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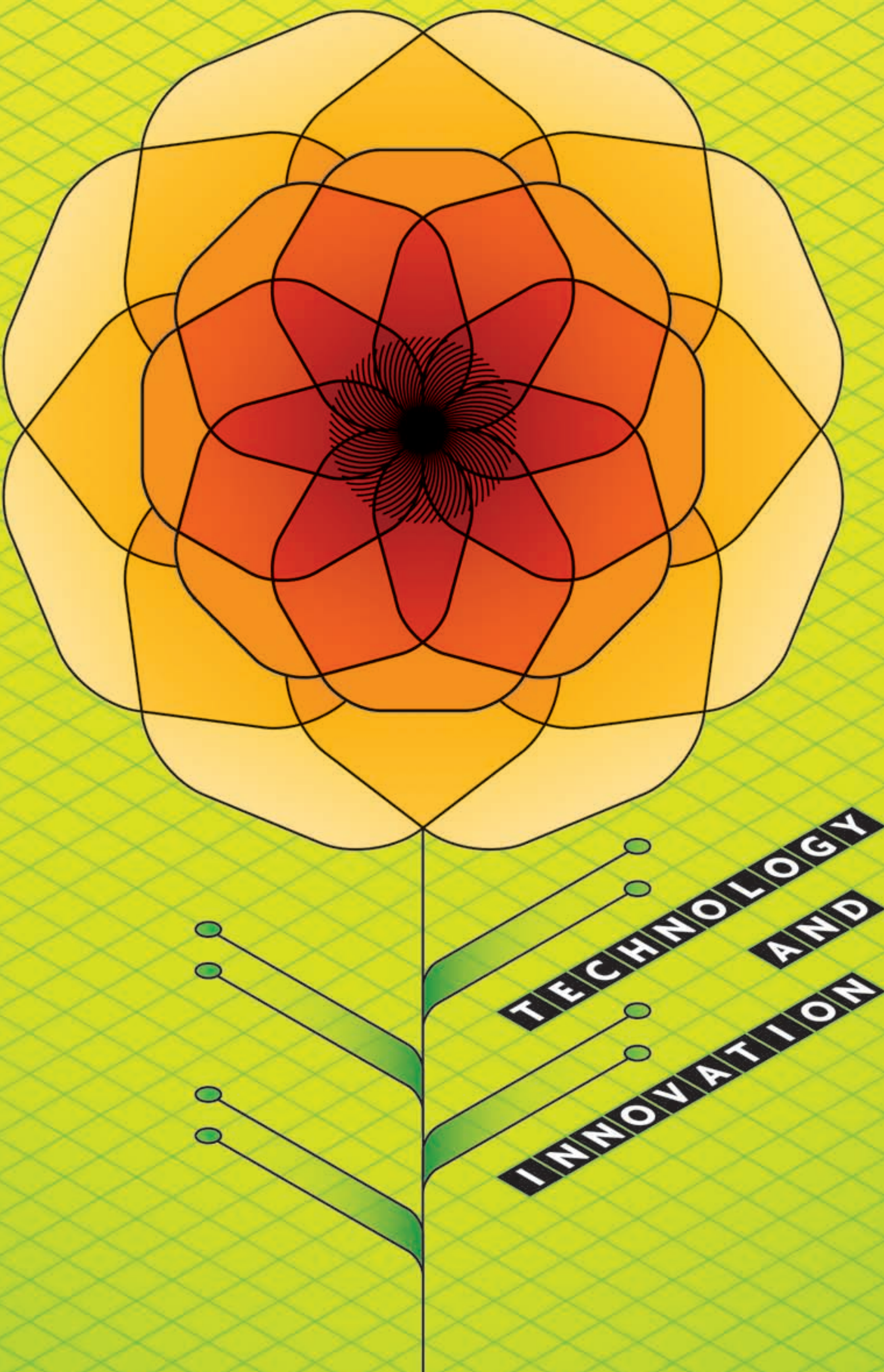

Resource efficiency and innovation

Technology and the environment have historically not been easy bedfellows. Innovations, mechanisation, and industrialisation have been responsible for large swathes of environmental degradation over the past century, but could they also prove its saviour?

In this edition of environmental SCIENTIST Professor Carolyn Roberts, Director of the Environmental Sustainability Knowledge Transfer Network (ESKTN), a government agency which is part of the UK's Technology Strategy Board, interrogates the opportunities and possibilities that technology innovation provides in the ongoing effort to reverse environmental damage and to create a sustainable future for all. The articles in this journal give insights into just a few of the ESKTN's areas of work, and capture some new initiatives and novel business areas that form part of the greener technology revolution.

Bringing together voices from diverse fields, such as water, waste, carbon sequestration and eco-innovation, Professor Roberts shows us how technologists are responding to the economic and environmental situation in which we find ourselves. As resources become scarce, how do we make the most of what we have? How are technologists and innovators reacting to novel technical and regulatory demands as policies and mitigation attempts stemming from climate change, filter into our lives?

In its exploration of technology and innovation, this edition of the Journal also touches on culture and society; that often overlooked section of the environment and technology Venn diagram. In a case study looking at a partnership between Indonesian government planners and the UK Foreign and Commonwealth Office (supported by the ESKTN), we get a glimpse of a scheme which demonstrates how sharing innovation across cultural and linguistic divides can reap massive rewards whilst disseminating best sustainability practice.

With new ideas, methods and approaches comes risk, and as environmental scientists we are all too aware that risks are never simple to appreciate. For every innovation or benefit to an ecosystem, watershed or urban landscape there may be ten impacts yet to be uncovered or realised. The flip-side of being an environmental scientist however, is the tenacious desire to understand these impacts, to mitigate or to facilitate. As Professor Roberts notes "Environmental scientists have an opportunity, and indeed an imperative, to understand the issues and to work with industry to shape our destiny and not to stand on the sidelines as the future unfolds."

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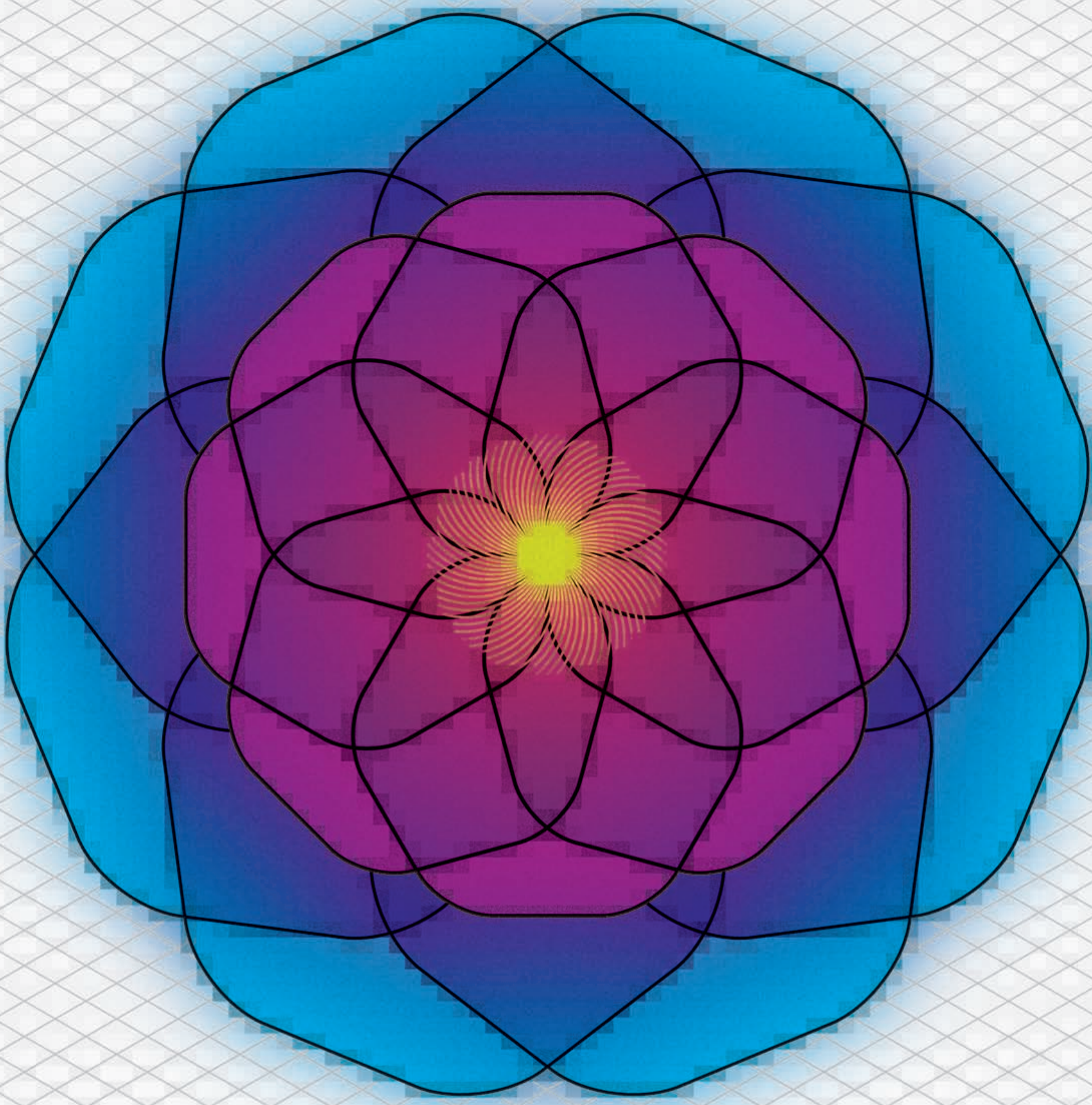
Hard Times: From Dickens to Digital in the green tech revolution

Carolyn Roberts explores innovation since industrialisation and how new, greener technology can provide the answer to many of today's problems.

This year is the bicentennial anniversary of the birthday of the incomparable (as the media so often repeat) Charles Dickens. Many of the Institution of Environmental Science's Members will have immersed themselves in his books, or at least in the black and white films screened during the childhoods of the older ones amongst us. In Dickens' novels we read of the blighted blacking factories, the dangerous mines, the horrific brickworks and the small lighters picking their way amongst floating debris in the Thames. His stories encapsulate some of the worst aspects of the urban industrial environment of nineteenth century Britain – giant dust heaps, sewage-clogged rivers, choking smog, and rubbish-strewn rat-infested streets. And triumphing over it all we read of rapacious businessmen squeezing excessive amounts of money from both the Earth's natural resources, and its people. Industry was clearly seen to be responsible for the environmental damage that afflicted everyone's life and health in Victorian Britain.

The worst excesses of Dickensian industrial blight have now all but disappeared from the UK, and despite the hidden legacy of contaminated land, damaged ecosystems, and insidious air pollution, environmental scientists are recording genuine improvements in soil, water and air quality across much of Europe as emissions have fallen and ecosystems been granted protection. Regrettably for Britain's economy, some of the local benefits have resulted from manufacturing capacity migrating to less economically developed countries, often with minimal environmental legislation, effectively exporting environmental damage. In a number of respects, this is clearly not the long term sustainable industrial solution we need, and nor will it lead to global scale environmental advances. But those industries who have retained capacity in the UK are also changing their approach, and supported by scientific evidence, are now leading moves towards increased environmental sustainability.

In the past, beneficial changes to the environment were mainly prompted by public outcry, political will and legislation, and by increasing levels of corporate social responsibility, underpinned by a better understanding of the science of the environment and the widespread nature of destruction. New technologies have also played an important role in creating change whereas global political agreements (with a few notable exceptions such as ozone layer protection afforded by the Montreal Protocol), have typically provided more limited incentives. However UK industry is increasingly responding to two additional environmental stimuli. Firstly, growing awareness of the need for resource efficiency is forcing senior management to pay attention to their businesses' fuel and water consumption, the escalating costs of discarding manufacturing constituents to landfill, and the security of their future sources of raw materials; economic pressures are powerful and growing. Secondly, some companies are spotting potential new opportunities for innovation arising from a future greener economy. Mitigation and adaptation strategies for climate change, for example, give rise to business prospects,

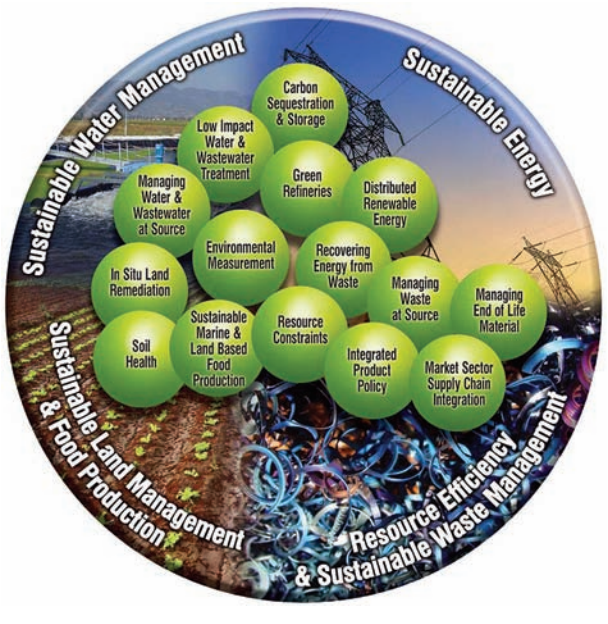


whether (in theory) manufacturing the equipment to suck greenhouse gases out of the air, or in designing and selling better cooling systems for buildings. Waste is increasingly being regarded as a potential industrial resource, rather than as a problem, with pioneering new technologies coming on-stream to generate value from what was previously a cost. Not only are companies finding that there is money to be made in reuse and recycling, but more benign materials are being developed to replace those hard-to-get elements such as neodymium and indium. Beyond that, some companies are starting to use eco-design principles to reduce consumption in total, or are exploring business models that emphasise circular economies, where products and materials are ultimately returned to the business for remanufacture. Businesses are at last starting to adopt the systems concepts so familiar to environmental scientists, although fully establishing the environmental credentials of these new products and services can nevertheless still require a great deal of research.

