficiency and/or lower environmental impacts) – that is around **£7.5 bn**.

Figure 8 – UK EG&S market 2007-08 (£m)



Appendix 5 – Glossary

BBSRC	Biotechnology and Biological Sciences Research Council
BERR	former Department for Business, Enterprise and Regulatory Reform
BIS	Department for Business, Innovation and Skills
BREW	Business Resource Efficiency and Waste
CBI	Confederation of British Industry
CEMEP	Commission on Environmental Markets and Economic Performance
CHP	combined heat and power
CO₂	carbon dioxide
CO₂e	carbon dioxide equivalent
DA	devolved administration
Defra	Department for Environment, Food and Rural Affairs
EC	European Commission
EfW	energy from waste
EG&S	environmental goods and services
ELV	End-of-Life Vehicles (Directive)
EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
EU	European Union
FP7	Seventh Framework Programme
GDP	Gross Domestic Product
GVA	Gross Value Added
KTN	knowledge transfer network
NERC	Natural Environment Research Council
NISP	National Industrial Symbiosis Programme
OECD	Organisation for Economic Co-operation and Development
RDA	regional development agency
TRL	technology readiness level
WEEE	waste electrical and electronic equipment
WRAP	Waste and Resources Action Programme

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