In the UK it is simultaneously the best of times and the worst of times for industries that are responding to environmental imperatives. It is the best of times for companies involved in sectors such as water management, renewable energy development, resource efficiency, and land management, because the UK has:

- Genuinely world class universities, with some of the greatest and most productive environmental researchers and technologists in the world;
- Rising raw material prices that are stimulating innovation to reduce dependency on scarce materials, eco-friendly design, and an emphasis on resource recovery;

Figure 1: ESKTN priority areas

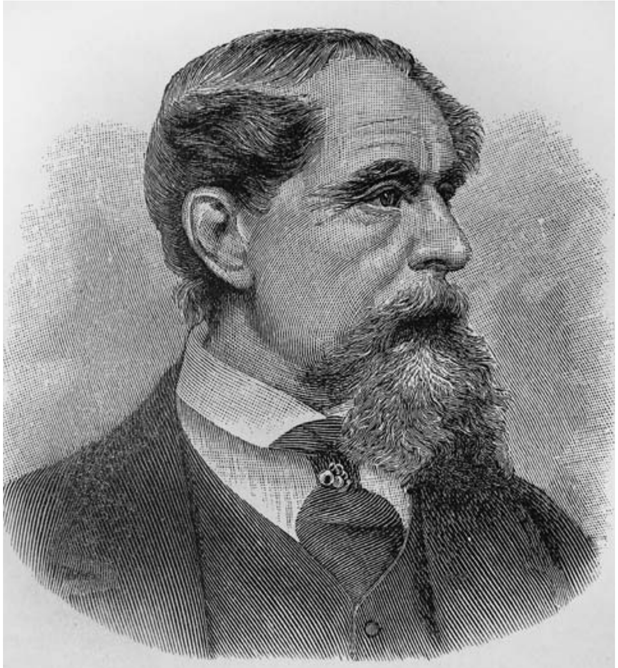


- Record-breaking global investment in renewable energy technologies, outstripping the money invested into fossil fuels for the first time and starting to stimulate a burgeoning green economy;
- A coalition Government that promotes its credentials as 'the greenest government ever';
- Green initiatives such as electricity market reform, the Green Deal, Renewable Heat Incentives, a feed-in tariff (albeit of variable magnitude) and, coming over the horizon, the Green Investment Bank;
- Partial international agreement at Durban on the need for specific action and targets to reduce climate change;
- Major companies with UK presence such as Arup, Siemens, Marks and Spencer, BT, Kraft, Velcourt and Unilever really thinking hard and acting to promote environmental improvements in their own activity and driving their supply chains to follow suit; and
- Increasing national interest in innovation, science and technological development.

But it is also the worst of times because we have:

- UK banks apparently averse to lending money to small businesses for technological development, investing too little and too late and seeing new environmental technologies as too risky for investment altogether;
- Major financial problems in the Eurozone, with spin off economic implications for the UK;
- Cuts or rapid turnover of staffing of government departments such as Defra, BIS, and to a lesser extent DECC, that are disrupting effective policy development, or slowing down completion of initiatives such as the Red Tape Challenge; and
- Companies such as Tesco pulling back from initiatives such as carbon labelling, on the basis that it may be too complex for consumers to understand.

The authors of articles in this edition are all associated with the Environmental Sustainability Knowledge Transfer Network (ESKTN), a government agency which is part of the UK's Technology Strategy Board. Based at the University of Oxford, and with a collaborating partner in the firm C-Tech Innovation, ESKTN is a specialist networking organisation that works to accelerate the UK's transition to a low-carbon, resource and energy efficient economy by connecting businesses, universities and other parts of the science base, and government agencies, catalysing a wide range of new environmental technologies. Alongside raising the profile of innovation, ESKTN brings industry and industrial partnerships into being to initiate research and development in the areas shown in **Figure 1**. ESKTN specialists act as mutual friends to assist businesses to find appropriate research teams and partners for specific environmental challenges, whether in the environmental chemistry of anaerobic



Charles Dickens.

Photo credit: © Nicku | Dreamstime.com

digestion, low input agricultural land management and food production, community-scale renewable energy, or the reduction of flooding in urban areas. The articles in this Journal give insights into just a few of the ESKTN's areas of work, and capture some new initiatives and novel business areas that form part of the greener technology revolution. Of necessity, business developments address some challenging and cross-cutting arenas such as:

- Ecosystem services and natural capital valuation – with its financially uncertain benefits, but with strong carbon imperatives for action
- Geo-engineering – technically and politically uncertain, and with a potential dilemma if reliance on fallible technology diverts attention away from climate change mitigation efforts
- Energy harvesting – generating energy from low density sources such as moving clothing, in tiny but critical amounts, to power such things as environmental sensors and controls
- Software systems to manage smart energy grids, and to undertake Life Cycle Analysis for products and services
- The future of the world's cities – an area that perhaps encapsulates in the strongest possible way, the need for cross-sectoral connections between environmental infrastructure such as water and energy supplies and waste disposal, ICT, transport, health and well-being, security and human happiness.

These new developments require careful scientific evaluation in order to understand their environmental impacts, and so that the most serious challenges may be addressed first. There are interest groups today who argue that for true sustainability, there can be no place on the planet for industrial scale manufacturing, and that a deep green future requires all of us in the developing and developed worlds to shed our material aspirations. Some of these technologies are also intrinsically controversial, and pose a risk of moral hazard, where attention is deflected from addressing the need to reduce consumption and emissions, through promise of a future technological 'fix'. Environmental scientists have an opportunity, and indeed an imperative, to understand the issues and to work with industry to shape our destiny and not to stand on the sidelines as the future unfolds. Dickens would be surprised, and let's hope, delighted. ES

"There are interest groups today who argue that, for true sustainability, there can be no place on the planet for industrial scale manufacturing, and that a deep green future requires all of us in the developed and developing worlds to shed our material aspirations"

Professor Carolyn Roberts is Director of the ESKTN, and a former Chair of the IES. Further details about ESKTN can be found at www.innovateuk.org/sustainabilityktn. Membership is free to anyone who is interested in the development of innovative environmental technologies.

Science at the centre

Environmental science plays a crucial role in resource efficiency. **John Whittall** discusses how this will contribute to minimising impending environmental damage.

Resource efficiency is a topic enjoying considerable prominence on political agendas at the moment, with the recent publication of the EU's Resource Efficiency Roadmap[1] and the emergence of "Green Growth" policies – at European level and within the UK – which are seen as a strategy both for growth and resilience in current difficult economic circumstances.

The drivers behind this are well documented: a global population set to exceed nine billion by 2050 and the consumerist aspirations of a growing global middle class. Rates of growth in consumption are highest in the developing world, where middle income families number two billion, and are predicted to treble their consumption by 2020. The growing affluence of the developing world is not the problem; rather it is the historical attitude that natural resources are inexhaustible and limitless that must be challenged if more people are to enjoy a decent quality of life in an increasingly populous, globalised economy.

The Roadmap paints a vision that is suitably ambitious: by 2050 all resources are sustainably managed, from raw materials to energy, water, air, land and soil. Climate change milestones have been reached, and biodiversity and the ecosystems services it underpins have been protected, valued and substantially restored. Resource-efficient development is considered pivotal to achieving this vision, and a means to enhance competitiveness and growth in the European economy. The priorities for action in order are: water, clean air, ecosystem services, healthy soils and marine environments with focus on three sectors which comprise up to 70-80% of all environmental impacts: food and food waste; buildings and housing; and transport and mobility.

Supporting these is a raft of suggested policy measures intended to provide appropriate incentives, remove barriers and address market failures. These include:

- methods to fairly assess the value of natural resources and improve the management of open access resources;
- measures to encourage more-long term thinking in business, finance and politics;
- a common methodological approach for measuring and comparing businesses' environmental footprints; and
- movement of taxation from labour to environmentally harmful activities.

These policy measures will require a body of evidence and tools to support their implementation – a timely and significant opportunity for the environmental sciences.

LIMITED ACCESS

Within the wider body of resources is a subset of materials whose primary importance lies in the benefits they can enable, rather than the impacts incurred as they are produced. Many clean-tech and high-tech applications rely on the inclusion, often in small amounts, of a limited number of technical and high-value metals. Continued access to these is therefore important to the European competitiveness agenda (as well as being an active area of interest in several national agendas). Europe is relatively poor in deposits of these materials and where the open market is not fully functional there is a risk of trailing behind international competition in developing these new markets.

The best known example of this is the case of the rare earth elements which are particularly suitable for clean-tech or high-tech applications such as lightweight permanent magnets (used, for example, in wind turbines and electric vehicles). For historical reasons, China holds over 97% of supply of these materials, and increasingly has constrained availability of these outside its national borders. However, the issue is wider than these materials alone; the European Commission has identified a list of 14 critical raw materials, the supply of which is potentially at risk[3].

These materials are ubiquitous, albeit in small amounts, in consumer goods that feature so heavily in modern life. A typical mobile phone weighing 100 grams contains around 14 grams of copper but also as many as 40 other chemical elements, including up to nine from the critical raw materials list. While these are present in trace amounts, measured in tens of milligrams, discarded mobile phones and other electronic devices can represent a richer source for these materials than the primary ores from which they are produced. While significant progress has been made in recycling commodity materials such as iron, copper or lead, or of high value materials from well-defined waste streams (palladium group metals from automotive catalytic converters), these dispersed sources of valuable materials are not recycled to any appreciable extent.

LIMITED AVAILABILITY

It is one thing to say that the resources at humankind's disposal are finite, but far more difficult to say where those limits lie, or how this compares with the current rate of utilisation. For mineral resources, geologists will point out the often-neglected distinction between resources (proven or otherwise amount existing) and reserves (amount which is economically viable to extract), and that the economic case for bringing a particular resource into production is a moving target; it is subject to the vagaries of commodity price movement but also potentially with technology improvements which could reduce the cost of its exploitation. Nevertheless, it is likely that mining and refining operations will remain carbon-intensive and in a carbon-constrained world secondary sources will have an increasing role to play.

Photo credit: © **Fechetm | Dreamstime.com**

It is equally difficult to characterise the limits of biotic resources, but an increasing body of evidence indicates the carrying capacity of significant ecosystems such as forests, soils, wetlands and marine environments has already been exceeded. That is, rather than living off the natural income these systems provide, reserves of natural capital are being drawn on. Biodiversity is an important indicator of the health of ecosystems, and one that tells an alarming story: the current extinction rate is now approaching 1,000 times the background rate, with the Millennium Ecosystems Assessment estimating in 2005 that between 10-30% of mammal, bird and amphibian species were threatened with extinction, attributable to human actions[2].

Concepts such as natural capital and the importance of biodiversity, while familiar to environmental scientists, are still relatively new and in some cases unfamiliar territory for policy-makers and many businesses. The publication of reports such as *The Economics of Ecosystems and Biodiversity*, and the *Corporate Social Responsibility* activities of an increasing number of blue chip companies are going some way to overcome this. However there remains a need for environmental scientists to provide better measurements for biodiversity and natural capital, and to engage as communicators of these key but difficult messages which risk being drowned out by the clamour of

more conventional thinking, particularly in difficult economic times.

The recent discovery of apparently large reserves of shale gas in the north-west of England is a case in point; the immediate media coverage focused heavily on potential availability of cheap UK supplies of gas, at a time when many consumers are acutely aware of high energy prices. A more sophisticated analysis, recognising the potential risks to the environment posed by the hydraulic fracturing or "fracking" technique necessary to exploit this resource, was slower to emerge. Good, quantitative environmental science will be essential to inform the decision whether (or not) to exploit this resource, when there are strong economic (energy prices) and political (energy security) factors that also need to be taken into account.

THE TIME FOR THE SCIENCE

The growing pressure of human activity is placing increasing stress on ecosystems of all kinds, and that stress manifests in various forums. The availability of freshwater, the capacity of renewable resources, use of land, nitrogen and phosphorous cycles, air pollution and ocean acidification all represent potentially critical constraints which profoundly affect human wellbeing. In some cases, thresholds have been exceeded which signal the onset of irreversible change (at least within human timescales) as is the case with climate change and biodiversity loss.

It should not be forgotten that these factors do not operate in isolation, and to understand them better thinking should be in terms of systems rather than individual factors. Sir John Beddington, the UK's Chief Scientist, has talked of the "perfect storm", that is the interdependence of future demand for energy, water and food. By 2030, the world's population will have increased from six to eight billion, and demand for food risen by 50%, for water 30% and for energy 50%. Add to this the fact that the impacts of climate change by this time could decrease the available resource for at least two of these and it could be a very different world to today.

Beddington's perfect storm is one scenario, and some would say a somewhat extreme one. However, the arguments are not about the connectedness of these factors, but more the rate and speed with which they will operate. Resource efficiency, in its widest sense, is a means to mitigate these changes, whatever their true timescale, and travel down a calmer course to enable adaptation to environmental change with the minimum detriment to quality of life. The environmental sciences are an essential tool in this feat of navigation to understand the best heading and the current true position. **ES**

Dr John Whittall is Lead Technologist, Environmental Sustainability, at the Technology Strategy Board.

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Carbon capture and recycling: Converting carbon dioxide into useful commodities

A vibrant 'low carbon economy' is the current mantra for Government and business. **Anna Weston** and **Carolyn Roberts** consider the opportunities for commercial reclamation of atmospheric carbon dioxide, and wonder whether any of the current technologies can make a real difference.

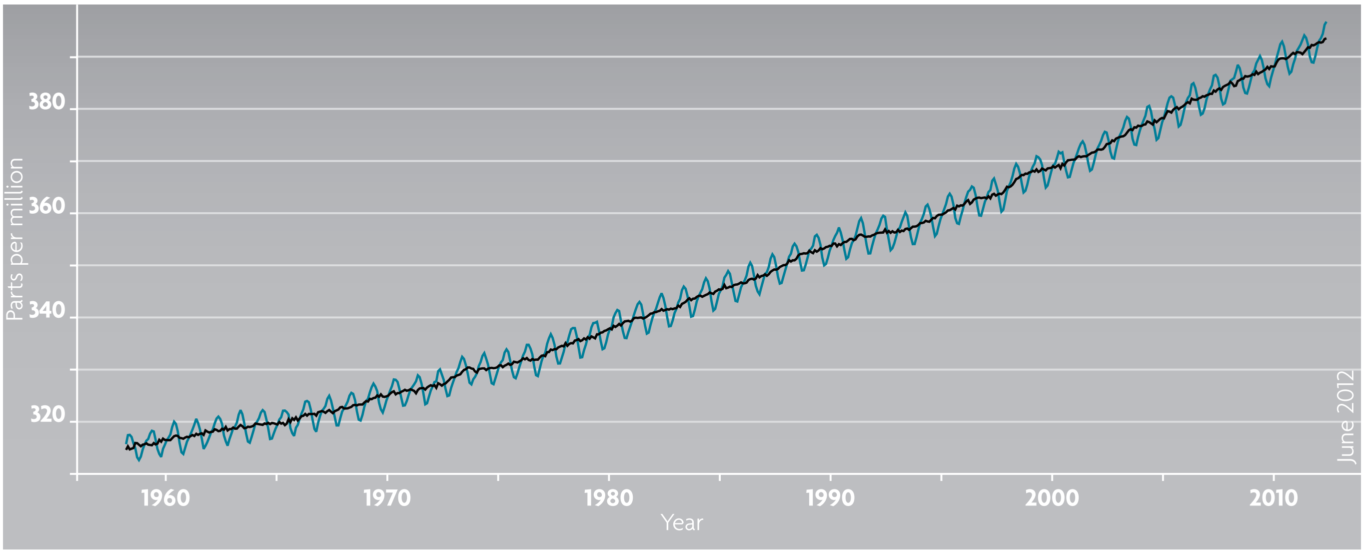
The vast majority of environmental scientists agree that the global climate is changing, moving Earth towards an uncomfortable pattern of increasing average temperatures and more unstable weather. The 'greenhouse effect' created by the atmosphere is one of the main factors determining the temperature of a planet. On Earth, naturally-occurring gases such as carbon dioxide (CO_2), ground level ozone (O_3), methane (CH_4) and nitrous oxide (N_2O), trap radiation that would otherwise escape into space, thereby keeping the surface warmer than its orbital position would dictate. Most scientists also concur that humanity has influenced the climatic balance by releasing large volumes of these greenhouse gases (GHGs) into the atmosphere by burning fossil fuels in power plants to produce electricity, from industrial processes such as chemical production, metal processing, paper, glass, ceramics and cement manufacturing, and from transport. Carbon dioxide atmospheric levels are also increased markedly by deforestation and conversion of land for agriculture. Carbon dioxide is the largest manmade contributor to the greenhouse effect, contributing between nine and 26 % of the warming, but artificially-manufactured GHGs such as hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride have compounded the problem during the last century or so[1]. It is estimated that only about 55% of all emissions of carbon dioxide from human activities are currently removed into natural sinks in the ocean and land, with the remainder contributing to the rising atmospheric concentrations[2].

Since most GHGs are carbon-based, much of the current debate on climate change refers to the global 'carbon cycle', the flows and storages of carbon within and between different elements of the Earth's system, the need significantly to reduce the rate of carbon dioxide addition to the atmospheric component, and possible ways of removing or 'capturing' it back into a terrestrial store. Environmental scientists are playing a key role in developing holistic thinking about carbon dioxide, as well as tracking the impact and fate of other GHGs. Such understanding is critical in order to establish the appropriate balance of activities that promote long-term sequestration of carbon in the ground or biosphere, as well as the development of technologies based on chemical 'up-cycling' (as the current parlance has it) of carbon dioxide into marketable commodities. Potential solutions to the problem of making carbon capture commercially viable and attractive to industry involve turning it into useful and profitable commodities. Such solutions could be applied to both carbon dioxide captured from a concentrated source (such as a power generating plant, cement and steel works) and that which has been removed directly from the atmosphere using other means. **See Figure 1**.

The UK Climate Change Act 2008 was the world's first long-term legally-binding framework to tackle the dangers of climate change. Becoming law on 26 November 2008, it is intended to ensure that the UK's net emissions for the six greenhouse gases included in the Kyoto Protocol (excluding O_3) for the year 2050 are at least 80% lower than the 1990 baseline, to be achieved through action both in the UK and abroad. The Act also set a legally-binding interim target for a reduction in emissions of at least 34% by 2020, again compared to the 1990 baseline. Government policy to achieve these targets addresses the reduction of carbon dioxide emissions through improved energy efficiency (and therefore a reduction in the amount of fossil fuels burned), the development of low carbon renewable energy technologies, and the capture and storage of the gas from the atmosphere.

To date, national and international policy on carbon dioxide capture has focussed mainly on methods of capturing the gaseous emissions from oil, coal and

Figure 1: Atmospheric CO_2 at Mauna Loa Observatory
Source: Scripps Institution of Oceanography, NOAA Earth System Research Laboratory



gas-fired power stations, its transfer by pipeline, and underground storage in depleted oil and gas reservoirs, or in saline aquifers. Such stores are assumed to be quasi-permanent, capable of trapping the carbon dioxide for geological periods of time. Plans for industrial demonstrator plants for carbon capture and storage (CCS) assume the use of amine 'scrubbers' to capture carbon dioxide before and after combustion of fossil fuels. However, energy input is required subsequently to remove it from the amine solution so that it can be stored or further processed; even for new power plants using post-combustion capture, 20-25% of the plant's total energy output would be necessary. Less energy-intensive technologies are currently being developed, such as chemical looping[3] and the use of ionic liquids[4] but this end-of-pipe approach to carbon dioxide removal is expensive and unlikely to be commercially viable in the near future; any additional costs will inevitably be passed directly onto the consumers of the power in the form of higher bills. In November 2007 the Department of Energy and Climate Change launched a £1 Billion competition for the first UK CCS demonstration projects, and two initiatives were shortlisted, one at E-ON's Kingsnorth power station in Kent and one at Longannet in Scotland (owned by Scottish Power). However both projects failed to progress, leaving the Government in a difficult position where alternative, more cost-effective methods of carbon capture will become increasingly important. A new £1billion competition was launched in April 2012 by the Department of Energy and Climate Change, for electricity companies to develop commercial carbon capture and storage systems.

POTENTIAL TECHNOLOGIES FOR CAPTURING ATMOSPHERIC CARBON DIOXIDE

The term 'end-of-pipe technology' is not restricted to literal interpretations of the phrase, however, but includes several other methods for capturing carbon dioxide from the atmosphere. Over the last few years a range of technologies have been suggested, including the use of edible sponges, molten salts, bacteria and polymers. However, the more common possibilities are outlined below.

CHEMICAL CAPTURE

Direct capture of carbon dioxide from ambient air, or 'air capture', is being explored as a potentially viable means of tackling distributed emissions such as those from vehicles. At present, three main technologies are being investigated, including adsorption onto solids derived from commercial ion-exchange resins[5] or solid amines on mesoporous silica substrates[6]; absorption into highly alkaline solutions[7, 8]; and absorption into moderately-alkaline solutions using catalysts[9]. Although these processes are intrinsically energy-intensive because of the thermodynamics of capturing low concentrations of carbon dioxide, they have the advantage that the gas can potentially be converted into a useful chemical at the site where it is required. For example, carbon dioxide could theoretically be captured and chemically converted to a fuel at a service station. This would potentially defray the cost and carbon dioxide emissions that are associated with the existing transport of petrol and diesel to stations, but both the technology and the carbon advantages of 'air capture' are a long way from being fully understood. Renewable energy sources would be required to power the process; there is no way around Newton's Second Law of Thermodynamics, so it is impossible to end up with a net benefit otherwise.

BIOLOGICAL CAPTURE

Since early in the history of life on earth, plants have been incorporating carbon into their cells through photosynthesis. Today, terrestrial ecosystems sequester about 3 GtC/yr from the atmosphere by photosynthesis[10], roughly equal to 30% of the combined carbon dioxide emissions produced by burning of fossil fuels and deforestation. Clearly, enhancing the volume and rate of growth of natural vegetation by cultivating more trees would be very advantageous, and this is probably the simplest method of promoting atmospheric carbon reductions. Its cost-effectiveness depends a great deal on local circumstances, although other potential benefits such as biodiversity enhancement, soil erosion prevention and the provision of shade can also be gained. Increasing tree cover is not entirely free from controversy, however, as land may have to be removed from food production, and some thirsty species such as Eucalyptus can have deleterious impacts on groundwater levels.

Promoting algal growth in lakes and oceans could also increase the removal of carbon from the atmosphere, albeit slowly. The Earth's oceans act as a natural biological pump for the removal of atmospheric carbon, through uptake in microscopic plants. As these algae die, their bodies sink into the deep ocean and become food for bacteria and other organisms. The combined effect of photosynthesis at the surface followed by the respiration of bacteria and other organisms deeper in the water column removes carbon dioxide from the surface and re-releases it at depth. This transferral can potentially be enhanced through the addition of artificial nutrients (such as nitrate or phosphate) using iron fertilisation or through artificial modification of oceanic upwelling or downwelling currents to redistribute the materials. However such stimulation involves manipulating the marine ecosystem and the possible consequences of such geo-engineering are currently the subject of speculation, and some alarm. It is also difficult to see how such methods could be economically viable, given the energy demands and transportation needs, even though it is estimated that they could theoretically remove between 1 and 30 ppm carbon dioxide from the atmosphere[11, 12].

AT A GLANCE: ALGAE IN INDUSTRY

In industrial applications, algae can also be harnessed to capture carbon dioxide by bubbling concentrated flue gas streams through an algae-containing reservoir. University of Sheffield Professor Will Zimmerman, working with company AECOM, has developed a cost-effective process to increase the efficiency of wastewater treatment by cultivating certain algae, at the same time as capturing carbon dioxide from the exhaust gas from chimneys at one of Corus's steel-making plants. Aeration is an essential part of most wastewater treatment processes, but Zimmerman's use of micro-bubbles improves the treatment efficiency and the quality of the effluent. The algae can then be harvested and used to make biofuels or converted to other biomaterials.

CHARCOAL USAGE

Historically, charcoal has been used as a soil improver. There is evidence of this in the terra preta soils of the Amazon Basin, which have high levels of fertility and nutrient retention, and store large amounts of organic matter, particularly in the form of black carbon. Such soils were generated by farmers using 'slash-and-char' methods to clear land and prepare fields for crops between about 450 BC and AD 950. Unlike the better known 'slash-and-burn' techniques, slash-and-char is based on low-temperature smouldering fires covered with dirt and straw, which produce carbon-rich charcoal as a result of oxygen depletion. The secrets of terra preta soils were rediscovered in 1874 by Cornell Professor Charles Hartt, but today's scientists are developing soil improvers based on the same principle.

CAPTURE IN SOILS

Fertile soils typically contain large amounts of organic matter, although there is some evidence that intensive agriculture tends to reduce this. Another option for removal and long term stabilisation of atmospheric carbon is to convert organic matter into a bio-based material such as charcoal that can be deposited deep within the soil column. Such materials can also enhance soil quality and productivity, or at least counteract some of the worst excesses of artificial wetland drainage and consequent peat oxidation. Improving soil quality is also becoming a priority in order to produce the amount of food required to feed a growing population and to achieve a higher level of food security. Moreover, it is crucial to increase soil productivity if a larger proportion of agricultural land is required to grow biofuel feedstocks.

Biochar is defined as the solid remains of any organic material that has been heated to at least 250°C in an oxygen-limited environment. Biochar reduces atmospheric greenhouse gas concentrations by converting the carbon molecules held in biomass to a stable form, rather than allowing rapid decomposition and the return of carbon dioxide to the atmosphere. Biochar is thought to improve the performance of soils by increasing water retention and creating an environment in which microbes thrive, therefore enhancing crop productivity. It has also been shown to reduce the amount of other GHGs emitted from the soil, such as CH_4 and N_2O[13]. Biochar production can provide some bioenergy for human use too, and can be used to dispose of certain carbon-based waste materials safely. The UK is a global leader in biochar research, with many universities carrying out cutting-edge experimentation into different aspects of its production and use. The UK Biochar Research Centre, a dedicated facility with twenty research staff and a pilot-scale processing facility based at Edinburgh University, is exploring

AT A GLANCE: BIOCHAR

Biochar company Carbon Gold was established in 2008 by Craig Sams, founder of chocolate company Green & Black, and Daniel Morrell, founder of The Carbon Neutral Company, to research a solution to two major environmental problems: the degradation of soil in some areas of industrial farming and climate change resulting from GHGs. Carbon Gold's main product is a Soil Association approved biochar which acts as both a soil supplement for degraded soils and a means of carbon capture and sequestration.

the role of biochar as a carbon storage and sustainable energy technology, and developing understanding of its agronomic, environmental and socio-economic impacts.

ENHANCED WEATHERING

The gradual weathering of carbonate and silicate rocks removes carbon dioxide from the atmosphere, and could be a promising carbon capture method, since silicate minerals are the largest class of rock-forming minerals, constituting approximately 90% of the Earth's crust. However, the natural reaction rate on exposed rock surfaces is very slow, rendering natural weathering unhelpful as a method of combatting the large amount of carbon dioxide humanity is currently pumping into the atmosphere. Through the action of heat and pressure on crushed rock, scientists have been able to speed up these reactions. The resultant silicates or carbonates are extremely stable and can be stored on land as building materials, through addition to soils[14] or dissolution in the ocean[15]. As the products produced by these processes occur naturally they are unlikely to create major environmental damage, but they are alkaline and although this may combat the acidity increase of the terrestrial and marine environments associated with elevated levels of atmospheric carbon dioxide, their storage would need to be properly managed.

NEW CLASS OF CEMENT: NOVACEM

Innovative company Novacem has developed a new class of cement based on magnesium oxide (MgO) and hydrated magnesium carbonates, with a carbon negative footprint. The production process uses accelerated carbonation of magnesium silicates under high temperature and pressure. The carbonates produced are heated to produce MgO, with the carbon dioxide generated being recycled back into the process. The use of magnesium silicates eliminates the carbon dioxide emissions from raw materials processing, and the production of the carbonates absorbs carbon dioxide so it can be produced by carbonating part of the manufactured MgO using atmospheric or industrial carbon dioxide. Overall, the production process to make 1 tonne of Novacem cement absorbs up to 100 kg more carbon dioxide than it emits.

Examples of chemical weathering reactions:

$CaSiO_3 + CO_2 \rightarrow CaCO_3 + SiO_2$

$CaSiO_3 + 2CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_{3-} + SiO_2$

$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_{3-}$

The data in **Table 1** is taken from the Royal Society's 2009 report 'Geoengineering the Climate'. It covers some of the technologies discussed above, as well as other methods. The technologies are rated from 1 to 5

▼ **Table 1: Different carbon storage mechanisms and their effectiveness, affordability, timeliness and safety.** From Royal Society (2009).

Capture technology type	Method	Effectiveness	Affordability	Timeliness	Safety
Biological capture	Afforestation	2	5	3	4
Biological capture & Flue gas scrubbing	BECS (bio-energy with carbon storage)	2.5	2.5	3	4
Biological capture	Biochar	2	2	2	3
Flue gas scrubbing	CCS at source	3	3	4	5
Air capture	CO2 air capture	4	1.9	2	5
Enhanced weathering	Enhanced weathering	4	2.1	2	4
Ocean ecosystem methods	Ocean fertilisation	2	3	1.5	1

CARBON8 SYSTEMS

Carbon8 Systems is a spin-out company from the University of Greenwich established to commercialise accelerated carbonation as a treatment for contaminated soils and industrial wastes. Carbon8 uses carbon dioxide gas to treat industrial wastes and contaminated soils. The technology not only renders these waste materials less hazardous, which means cheaper and easier disposal and the avoidance of landfill, but also manufactures aggregate products for the construction industry at the same time as capturing carbon. http://c8s.co.uk/index.php

in the areas of effectiveness, affordability, timeliness and safety, where 5 is very good and 1 is very poor.

POSSIBLE COMMERCIALLY VIABLE APPLICATIONS AND POTENTIAL MARKETS FOR CAPTURED CARBON DIOXIDE

The commercial potential of different technologies can be enhanced where specific products are generated as a result of the process, and companies have been quick to explore the possibilities. For example, carbon dioxide injection has been used to increase the amount of crude oil that can be extracted from oil fields, by displacing oil from small pores in the underground strata. Currently, most of the injected gas is obtained from natural underground reservoirs and captured gas is not widely utilised for reasons of availability and economics; economic incentives for carbon dioxide storage could change this balance. However, although this process may help to keep oil prices low, enhanced oil recovery is not a sustainable solution for carbon sequestration since the net effect is to increase the amount of atmospheric carbon dioxide when the extracted crude oil is burnt to generate electricity or to fuel our cars.

PLANT AND ALGAE BASED BIOFUELS

The oils contained in algae and some plants (e.g. rapeseed, palm or nuts) have been extracted and used as a fuel for many years. The combustion of these biofuels does return the carbon dioxide to the atmosphere, but they can replace fossil fuels and therefore result in smaller net impacts on atmospheric carbon dioxide levels. The rapid growth and high oil content of algae means that it can theoretically sequester a large amount of carbon, and produce a lot of biofuel in a relatively short period of time. Algae also have the advantage of being able to be grown in areas such as ocean margins and saline lakes, which do not compete with agricultural production. A disadvantage of the method is that a large amount of energy is required to dewater the algae in order to obtain usable oil.

HYDROGEN-BASED FUELS

Chemists have shown that it is possible to use catalysts to convert carbon dioxide into the raw material for a wide range of products, including plastics and gasoline[16]. The conversion of carbon dioxide to carbon monoxide produces an intrinsically valuable commodity that is widely used to make plastics (polyesters and polyketones) and other products. Carbon monoxide is also a key ingredient of synthetic fuels, including syngas (a mixture largely of carbon monoxide and hydrogen), methanol, and gasoline. Naturally, the energy requirement of the processing has to be included in the balance for carbon.

OTHER PRODUCTS

Whether carbon dioxide has been captured either from dispersed or concentrated sources, it can be converted to many different products including cement, fertiliser, plastics and fine chemicals. Carbon dioxide can either be directly converted into a chemical or it can be converted via a plant or algae to produce fine chemicals such as pharmaceuticals, flavourings and fragrances. It can also be used in greenhouses to improve the growth of crops, for example at British Sugar, waste carbon dioxide is pumped into a number of large greenhouses and used to enhance the photosynthetic rate, and therefore the growth rate, of tomatoes.

In 1999, the US Department of Energy outlined the top twelve most important biologically-derived chemical building blocks for plant-based production of chemicals in a ‘roadmap’ publication[17]. As a result of the high price of oil, agricultural raw materials have now become cheaper than oil and these building blocks can be used to make biofuels, bioplastics and fibres (such as spandex and nylon) at prices which are competitive with products derived from fossil fuels.

Carbon dioxide is currently used as a feedstock in a number of commercial processes, the details of which are shown in **Table 2**[18]. To put this in context, humanity generated 5.6 Gt of carbon dioxide in 1990.[19]

A small number of potential ways of converting carbon dioxide into profitable commodities appear to have some potential to address the escalating problem of atmospheric greenhouse gases, however more environmental research is required to develop these technologies and demonstrate their potential to have a significant impact of atmospheric greenhouse gas levels over time. We need to know if they are scaleable, for example, from the laboratory to the ground. It is also critical to fully ascertain what the long term environmental effects of these technologies may be, as well as the technical, economic and social challenges, before assuming that they provide a solution to global warming problems. There is nervousness about their deployment which is similar to that relating to geo-engineering technologies such as atmospheric radiation deflection using shields, or pumping water vapour into the atmosphere to increase cloudiness, and there is also a fear of the moral hazard which suggests that investment

▼ **Table 2: Carbon sources and rate of return to the atmosphere.**

Process	Global annual CO2 usage Mt	Lifetime of storage before release to atmosphere
Urea	65-146	6 Months
Methanol	6-8	6 Months
Inorganic carbonates	3-45	Decades
Organic carbonates	0.2	Decades
Polyurethanes	10	Decades
Technological	10	Days to years
Food and drink	8	Days to years
Total	**102-227**	

in these technologies may deflect effort that would better be made into GHG emission reductions. However, UK resources for research in this area is limited, although the Natural Environment Research Council are now looking at further investment. According to a report written by the Centre for Low Carbon Futures, the US government has invested over US$ 1bn in research into the utilisation of carbon dioxide and the German government has invested €118M in one project with Bayer to research the use of carbon dioxide as a raw material, leaving the UK lagging behind.

The utilisation of carbon dioxide will not sequester the required levels of gas to meet the UK's reduction commitments and these technologies should only be used in conjunction with CCS, using renewable technologies to provide the energy required for the transformations. However, the UK government's current strategy of burying all of our unwanted carbon dioxide in the ground is a little short-sighted. Carbon dioxide recycling will help to reduce the UK's dependence on fossil fuels creating valuable commodity chemicals, intermediates, fuels and other products. We recycle metals, plastics and paper, so why not carbon dioxide? **ES**

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Biofuels – A genuinely renewable substitute for oil?

The increasing use of biofuels as substitutes for fossil fuels has generated optimism and antagonism in almost equal measure. **David Gardner** describes the background to the issues and the technologies, explains why the controversies have arisen, and suggests that whilst the early expectations for biofuels were misplaced, they still do have a significant role to play as we move away from the reliance on fossil fuels.

BACKGROUND – WHY ARE BIOFUELS NEEDED?

The production rate of fossil fuel oil has been increasing steadily since the Industrial Revolution. However, it has long been recognised that fossil oil resources must be finite, and the balance between the rate of discovery of new reserves and the increased demand for fuel has led to a debate on the timing of 'Peak Oil'. 'Peak Oil' is the point at which the global production of oil goes into permanent decline. The estimated date for this is contested and, for example with new production techniques, current predictions vary quite significantly. The Department of Energy and Climate Change started an investigation in 2007, and issued some updated conclusions in 2009, but still assumed that peak oil would occur after 2020[1]. In the World Energy Outlook 2010 report[2], the International Energy Agency pointed out that crude oil output will hit an "undulating plateau of around 68-69mbpd by 2020", but that total oil, which includes unconventional oil and gas supplies (i.e. those supplies that are not extracted by the traditional methods, and include shale oil and shale gas, and coal bed methane), is expected to peak at around 96mbpd sometime after 2035. However, at some point, fossil oil will have to be replaced, particularly for transport uses. The Department of Energy and Climate Change reported that the total oil equivalent energy demand for the UK in 2010 was 159.1 million tonnes (Digest of United Kingdom Energy Statistics 2011). The energy for transport was estimated to be the largest of groups, consuming 35% of this. But why have biofuels attracted so much attention as a potential substitute?

Peak Oil is not the only reason for seeking to replace fossil oil of course. The recognition of climate change and the link to carbon dioxide emissions has resulted in a raft of legislation and regulations. David Cameron, Nick Clegg and Chris Huhne have all signed the Government's "Carbon Plan". As stated in the first paragraph in the Foreword of this document:

> "This Carbon Plan sets out a vision of a changed Britain, powered by cleaner energy used more efficiently in our homes and businesses, with more secure energy supplies and more stable energy prices, and benefiting from the jobs and growth that a low carbon economy will bring."

The current global infrastructure for the supply of energy for transport is substantial and complex, and consequently difficult to change. Moreover at local level, liquid fuels such as petrol and diesel can be transferred into vehicles very quickly, whereas alternatives such as the exchange of stored electricity require long charging times. For cars, this would mean a significant change from the current human behaviour of refuelling while standing on a garage forecourt. Alternatives to reduce the waiting have been suggested, such as battery swap facilities for electric cars, but commercial deployment is still some time away. For aviation, there are parallel developments in electrically-driven planes, with a two seater (a Diamond DA36 E-Star) making its maiden flight in June 2011. However, it remains unlikely that commercial flights will take place in the near future. The potential for developing an almost direct replacement for petrol and diesel, pending longer term fuel solutions and the associated infrastructure to facilitate their use is therefore very tempting.

Studies are also being conducted to test the long term use of biodiesel for ships. For example, Lloyd's Register have been working with Maersk for almost two years on the use of biodiesel, and a call for action from the Forum for the Future's Sustainable Shipping Initiative was published in May 2011. Some people may also remember the Earthrace powerboat that made headlines in 2008 by circumnavigating the globe in just under 61 days, and powered by 100% biodiesel.

"Ethanol produced in Brazil results in 80% reduction in greenhouse gas emissions. However, ethanol produced in the United States from maize may only produce savings of 10%"

THE BASIC FACTS

Biofuel is the term used to describe the plant-derived replacements for fossil fuels. In theory these could include fuels in solid forms, but the greatest interest is currently being shown in liquids and gases, including bioethanol, biodiesel, biobutanol, and biogas. World production of biofuels is currently dominated by the US and Brazil, particularly for bioethanol where estimates from the International Energy Agency for 2010 put production at 50 billion litres for US, and 27 billion litres for Brazil[3]. Supply of biodiesel is headed by European production at approximately 10 billion litres (for OECD members in Europe), and just under 8 billion litres for all other producers in the world. Within the UK, the Department of Transport suggests that biodiesel and bioethanol accounted for almost all the biofuel production in 2009/10, 1,113 million litres and 455 million litres respectively[4]. Reported biogas production was only 0.2 million kg.

▼ **Table 1: Source of biofuels used in the UK 2009/10**

Bioethanol Source	Volume/million litres (%)	Biodiesel Source	Volume/million litres (%)
Sugar cane	305 (67)	Soy	454 (41)
Sugar beet	76 (17)	Oilseed rap	226 (20)
Wheat	40 (9)	Tallow	186 (17)
Corn	14 (3)	Palm	106 (10)
Molasses	5 (1)	Used cooking oil	48 (4)
Other[a]	2 (0.4)	Other[b]	0.3 (0)
Unknown	14 (3)	Unknown	93.6 (8)
Total	**456**	**Total**	**1,113**

a Includes barley, cassava, corn, molasses, sulphite, and triticale
b Includes corn oil and sunflower

Most production of bioethanol and biodiesel currently comes from the conversion of crops grown specifically for energy use. Feedstocks for bioethanol and biodiesel used in the UK in 2009/2010 are given in **Table 1**, which also shows information on the production of biofuels from by-products.

One mechanism that has been adopted by the UK Government is to drive the use of biofuels directly through legislation. The Renewable Transport Fuels Obligation (RFTO), the product of legislation passed in 2005 and implemented in 2008, requires that all suppliers who provide more than 450,000 litres of fuel per annum in the UK must include a given percentage of biofuel. The amount required is increasing year-on-year, with a figure of 5% being the target for 2013. In 2010/11, returns to the Department of Transport identified sixteen suppliers that were obligated under the RTFO, and 29 companies that were not, with the majority of the latter supplying biofuels.

APPARENT BENEFITS OF USING BIOFUELS

The initial benefits of using biofuels were assumed to be the potential for carbon-neutrality, with the carbon dioxide produced during the use of the fuel being offset by the uptake during growth of the crop. Indeed, the evidence base continues to suggest that this can be the case if the materials used for producing the biofuels are sourced in a sustainable manner[9]. Of the sixteen businesses that come under the RFTO (for 2009/10), all reported greenhouse gas savings resulting from the biofuels they used, ranging from just over 10% savings (Chevron), to over 80% reported by Topaz and Lissan4. Indeed fourteen out of the sixteen achieved the target of 45% GHG savings, or were within 10%. However, the provisional figures for 2010/11 have only twelve out of the sixteen meeting the same criteria (although the target was increased to 50% greenhouse gas saving).

There are wide variations in the calculated benefits of producing and using bioethanol compared to fossil fuels. The location and conditions under which the crops are grown has a significant impact. For example, ethanol produced in Brazil results in 80% reduction in greenhouse gas emissions. However, ethanol produced in the United States from maize may only produce savings of 10%[9].

Although the initial dash to produce and supply biofuels for transport has sparked many discussions on their long term sustainability, new legislation and policy is now setting out realistic limits on where feedstock crops should be grown, and the impact on local communities. Also, the uptake of biofuels has supported research into so-called second and third generation biofuels that could prove to be more sustainable, and these will be discussed later.

THE ISSUES OF SUSTAINABILITY AND ETHICS

Despite the initial commercial enthusiasm for biofuels, it was quickly realised that biofuels were not the immediate panacea to the issue of peak oil. In fact, uncontrolled planting and supply of biofuel crops has the potential to have a large negative impact on greenhouse gas emissions, water use, food production and the local environment, including the potential threat of introducing invasive species to local and vulnerable ecosystems. UNEP has issued four papers that covered some of these issues[5, 6, 7, 8].

The production, harvesting, transport, and use of biofuel crops clearly has a potential impact on the overall carbon cycle. Initial claims for the benefits of biofuels were sometimes based on the fact that, by growing biomass, carbon emissions arising from the burning of the fuel would provide a near carbon-neutral solution. However, it was soon realised that this was based on a set of naive assumptions, as the growth of the biomass, their transformation into a fuel and its final transport to point of use was considerable, and in some cases outweighed any advantage.

Planting crops for bioenergy production may be fitting when land has limited suitability for other uses, is not used by the local communities, and does not have significant environmental value. Conversely, ecologically-valuable wetlands and peat tracts can be compromised, and land that is currently being used for food production is unlikely to be appropriate for biofuels when global food supplies are under pressure. As more detailed reviews were performed, so policy changed. In 2008, UK strategy was influenced by the publication of "The Gallagher Review of the indirect effects of biofuels production"[9]. Current issues that are now being discussed reflect, for example, the importance of indirect land use change (iLUC), and broader ethical issues. The direct impact of land use change locally has previously been seen as of primary importance, but it is now recognised that if crops are grown for energy, and this displaces other crops, then these may need to be grown elsewhere. The report "Global Trade and Environmental Impact Study of the EU Biofuels Mandate" modelled the impacts in detail, including the global impact of iLUC[10].

The Nuffield Council on Bioethics followed this with a report in April 2011 simply entitled "Biofuels: Ethical Issues"[11]. The report integrates the issues of sustainability with human rights issues, and trade requirements for the global exploitation of biofuels. Their view was that only by combining these issues into a clear set of linked principles will it be possible for the successful and ethical development of this fuel source.

WHERE NEXT FOR BIOFUELS?

There are so called first, second and third generation biofuels, although even this terminology has given rise to some debate. The International Energy Agency published its "Technology Roadmap: Biofuels for Transport" in 2011, and they simply discuss conventional and advanced biofuels based on levels of technology development[3].

Conventional biofuels: Sugar and starch based ethanol; oil-crop based biodiesel and vegetable oil, and biogas from anaerobic digestion are all classed as conventional biofuels because the technology used to convert them to the final product is well developed, such as anaerobic digestion or fermentation. The feedstocks for these have been outlined in **Table 1**.

Advanced biofuels: There is a wide variety of developing technologies. Some are based on being able to access a wider variety of feedstocks, such as lingo-cellulosic materials that are either grown specifically or come from waste materials, algae biomass, and even animal and plant fats. Also, new transformation technologies are being developed, including the production of diesel from sugar based feedstocks using biological or chemical catalysts.

The production of biofuels is just one aspect of useful materials that can be obtained from organic material. In the same way that oil refineries produce a vast range of products, not just fuels, so bio-refineries are being developed that use bio-based materials to produce a wide range of end products, only one of which is biofuel. By moving to a larger scale and producing a wider range of products in a bio-refinery, the overall efficiency of producing biofuels from its feedstock will increase.

The impact of advanced technologies on greenhouse gas emissions is still under debate, and there have been many lifecycle-analysis studies conducted to assess

Photo credit: John Meikle

"Despite the initial commercial enthusiasm for biofuels, it was quickly realised that biofuels were not the immediate panacea to the issue of peak oil"

THE SIX ETHICAL PRINCIPLES FOR THE PRODUCTION AND USE OF BIOFUELS

i. Biofuels development should not be at the expense of people's essential rights (including access to sufficient food and water, health rights, work rights and land entitlements).

ii. Biofuels should be environmentally sustainable.

iii. Biofuels should contribute to a net reduction of total greenhouse gas emissions and not exacerbate global climate change.

iv. Biofuels should develop in accordance with trade principles that are fair and recognise the rights of people to just reward (including labour rights and intellectual property rights).

v. Costs and benefits of biofuels should be distributed in an equitable way.

vi. If the first five Principles are respected and if biofuels can play a crucial role in mitigating dangerous climate change then, depending on additional key considerations, there is a duty to develop such biofuels.

these. The IEA analysis[3] Roadmap combined 60 different LCAs to evaluate the true potential impact of biofuels. Although some improvements appear to be possible for the advanced technologies over the currently available fuel production routes, the case for biofuels remains insecure. Even this apparently comprehensive analysis excludes the impact of indirect land use change.

While many of these advanced technologies show promise, commercial exploitation is still some way off. There has been a considerable amount of interest shown in the use of algae as a viable source of both fuels and other products. The US Department of Energy Roadmap on Algal Biofuels highlighted many of the advantages, which includes a high production level per acre; non-food based feedstocks; and the use of otherwise unusable land (including, for example, brackish water sources)[12]. However, the roadmap recognised that:

> "Despite their potential, the state of technology for producing algal biofuels is regarded by many in the field to be in its infancy and there is a considerable amount of RD&D needed to achieve affordable, scalable, and sustainable algal-based biofuels."

A PANACEA FOR FOSSIL FUELS?

It is perhaps unfair to expect any technology to produce a complete solution to the issues of energy and fuel security, and this has proved to be the case for biofuels. Optimistic early expectations rapidly drove the market into an unsustainable position. However, this was recognised and new policies and mandates around the world attempt to provide a framework for sustainable growth in the supply of biofuels. There is still much work to be done, but with the commercialisation of the first generation of biofuels now just about complete, efforts are being focussed on the improvement of existing processes to plant and harvest the various feedstocks, and the development of the advanced technologies that will be able to process a wider variety of materials and produce a wider selection of end-products.

The production of biofuels is only one small contribution to the overall energy balance for the way we live our lives today. There is still plenty of development work required before we can be sure that biofuels will provide a sustainable alternative that meets all the ethical criteria. However, many of the major pitfalls have been recognised, and future developments should provide a part of the solution to a more sustainable way of life and, as stated by the sixth principle of ethics given by the Nuffield Council on Bioethics, there is a duty to develop biofuels if they meet the first five ethical principles based on sustainability and preservation of human rights. **ES**

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Anaerobic Digestion Units

Liz Mullis provides an overview of energy from waste initiatives in the UK, including incineration and anaerobic digestion, highlighting the importance of financial incentives if we want to reduce our dependence upon fossil fuels and prevent further expansion of landfill sites.

Energy from Waste

The search for alternatives to landfill for the disposal of waste, and the threat of climate change exacerbated by the burning of fossil fuels, have led to a resurgence of interest in recovering energy from waste (EfW). According to DEFRA[1], over 80 million tonnes of waste are produced each year by householders, commerce and industry, placing pressure on the environment and adding cost to businesses, and ultimately to their customers. In combination with the increasing demand for renewable energy sources, this has resulted in significant growth in the potential for the generation of energy from waste. Energy generated from waste can contribute to the achievement of climate change targets and to the movement towards a zero waste economy, and has consequently been supported by the UK Government. The Government Review of Waste Policy in England 2011[2] recognised the need for growth, and industry has also spotted the opportunity. In October 2010 the Confederation of British Industry (CBI) called on the Government to encourage more energy from waste projects. In its report, 'Going to Waste: Making the Case for Energy from Waste',[3] the CBI stressed the necessity of using non-recyclable waste to help meet the UK's energy needs, reducing the amount of rubbish being sent to landfill sites and meeting climate change targets. "We cannot continue dumping rubbish in landfill sites," said Neil Bentley, CBI Director of Business Environment. "Waste that can't be recycled could be used to heat homes and produce electricity, as well as improving our energy security."

EfW technologies recover energy in the form of electricity and/or heat from residual waste. Residual waste is that fraction of waste which is unsuitable for reuse, recycling or composting, and which remains after traditional waste treatment processes have taken place. Many people feel that generating energy from waste is incompatible with resource efficiency and recycling, and even if local fears over airborne emissions can be overcome, the building of new facilities can consequently be controversial. However, the two perspectives can be complementary as long as the so-called 'waste hierarchy' is recognised. For true sustainability, product design needs to minimise the use of basic materials through 'eco-design', which can drive down the overall consumption of resources. Beyond that, the waste hierarchy principle favours prevention, minimisation, and reuse of waste materials, followed by recycling, and then energy recovery; disposal to landfill is the least favoured waste option. If energy is to be generated from the waste, gaseous and liquid fuels can also be recovered, as an alternative to electricity generation. Energy is generated directly in the case of heat or bio-methane which can be cleaned up for direct injection into the gas grid for example, or indirectly, as is the case with electricity.

The three main ways of recovering energy from waste in common use in the UK are listed in Table 1 below.[4]

THERMAL TREATMENTS

Thermal treatment includes:

- Direct combustion (conventional incineration).
- Use of secondary recovered fuel which is an output from mechanical and biological treatment processes (MBT).
- Advanced thermal treatments such as pyrolysis, gasification and plasma arc heating used either on the waste directly, or on refuse-derived fuels (RDF).

The UK's thermal installations currently have the capacity to handle 2.5 million tonnes per annum of municipal, commercial and industrial waste and to generate 200 Mega Watts (MW) of electricity; this accounts for 10% of municipal solid waste in the UK. The treatment also allows the recovery of materials such as metals from incinerator ash, and displaces carbon dioxide emissions that would otherwise be emitted by fossil fuel power stations. This increases the UK's own fuel security, and reduces the volume of material put into landfill.

Thermal treatment facilities do result in some emissions to air, principally carbon dioxide and water, with smaller volumes of other substances. Strict environmental standards governing the emissions from EfW plants now apply in all European countries, particularly for heavy metals, furans and dioxins that have been the subject of environmental concern. Dioxins and furans are the abbreviated name for a family of toxic substances that share a similar chemical structure. Dioxins, in their purest form, resemble crystals or colorless solids, and are not produced intentionally, but are created as byproducts when other chemicals or products are manufactured, for example, during thermal incineration of waste. All UK EfW plants must now meet these European emission standards, which are more rigorous than those which apply to coal and oil-fired power stations, and they do so through the installation of very effective gas cleaning systems.

Conventional 'mass burn' incineration reduces the volume of the waste solids by around 90%, and their weight by around 75%. The residual material is known as bottom ash, and a small volume of air pollution control residue (APRC) is also recovered from chimneys. About 40% of the bottom ash produced from EfW facilities in the UK is recycled for use in road building, asphalt or building blocks. APCR consists of a fine powder that remains following the cleaning of the gases from EfW waste facilities. The powder consists mostly of lime, which is alkaline and contains higher levels of metals such as lead, chromium and nickel than bottom ash. Consequently, APCR is classified as hazardous waste and must therefore be treated and neutralized before being stored in specially constructed landfills designed for hazardous materials. The treatment process reduces the hazardous qualities of the APCR, so that it meets the hazardous waste acceptance criteria and is chemically stable.

▼ Table 1: Energy from Waste Technologies

Technology	Method
Thermal	Conventional mass burn incineration and other thermal treatments with energy (and heat) recovery
Thermal	Wastes converted to use as fuels for subsequent thermal treatment, e.g. secondary recovered fuels (SRF) and refuse-derived fuels (RDF)
Biological	Anaerobic digestion (AD) which produces biogas for electricity generation or fuel which is either gaseous or liquid (methane based)

ADVANCED THERMAL TECHNOLOGIES

Where the waste stream is relatively uniform, for example, if it has been processed at a mechanical or biological treatment plant into a homogenous fuel with known moisture content and calorific value, it is well suited to advanced thermal technologies such as gasification or pyrolysis. Mixed and municipal "black bag" wastes, with their unknown composition, are less suited to this; technologies are still being developed to handle these more challenging materials. Usually, the waste is heated under enclosed conditions until it releases low-to-medium-calorific value fuel gases, together with tars, char and ash. These products are ultimately dependent on the type of reactor and the type of waste, but most systems produce a raw gas suitable for direct firing in kilns or boilers. Advanced thermal technologies are potentially more flexible and less destructive than incineration, giving more scope for greater recovery of products from waste. Where refuse-derived fuels are gasified or pyrolysed, the energy required to produce the fuel must naturally

OPINIONS

"Defra still appears to lack the capacity, the vision, the sense of urgency and the political will to break the mould and bring about truly sustainable waste management in this country."
House of Commons Environment, Food and Rural Affairs Committee: The Future of Waste Management Eighth Report of Session 2002–03, Volume I

"Pollution is nothing but the resources we are not harvesting. We allow them to disperse because we've been ignorant of their value."
Richard Buckminster Fuller

be accounted for in carbon balance calculations, but overall the efficiency is greater.

GASIFICATION

Gasification is one of the newer technologies increasingly being used to generate energy from waste. It is a thermo-chemical process in which carbon-based materials are heated in an oxygen-deficient atmosphere to produce a low-energy gas containing hydrogen, carbon monoxide and methane. The gas can then be used to generate electricity in a turbine or combustion engine. Gasifiers fuelled by fossil sources such as coal have been operating successfully for many years, but increasingly they are being developed to accept more mixed fuels, including wastes. New gas clean-up technology ensures that the resulting product can be burnt in a variety of gas engines, with very low emissions. In the UK, gasifiers operate at a smaller scale than conventional mass burn incineration plants, and they can also be deployed in modular form at different scales varying from 20,000 to 100,000 tonnes per year treatment capacity.

PYROLYSIS

Pyrolysis is another emerging technology that shares many of the characteristics of gasification, the difference being that with gasification partial oxidation of the waste occurs, whilst with pyrolysis the waste is heated in the complete absence of oxygen. Synthetic gas, liquid olefin and char are produced in various quantities. The gas and oil can be processed, stored and transported if necessary, and combusted in engines, gas turbines or boilers. Char can be recovered from the residue and used as a fuel, or the residue passed to a gasifier and the char itself gasified. The tars, char and ash are also used in the petrochemical industry, and in other applications such as plastics manufacture.

SECONDARY RECOVERED FUEL (SRF)/ REFUSE DERIVED FUEL (RDF)

These fuels are products generated from the output of mechanical and biological waste treatment plants. The difference between SRF and RDF is one of legality: SRF meets the European Committee for Standardization (CEN) standard, whereas RDF generally does not. In the UK most SRF is either used in cement kilns or is landfilled, but some is burnt for energy recovery and electricity generation in EfW plants. SRF is not currently a viable saleable product as its calorific value is too low and its moisture and chlorine content are frequently too high. A new standard is required in the UK for all recovered fuels if they are to have a future value, which would ensure that a higher proportion could be utilized in EfW plants. Better quality fuel is produced if the input material is source-segregated and uncontaminated. Again, the energy required to produce the fuel at the Mechanical and Biological Treatment plant must be taken into account in the overall carbon balance of the process when the fuel is burnt. It is currently quite difficult to find commercial outlets for RDF and the majority is burnt in cement kilns or landfilled.

BIOLOGICAL TREATMENTS AND ANAEROBIC DIGESTION

Biological treatment for energy recovery is achieved through anaerobic digestion, essentially the same processes that occur naturally in sealed landfills. Organic waste is reduced to a relatively stable solid residue (digestate) similar to compost, in an oxygen-free environment, and bio-methane gas is produced as well as a nutrient-rich liquid. Anaerobic digestion is particularly suitable for wet wastes and it has been used for the treatment of sewage sludge from water treatment facilities for over a century. Efficient digestion is dependent on a good quality, source-segregated waste streams and high levels of contamination, for example with inorganic wastes or heavy metals, can inhibit the process and consequently raise the costs.

In the UK, apart from its increasing use in the treatment of sewage sludge, anaerobic digestion has until recently been limited to small digesters on farms. However, there are now about 65 new plants operating. The UK currently produces over 100 million tonnes per year of organic material that is suitable for anaerobic digestion[5], including:

- 90-100 million tonnes of agricultural by-products such as manure and slurry
- 12-20 million tonnes of food waste (from households and industry)
- 1.7 million tonnes of sewage sludge

The amount of energy produced by anaerobic digestion will vary depending on the feed material and the particular type of digester used. One tonne of food waste typically yields about 300 kWh of energy. Currently, only about one per cent of the UK's domestic food waste is treated by anaerobic digestion, equating to 50,000 tonnes per annum. According to a report by WRAP[6] (the UK Government's Waste Resources Action Programme) 'Household Food and Drink Waste in the UK', treating 5.5 million tonnes per year of food waste by anaerobic digestion could generate between 477 and 761 GigaWatt hours (GWh) of electricity each year, equivalent to the average consumption of 164,000 households.

These figures clearly show that unavoidable food waste (domestic and industrial) that remains once the waste hierarchy's more favorable options have been sought is still a largely under-utilised resource. The Government made a commitment to work towards a 'zero waste' economy in the Coalition Programme for Government of 20th May 2010, and to introduce measures to increase energy from waste through anaerobic digestion. DEFRA subsequently published an Anaerobic Digestion Strategy and Action Plan[7]. The Strategy sets out a vision, whilst the Action Plan sets out in detail the actions that are needed to bring about an increase in energy from waste through anaerobic digestion.

been developed by successive UK administrations to stimulate economically the adoption of new technologies for generating energy from waste and to increase investment into associated aspects of renewable energy production. The different incentives currently being implemented are summarised below.

THE LANDFILL TAX ACCUMULATOR

This escalating tax provides the principal pressure for the development of new EfW plants, because the combined fees that landfill operators charge for waste disposal make alternative treatments more economically viable. The Landfill Tax for biodegradable waste is set at £56/tonne for 2011-2012 and is scheduled to rise by £8 each year until it reaches £80/tonne in 2014-2015. The guarantee provides sufficient incentive for the development of alternative waste management infrastructure, irrespective of the classification of the waste.

"The UK currently produces over 100 million tonnes of organic material that is suitable for anaerobic digestion every year; treating 5.5 million tonnes per year by anaerobic digestion could generate between 477 and 761 GigaWatt hours (GWh) of electricity each year, equivalent to the average consumption of 164,000 households"

DRIVERS FOR CHANGE

There are several drivers for change in the methods used to dispose of waste, specifically to divert potentially valuable biodegradable materials away from landfill. The EU Landfill Directive (1999/31/EC) sets targets for reducing the proportion of biodegradable waste landfilled, as space is becoming less readily available, and costs are increasing. Emissions of methane from landfill sites also make a significant and undesirable contribution to global warming. The Directive sets a challenging target for a progressive reduction in the proportion of biodegradable municipal waste directed to landfill, of 15% by 2020. Other key drivers for change include the cost of energy from fossil fuel and the security of future energy supplies. Research shows that recovering energy from waste can significantly reduce the carbon footprint of the waste management industry when compared with other treatments such as mass incineration.

Despite these obvious environmental advantages, EfW technology remains relatively expensive in comparison with simply burying or burning waste. Consequently, a highly complex matrix of fiscal incentives (and their associated acronyms), have

THE RENEWABLES OBLIGATION (RO)

The RO[8] is primarily aimed at promoting the development of large-scale generation of renewable electricity and is reflected in the form of a subsidy paid per unit of renewable electricity generated (Renewable Obligation Certificates). In real terms, registered producers of renewable electricity currently benefit from an index-linked income of £38.69 per MWh.

FISCAL INCENTIVES FOR ANAEROBIC DIGESTION

The RO was banded by technology type in 2009, with anaerobic digestion benefiting from a 'double-ROC' for each unit generated. The ROC scheme adds approximately an additional 8p/kWh income for electricity generated by an anaerobic digestion facility. The RO is well understood by and popular with UK investors as it has been widely applied across other more mature renewable energy sectors.

THE ENERGY ACT 2008

The Energy Act 2008[9] includes the Feed-In Tariff (FIT) and the Renewable Heat Incentive (RHI), both of which are relevant to Anaerobic Digestion plants. Recent adjustments to the tariff levels for both were made in March 2011.


Cranfield DD gasifier

FEED-IN TARIFF

FITs provide a similar subsidy to ROCs for the generation of renewable electricity but are focused on small scale developments. Anaerobic digestion is the only EfW technology eligible for FITs, and other technologies such as advanced thermal conversion are not covered by the scheme. The FIT scheme is potentially a more profitable subsidy compared to the RO for small scale anaerobic digestion facilities, and is comparable even for projects generating more than 500 kW. FIT tariffs are intended to last for twenty years from the start of a project, and are thus a reliable basis for an investor considering an anaerobic digestion project. The FIT scheme is inapplicable to projects over 5 MW, but anaerobic digestion plants at this scale are unlikely as such a facility would require a huge input of approximately 150,000 tonnes per year of organic waste or 100,000 tonnes per year of another energy crop.

RENEWABLE HEAT INCENTIVE

The Renewable Heat Incentive[10] has provided a subsidy for the generation of renewable heat since November 2011. It also provides a small incentive to the suppliers of renewable heat through biogas combustion, although take up of this is still driven mainly by the proximity of suitable heat users beyond the plant itself, and the associated infrastructure costs of providing a supply to them.

THE RHI AND THERMAL EFW TECHNOLOGIES

Other EfW technologies will qualify for subsidies through the tariffs available for biomass. These are set at varying levels, with a higher tariff available for smaller facilities. According to DECC the biomass tariff will apply to solid biomass from municipal solid waste (MSW) sent for combustion, gasification and pyrolysis. This includes solid recovered fuel from MSW. DECC states: "In addition, other wastes where at least 90% of their energy content is comprised of solid biomass will receive support. Examples of such wastes include waste wood and residues from the paper manufacturing industry." However, DECC notes that, as with the ROC subsidy for renewable electricity generation, the subsidy can only be claimed against 50% of MSW, using a process known as 'deeming' the renewable content of the material, unless operators can prove a higher degree of biomass content in their waste. Clearly, such guarantees for mixed wastes are challenging. The Government is therefore considering whether a specific, dedicated tariff for MSW could be introduced from 2012, as long as "sufficient evidence" is available.

ROCS AND ROC BANDING FOR THERMAL ENERGY-FROM-WASTE PROJECTS

Unfortunately for those involved in developing thermal energy-from-waste projects, the most complicated aspects of the RO relate to those technologies fuelled by plant and animal matter. The eligibility for ROCs of electricity generated using fuels derived from plant and animal matter depends upon:

- The technology used (mass burn incineration, gasification or pyrolysis);
- Whether the plant is a qualifying Combined Heat and Power (CHP) scheme;
- The proportion of the energy content derived from plant/animal matter as opposed to fossil fuels;
- Whether the plant or animal matter is an energy crop; and
- Whether the fossil fuel is waste (and, if so, whether it is solid recovered fuel).

In the case of gasification and pyrolysis (referred to in the RO as 'advanced conversion technologies'), generators will receive ROCs for each MWh of electricity attributable to the renewable energy content of the fuel, according to certain predetermined conditions. Waste

▼ Table 2: Anaerobic Digestion Industry Capacity in the UK

Treatment capacity of existing AD plants not including sewage sludge facilities	534,200 tonnes of commercial waste 382,000 tonnes from food and drink manufacture 136,156 tonnes in farm based plants
Output capacity of existing plants	35 megawatts electrical MWe
Output capacity of 50 AD plants currently in planning	70 MWe

From Anaerobic Digestion Action Plan and Strategy 2011 DECC/DEFRA incineration projects will not generally be eligible for ROCs in the absence of CHP, unless the waste qualifies as biomass. The position changes with the inclusion of CHP as the 'good quality' element of the CHP-generated electricity will receive ROCs for each MWh of electricity attributable to the renewable energy content of the fuel.

CONCLUSIONS – REPLACE WITH SOMETHING ELSE

In the view of energy specialists and waste disposal companies, the UK needs to increase its capacity and capabilities in EfW technologies still further, as this will reduce the dependence upon unsustainable fossil fuels and address some of the associated environmental problems. When trying to assess how effective the current fiscal incentives have been, it is apparent that anaerobic digestion facilities have expanded more rapidly than thermal treatment technology facilities, which can be seen in the number of sites listed on the anaerobic digestion web portal commissioned by DEFRA. The number of operational anaerobic digestion facilities in the UK now stands at 68, an increase of 20% over the past year, according to latest figures collected by UK's National Centre for Biorenewable Energy, Fuels & Materials[11]. Together, these facilities process over a million tonnes of biomass each year. Data from OFGEM[12] shows that anaerobic digestion has also has the highest uptake of the Government-backed fiscal incentive schemes when compared to other eligible EfW technologies, as shown in Table 2. The availability of two ROCS for anaerobic digestion was clearly a substantial incentive for investors, as was its inclusion in the Feed in Tariff Scheme.

Advanced conversion technologies, despite their partial inclusion in the 'double ROCs' scheme, have not seen similar expansion largely as a result of difficulties with guaranteeing the biomass content of waste, and nor are these technologies eligible for FITs. It is acknowledged that research is taking place to make it easier to measure the renewable content of waste and DECC explain that "We have noted industry's concerns regarding the need for a more reliable and cost-effective methodology for establishing the renewable content of mixed wastes and work is underway to address this issue." DECC also noted investigations into whether a specific, dedicated tariff under the Renewable Heat Incentive scheme for municipal solid waste could be introduced from 2012, as long as "sufficient evidence" of the biogenic content of the waste was available.

Mass burn incineration with energy recovery has also not really benefitted from the financial incentives, as the subsidy for renewable electricity generation can only be claimed against 50% of municipal solid waste, using the 'deeming' principle, unless operators can prove that their waste contains a higher degree of biomass content than 50%. This is the same difficulty which has beset the advanced thermal technologies mentioned above. Mass burn incineration with energy recovery capacity has increased as a result of long term finance schemes for municipal solid waste with local authorities, and the operation of the escalating Landfill Tax. The RHI struggled to gain approval from the EU, so it is too soon to tell what, if any, effect this will have on the expansion of EfW infrastructure in the UK. ES

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Waste as good business?

Environmental scientists and business are often thought to be on conflicting sides of the environmental agenda. Looking at waste use, **Colin Drummond**, Chief Executive of Viridor, argues that the opposite can be true.

Environmental scientists are well aware that the world is using many resources at an unsustainable rate. People have used as much raw material in the past fifty years as in all previous history. There are emerging, well-documented shortages in a whole range of non-renewable materials including oil and related hydrocarbons, water and other renewable resources. There are rather less well articulated concerns around resources such as topsoil; it is believed that one third of the world's topsoil has been lost in the past century. There is an increasingly intense search by companies and countries worldwide for raw materials such as rare earths and even bulk materials such as sand and gravel in developed regions. These pressures are made all the more acute by a world population likely to grow to nine billion by 2050, from seven billion today.

"Few people realise that waste (municipal, industrial and commercial) is already used to generate 1.5% of UK electricity, which is comparable to the output of all our current wind farms."

It is often thought that the concerns of environmental scientists and businesses are in conflict, with businesses viewed as fighting the environmental agenda. However, action is already being taken by industry at every stage in the cycle of production, from new product design using fewer or less scarce resources, to 'end of life' considerations such as recycling potential. 'Cradle-to-cradle' is becoming part of many companies' philosophy. However, for some products, large volumes of basic substance are already in circulation. Given this situation, it is both an environmental necessity and a business opportunity to recognise that the waste we throw away is actually a potential resource and to find ways of recovering value from it based on a full scientific understanding of the issues.

There are two principal ways of recovering value from waste:

- Recycling (producing a recyclate which can be used to produce new products); and
- Using the residual waste for renewable energy generation.

As long as quality standards can be met, recyclate is normally much cheaper for industry to use than virgin materials for the manufacture of products such as paper and card, plastics, glass and metals. To take a specific example, to make paper from virgin pulp, trees have to be grown, cut down and transported, added to almost an equivalent volume of water, heated, pulped, and dried. This is a very energy intensive process and a great deal of fuel and cost can be saved by putting waste paper back into the pulp. Growth of the recyclate market was historically held back by quality issues, which have now been addressed through improved collection methods, with waste being increasingly segregated at source, and by heavy investments in sophisticated material recycling facilities. As a result, good quality recyclate is now a mature market with prices holding up despite weak world economic conditions. However, there is no point in recycling if the quality cannot be guaranteed, or if the materials are effectively unable to be separated; in this case it is preferable to use residual waste for energy recovery.

Many residues have substantial embedded energy. There are two routes to recovering energy from residual non-recyclable waste: methane gas (landfill gas and anaerobic digestion technologies) and combustion technologies. Few people realise that waste (municipal, industrial and commercial) is already used to generate 1.5% of UK electricity, which is comparable to the output of all our current wind farms. Of this 1.2% is landfill gas, and 0.3% represents combustion.

Waste combustion has certain advantages over using some renewable sources such as wind energy. It can provide base load power (with 80 to 90% load factors), can be distributed around the grid near to energy users, and is a by-product of required waste treatment for which payment has already been made. Unlike alternatives such as agricultural biomass, it does not require agricultural land to be used to produce fuel, or necessitate importing materials into the UK with the consequent transport-related environmental pressures. This is not to deride wind or agricultural biomass developments, but despite energy saving initiatives, we are sleepwalking into an energy crisis and need every form of energy we can get. Recovering the energy from residual waste is therefore an environmental and economic necessity.

Regulatory requirements are obviously also relevant here. The EU Landfill Directive requires a major reduction in the amount of residual waste going to

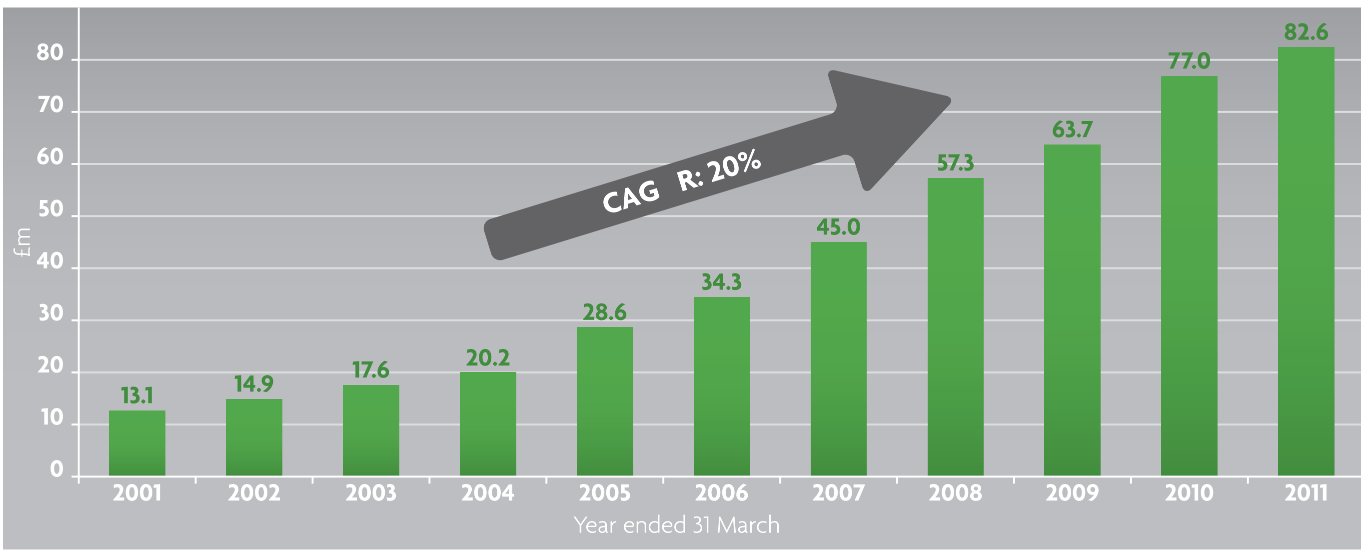
"We are sleepwalking into an energy crisis and need every form of energy we can get."

landfill. At the same time the UK has challenging renewable energy targets including 15% of electricity from renewable sources by 2015. It is a 'no-brainer' that the two targets should come together and this waste will need instead to be redirected towards energy generation.

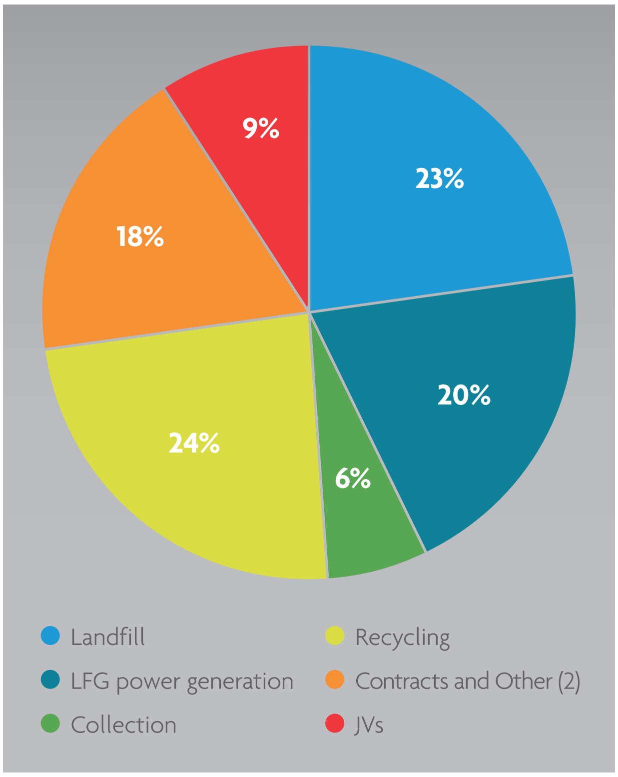
Waste could readily account for 6% of UK electricity by 2015 (i.e. 40% of our 15% renewable target). In longer terms, according to both the Institution of Civil Engineers and the Institution of Mechanical Engineers, it could account for 15% to 20% of total UK electricity demand. The benefits are further enhanced if surplus heat is also recovered and can be used by a nearby consumer, an example of this being the Viridor/Laing/Ineos energy from waste plant being built at Runcorn, which is one of Europe's most advanced waste combined heat and power schemes.

So what is preventing this from happening widely across the UK? Planning permission remains a major challenge, despite the recent successes of some iconic projects demonstrating state-of-the-art technology and a range of innovative solutions being used together. The Greater Manchester Waste and Renewable Energy project, for example, is the largest such facility in Europe and will handle a total of 1.1 million tonnes of waste per year. This project is being delivered in the depths of the

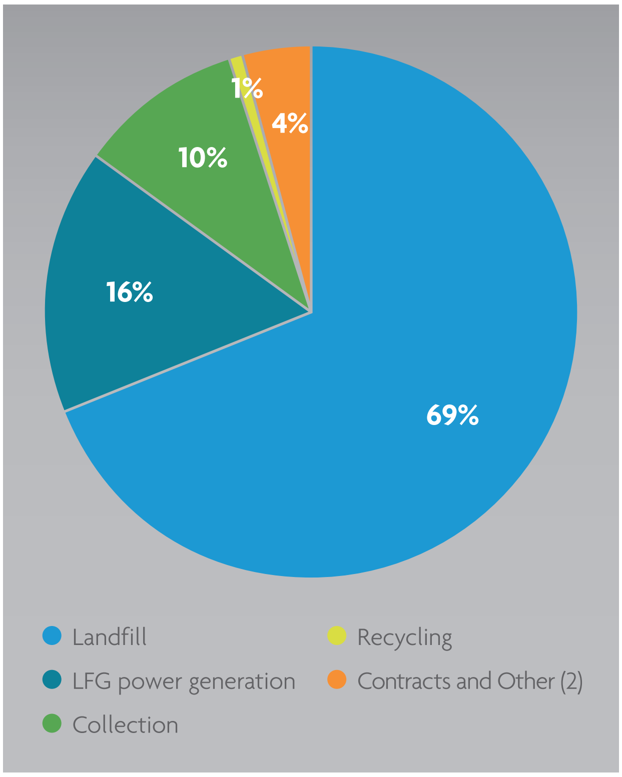
▼ **Figure 1: Viridor Profit Growth from 2001 to 2011. EXPLAIN R: 20%**



▼ **Figure 2: Viridor profit mix year ended March 2011**



▼ **Figure 3: Viridor profit mix year ended March 2001.**



As can be see in Figures 2 and 3, the proportion of Viridor's profits that now come from recovering value in waste (including power generation/ recycling in joint venture and contract segments) is much greater currently than compared to the 2001 levels.

world banking crisis. A Private Financial Initiative, it is a prime example of the various targets and technologies coming together. The total energy potential is 140 MW, which includes one 'Energy from Waste Combined Heat and Power' plant at Runcorn, a second at Bolton and four anaerobic digesters. It was its category winner in the world's top 100 infrastructure projects in 2009 and shows what the UK can do if a logical approach to environmental sustainability is adopted.

Individual British companies are centrally involved in these initiatives and those making the transition ahead of the competition have reaped benefits. Viridor (one of the UK's leading recycling, renewable energy and waste management companies), for example, has invested £1 billion in recycling and renewable energy technology over the past decade. Though some of these investments seemed very risky at the time the Viridor staff fundamentally believed in the resource value of waste. As a result, it topped two million tonnes total recycled material in 2011 (compared to 0.1 million tonnes in 2001) and is now the largest operator of material recycling facilities in the UK. It has simultaneously increased its renewable power generation to 136 MW operating capacity in 2011 (compared to 28 MW in 2001) and has additional 60 MW under construction. The target is to exceed 300 MW operational capacity in a further five years' time, thus reducing the demand for fossil fuels, the space required for landfill, and the pressure on some raw materials. Moreover, the bottom line has benefitted too; Viridor's profits have grown 20% each year since 2001, and nearly half of the profits now come from recovering value in waste (see Figure 1).

Taking care of the environment can be good for businesses. With farsighted businesses increasingly embracing the environmental agenda because there is good money to be made (as well as saving the planet) other companies should not be afraid of the environmental agenda, but indeed will have to embrace it. **ES**

Colin Drummond is an Executive Director of Pennon Group PLC and Chief Executive of Viridor. He received an OBE for services to innovation and environmental technology in the latest Honours list.

The newly constructed San Francisco Public Utility Commission (SFPUC) has raised the bar quite high for energy efficiency and sustainability. The building's design features include wind turbines, operable windows that allow for natural ventilation, three rooftop solar platforms with 684 panels and wastewater recycling. Photo credit: www.sfdpw.org

Greening buildings use

Fionnuala Costello discusses how user-centred design provides a practical way for the buildings sector to reduce energy demands.

Climate change from greenhouse gas emissions is a major global issue. The UK Government has set a number of challenging targets for improving sustainability, starting with the most ambitious legally binding carbon reduction target reduction in the world: an 80% reduction in carbon dioxide emissions in the UK by 2050[1]. To decarbonise the grid, the UK energy industry is seeking to increase the use of renewable energy generation and to improve the efficiency of the electricity distribution and transmission networks. However, reductions in energy and water use are crucial to achieving UK carbon emission reduction goals.

Some of the largest environmental impacts in the UK come from buildings. For example:

- Buildings account for 45% of total UK carbon emissions (27% domestic, 18% non-domestic);
- 73% of current domestic emissions arise from heating space and water;
- Domestic use accounts for 58% of the public water supply (all other uses account for 24%, with 18% being lost in the system);
- 32% of all landfill waste comes from the construction and demolition of buildings; and
- 13% of products delivered to construction sites are sent direct to landfill without being used.

The UK cannot meet its declared environmental targets without dramatically improving the life-cycle environmental cost of buildings. Businesses in the environmental sector have a key role in reducing these environmental impacts through new innovations and business models.

Within buildings, there is the potential to reduce the embodied carbon contained in construction materials; however, this accounts for less than 1% of the overall energy use of the building over its lifetime, with the majority being energy consumed by users and occupants. Technology on its own is not the silver bullet that will reduce energy consumption. The way that people interact with buildings and use the available technology is crucial. An estimated 13% of all energy used by building occupants can be reduced solely through human behavioural changes[2].

However, despite significant UK academic work that recognises the role of building occupants in achieving energy demand reduction[3], this has not translated widely to the products and buildings produced by the sector. The reason for this is the 'wicked' nature of this problem[4] (marked factors including complexity, ambiguity, tension, uncertainty and risk). Energy use in non-domestic buildings is affected by the design and usability of technology, and also by the complex interplay between various parties who have their own roles, perspectives and motivations. For example, facilities managers can play a major role in improving energy efficiency but they are challenged by powerful behaviour patterns from building owners, tenants, occupants and visitors. Users' responses to new technologies are often unknown and can lead to unintended consequences. When automatic systems fail to create a comfortable environment, occupants may intervene: for example, by propping open fire doors to create a draft or manually closing vents to prevent one.

Adding to the problem, there may be longer-term impacts on energy consumption from introducing energy efficiency measures, also known as the 'rebound effect', for example when improving the insulation of homes, occupants generally choose to enjoy greater comfort rather than lower energy bills[5]. Therefore, what seems like a simple problem of controlling carbon emissions is actually a complex interwoven system of technologies, human behaviours, psychology, cultural change and engineering. Each individual can only control their own energy use behaviours and no-one has the power to reduce the UK's overall energy consumption or carbon emissions.

CREATING SOLUTIONS

To address the complexity of this problem, two UK government funding agencies pioneered the

Photo credit: Andy Burnett, Know Innovation

BUILDING BANTER

Led by Moixa Energy, the key innovation of the 'Building Banter' project is the development of 'conversational tools' through which people and buildings can input and receive information about themselves and each other. The tools foster interactivity, play and invention while helping users to understand how to control the building to reduce energy use, and provide them with tools to easily and intuitively take actions.

This large and truly multidisciplinary team would not have come together without the duration and intensity of the sandpit. Their work is focussed on an established Federal Mogul industrial site, with both factory and office environments, which currently has an energy bill of approximately £2m per year. The team is making innovative (re)use of existing technologies, both installed in the building (existing building management system) and familiar to the individuals working in the building (e.g. mobile phones and email).

The focus on 'play and invention' comes from the diversity of the eight partners involved, from dance (Leeds University), to magicians (Vitamins), through to experts on spatial interactions (Dundee University), interface design (Moixa Energy), agent-based software/algorithms (Southampton University), consultancy and modelling (Arup), and user-centred expertise (University College London).

The final outputs of the project will be low cost, easy to retrofit commercial products and a user-centered consultancy package. There is also a commercial opportunity in ongoing support for installed solutions and building performance monitoring.

development of innovative approaches to energy efficient buildings through user-centred design. The solution was a competition to attend a week-long, intensive, project development workshop in 2009 (called a 'sandpit', a common term for a creative meeting) where funding was awarded on the final day, bringing together multidisciplinary experts and ensuring genuine collaboration[6]. The goal was to overcome the complexity barriers by removing communication barriers between the different disciplines and creating an environment of creative exploration. This solution was adapted from a mechanism that the sandpit facilitators, Know Innovation[7], first developed using the Creative Problem Solving methodology[8] for the UK Engineering and Physical Sciences Research Council in 2003.

WHO CAN PLAY?

The sandpit was designed to bring together a new community and fund commercially-viable research projects offering innovative approaches to improving energy efficiency of non-domestic buildings. Having the right mix of participants influences the success or failure of such an event. Individuals from a broad range of disciplines were crucial; the whole approach

Table 1: Sandpit Agenda, with activities linked to the creative problem solving process

Day	CPS process stage	Sandpit activities
1	Data Gathering	Introductions and initial knowledge mapping: What does everyone bring, and where are there knowledge gaps? Presentations from stakeholders to provide context for the wider issue.
2	Problem Reframing	Collected data, combined with stakeholder input is used to generate a diverse range of problem statements.
3	Idea Generation	In self-selecting groups, a range of idea generation techniques are applied to help stretch the teams' thinking. Ideas are formed into potentially workable research proposals.
4	Solution Creation	Several cycles of development and real-time peer review, both from other participants and mentors helps to develop the embryonic proposals.
5	Action Planning	Final peer review and awarding of funding subject to submission of written proposals.

Days 1 and 2 focussed on communicating and understanding the challenge and overcoming barriers between the participants. On day 3, participants formed self-selecting groups to begin develop solutions, creatively exploring their multiple objectives and differences in viewpoint. Individuals moved from group to group inputting their thoughts and then moving on. Research proposals were further developed on day 4 through an iterative process of development and feedback from peers and the mentor team.

is about bringing people together who would not normally interact.

Getting into the sandpit is competitive yet the atmosphere is collaborative once a place has been secured. Places were offered to specific individuals based on their applications demonstrating their expertise relevant to the challenge of users and energy demand, communication style, approach to working with others, personal qualities and their appetite to take part. A total of 180 candidates applied from a wide variety of technical disciplines: from conventional construction industry professions such as engineers, architects, quantity surveyors and designers to experts in psychology, persuasive technologies, user behaviour and academics working on energy efficient buildings. The selection of the 30 participants achieved a balance from academia and industry, with a broad spread of expertise.

SETTING THE AGENDA

To build a new community with multiple perspectives on the topic, an online discussion forum was created six months before the applications for the sandpit. This grew steadily to over 200 members and was populated by their photographs, blogs, videos and discussion threads on achieving energy efficiency through automation or engaging users. The forum was migrated to a new platform in July 2011 and is still in active use after two years[9].

The agenda for the workshop itself was created by the facilitators to tackle some of the complexities of the problem (see Table 1).

THE GOAL ACHIEVED?

At the end of the sandpit, four industry-led projects were awarded funding with £2.25m (half funds were provided by the industry partners, half by government funding agencies). The projects are highly practical, yet innovative and creative in their approach. The sandpit process was an effective mechanism for overcoming communication, cultural and interdisciplinary barriers and was effective at promoting genuinely collaborative and creative project ideas that could not have come about any other way (for example, the Building Banter project).

Building Banter has limitations, however, in that only a restricted number of people can be involved in such an intensive process, thus curbing the potential contributions. It also relies on the quality of people selected to attend, and their ability to set aside their own viewpoint and work collaboratively with others.

WIDER IMPACTS

Reducing UK carbon emissions is a complex challenge and requires innovation from UK environmental sector businesses to achieve the ambitious targets to which

the UK has legally committed. Creating technologies that engage users in energy efficiency behaviours could unlock the savings attributable to human behaviour alone. The sandpit methodology was used to overcome the complexity of the problem where there was no pre-existing community and little awareness of the need to incorporate user centred design processes into the design of technologies for energy efficiency in buildings. This mechanism can be seen as an essential step in proving the economic value of user-centred design expertise in achieving the potential 13% reductions in energy use. ES

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The Challenges of Knowledge Exchange and Water Research

Kerry Thomas and **Carolyn Roberts** reflect on knowledge sharing between researchers and the water industry, how funding can be drawn in to support innovation, and the defining qualities of research and development projects with real impact on sustainability.

Water security is rising rapidly up the agenda of global challenges, and with shortages affecting Africa, Australia, and the UK again in recent months, changes are needed to bring the world's water demands closer to a sustainable position. The latest Institution of Civil Engineer's Report (2012) captures the imperatives for action very ably[1]. The major driver for many research projects is the impact of climate change on water supplies, water quality, flooding and drought, at a time when global populations are rising dramatically, and expectations increasing. Permeating this is also an increasing realisation of the mounting levels of carbon emissions involved in treating and transporting water for drinking, or cleaning up human effluents to allow the criteria for water quality in the EU Water Framework Directive to be met.

However, the climate change issue is characterized by a number of ironies. Whilst the science of climate change has been the subject of the most extensive review process ever undertaken, and there is probably more consensus on the findings amongst the relevant scientific communities around the world than for any other high-profile environmental problem, progress on mitigation measures has been limited. The degree of agreement within the scientific community seems to be inversely related to the degree of perceived uncertainty outside it. Although there is ample evidence to suggest that measures that mitigate against, or adapt to, future climate impacts are available at low cost, and in some cases may be economically beneficial, the international political community is in an apparently perpetual state of paralysis on climate change policy. As environmental scientists we understand, with a high level of certainty, that future UK average temperatures will be higher, and rainfall events will be distributed in new ways that are likely to increase the probability of floods and droughts across large areas of the country[2]. But even ignoring the worst excesses of 'Climategate' where emails from the University of East Anglia's researchers were hacked and broadcast by climate change deniers in an attempt to highlight minor differences of scientific opinion, the environmental science of what is admittedly a complex issue has not been shared with the public and politicians in a way that has accelerated action. As a consequence, innovators in the water sector are faced with controversy and lack of public and political understanding of the repercussions of climate change, which hampers their ability to act, despite recognising prospective commercial opportunities.

The solutions to some water problems will inevitably lie in new, cleaner and lower carbon technologies. Unfortunately, developers of such technologies have found severe difficulties in accessing suitable research funding; although the potential gains are high, the financial risks are also considerable, particularly when these technologies are at the earliest stages of development. There is an urgent need to look for ways to improve the funding flow in this area, not only from traditional government sources such as the UK's Research Councils, but from commercial players such as banks, venture capitalists and large corporations.

The Itaipu dam. Photo credit: Adam Donnan

The European Commission have been considering this matter for some time. FUNDETEC[3] , an EU FP6 project, examined the funding available for the development and commercialisation of environmental technologies and highlighted ways to improve the flow of resources to the best new ideas. This project concluded gloomily that "the typical length of time needed to complete the development cycle (in the water sector) is ten years". This means that water-related research projects commissioned today might generate viable products or have impact on water management practices within twelve to fifteen years, a delay which would miss the next two deadlines for the implementing sections of the Water Framework Directive (in 2015 and 2021).

The transfer of environmental research outputs to organisations involved in water management (such as water utility companies, river basin authorities or city authorities) clearly needs to be accelerated, in order to address the serious impending issues of economic and physical scarcity of water resources. To that end, the Environmental Knowledge Transfer Network (ESKTN) has been a partner in WaterDiss2.0, a European FP7 project that is analysing the rate of uptake and the impact of European Framework-funded research in more detail[4]. WaterDiss2.0 involves evaluating the impact that water research projects have had on water management, be it in delivering new technologies, or impacting on policy or public perception. The project is identifying best practice and building the lessons learnt into the criteria for assessing forthcoming FP8 proposals and programmes. Unless this is done, there is a high risk of research funding being wasted on projects whose findings languish in academic journals and do not result in genuine progress.

For research projects led by academics, the motivations underlying decisions about what and where to disseminate findings vary, including the likelihood of receiving recognition from peers, and responding to external pressures such as research assessment criteria. The time taken to have a major article published in a peer-refereed journal can be lengthy, and indeed the anticipated delay in getting work published is sometimes seen as a positive indicator of the level of competitive pressure within specific research areas. The peer-refereed journal nevertheless remains the preferred output for most academics. Sometimes there are attempts to reach the appropriate target audiences for a more immediate impact, and this is increasingly stressed by funders such as the UK's Natural Environment Research Council, who have recently established a formal Water Security Knowledge Exchange Programme (WSKEP)[5]. There is already some tradition of academics broadcasting their findings using channels beyond the scholarly journals, the wider range including not only conference papers, e-monographs and 'grey literature' such as reports, but outputs such as patents and spin out companies. Some of these routes are challenging; the Internet and social networking have facilitated the dissemination and greater availability of grey literature for example, but this has raised issues of quality assurance, given that grey literature is broadly understood not to be peer-reviewed. Spin out companies, and other direct commercial outcomes are also very challenging now, as finance is difficult to raise.

Research suggests that a more open framework for innovation, led by commitment to collaboration and partnership across different organisations, is required in order to secure speedier progress. The shift in emphasis amongst funding bodies internationally over recent years has resulted in some increases in collaboration and associated co-authorship, which should be increasing the rate of project development and take up. In the UK, Government has suggested that the nation lags behind international comparators such as the US in the numbers of papers jointly authored by academics and industrial partners for example, and that this needs to increase. There is some evidence that co-authorship generates more citations than single-authored papers, and that collaboration with an author from another country increases it further. Inter-institution collaboration amongst universities is also increasing, and there is a widely-held perception that this should be favoured over inter-departmental collaboration within a university or research centre because of potential effects on what can be submitted for assessment in the all-important 2014 Research Excellence Framework.

Knowledge exchange is thus seen as essential to make an impact. Within large or multinational commercial water organisations, knowledge exchange can be achieved relatively easily by the transfer of employees from one division or country to another, or perhaps by secondments from industry to Higher Education, and vice versa. However, for most of the water sector (including smaller companies, government departments, third and voluntary sector organisations), this option is limited by human capacity, and a range of other stakeholders may need to be involved.

The principal stakeholders in knowledge exchange within the environmental sciences include:

- Companies or entrepreneurs who have specific technical challenges and are potentially prepared to commercialize new technologies;
- Academics, who may generate an innovative idea or technology;
- University technology transfer departments that are intended to act as a liaison between academics and industry, and to manage their university's intellectual property;
- National research funding councils, or other funders of research who may require collaborations as a precondition of receiving awards;
- Government agencies who have a regulatory role in terms of the implementation of some environmental technology solutions, and maintenance of acceptable quality in natural environmental elements such as rivers, soil or air; and
- Other potential purchasers of technological solutions.

The role of the Environmental Sustainability Knowledge Transfer Network is intended to be catalytic in bringing different parties together on neutral territory at an early stage to exchange ideas, and in establishing a strategic direction for the research requirements. Over the last few years, ESKTN has published a number of Business Cases which identify market drivers, barriers to uptake, technology needs and research and development challenges, for example the ' Energy Efficient Water & Wastewater Treatment Business Case'[6]. These Business Cases are used to signpost needs and influence funders to address specific environmental challenges; they also provide a focal point around which research partnerships can coalesce. Sometimes these partnerships can yield tangible results and make a significant impact in a much shorter time.

For example, ESKTN acted as agents for the Engineering and Physical Sciences Research Council in allocating an Industrial Case Award to Liverpool John Moores University and Hydro-International Ltd to develop more efficient and effective wastewater treatment that would remove ammonia from wastewater, with less energy consumption than conventional technologies. Within three years the partnership had developed and built a pilot plant at a United Utilities wastewater treatment works in the North West of England, fed back knowledge gained from the trial into the water industry in order to raise awareness of the technology, generated performance verification information and started work on optimising the process. This will be useful for all of the parties involved[7, 8].

Solutions to environmental problems, however, cannot be achieved by technology alone and a level of social change is also required. Work undertaken by ESKTN in its water-related business cases[2] suggest that a paradigm shift in thinking is needed in the way water

"Technology cannot be deployed in isolation however, and potential water-related innovations often spark particular sensitivities that hold back their wider deployment"

and wastewater services are provided and this will challenge social acceptability. For example, there has been a longstanding deterrent to the use of 'grey' water from the roofs of UK houses because of health-related fears for the safety of the users. It is important that water and wastewater treatment is considered holistically across all sectors as a community resource recovery processes which is flexible and responsive to rapidly changing global challenges, thereby contributing to the UK's carbon reduction target of 60% by 2050, whilst minimising the impact on the environment, and not compromising public health and quality standards. To this end, ESKTN supported Albion Water's innovative ideas for the provision of community-scale water and wastewater services at Knowle, Hampshire, by bringing together some of the stakeholders to address issues of water efficiency/water poverty, water reuse, rainwater harvesting and sustainable drainage, low carbon technologies, co-digestion of sewage with food waste, and biodiversity, in an integrated way.

Technology cannot be deployed in isolation however, and potential water-related innovations often spark particular sensitivities that hold back their wider deployment. We might examine this by analogy with a period where major social change took place in Europe – the English Reformation. Many of the ideas of Protestantism had been around since the mid-fourteenth century, embraced by the followers of John Wycliffe, and notably the religious group known as the Lollards. However, Protestant ideas were generally restricted to academia and even though Wycliffe was a significant figure, the extent of his influence was initially limited[9]. Despite this, a series of events in sixteenth century England resulted in the Church of England breaking away from the authority of the Pope and the Roman Catholic Church. Many factors contributed to the upheaval, but it was the invention of the printing press and increased circulation of the Bible in the fifteenth century, and Henry VIII's desire for an annulment of his marriage to Catherine of Aragon that are most often cited as critical. So, at that time major social change was largely brought about by a new mass media communication technology and through firm (albeit undemocratic) political leadership.

What influence the new mass communication technologies of the twenty-first century such as Facebook, the 'blogosphere' and Twitter will have on uptake and impact of ideas to deliver sustainability is yet to be established. Getting information from the internet can be the equivalent of taking a drink from a fire hydrant – the rush of substance drowns, rather than refreshing. But other evidence suggests that social networking can be a very effective indeed, and in recent events in the Middle East[10] it appears to have been a critical factor in stimulating regime change. It is nevertheless difficult to imagine the political leaders of today achieving social change needed to overcome the challenges of generating water security without the collaboration of all stakeholders: government, industry, funding bodies, academia and the wider public. At its root, most creativity is collaborative; it is not the product of a lone individual's flash of insight[11].

CONCLUSION

Climate change is not 'a problem' waiting for 'a solution,' rather, it is an environmental, cultural and political phenomenon which could re-shape the way we think about ourselves, our societies and humanity's place on Earth[12]. Civilized societies have long been adaptive to new technologies and include many of these things as "must have" items. But at some point soon we need to put down our gadgets and concentrate on shaping our future and achieving a sustainable society for our children. Climate change should be used to rethink and renegotiate our wider social goals about how and why we live on this planet, with the imperative for water driving the agenda in the UK. **ES**

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CASE STUDY

Crossing the cultural divide

What might it take to achieve sustainability? **Anne Miller** discusses sharing innovative UK technology solutions for sustainability.

It is always instructive to look at yourself through another's eyes from time to time, and to be given the opportunity to take stock of how we are approaching the challenge of becoming more sustainable in our energy and food production. A recent group of Indonesian visitors provided us at the Environmental Sustainability Knowledge Transfer Network (ESKTN) with the chance to review progress with some exciting and innovative distributed renewable energy and low-input agriculture initiatives in the UK.

Papua is a large Indonesian province, 80 per cent of which is still covered in undamaged tropical rainforest. Lying in the remote western part of New Guinea, its 400,000 km^2 (roughly nineteen times the size of Wales) supports a population of some three million people. The pressure for deforestation is ever-present with continuing demand for tropical hardwood for construction both locally and regionally. However, the province now faces major choices centred on whether to follow a conventional development pathway using large scale dam projects and intensive production systems, or to opt for a radically new development alternative. Over the past two years the UK's Foreign and Commonwealth Office (FCO) have undertaken a pioneering project, working with senior Indonesian government officials to examine this question, and helping them with capacity-building which will enable development of alternative strategies; these could potentially allow them to 'leap-

Photo credit: Anne Miller

frog' away from the traditional and commercially attractive mining and forestry dependent 'resource trap'. Recommendations needed to be based on sound environmental management, to provide evidence of success and to be economically sustainable in a developing world context.

Our team supported the FCO project by linking a group of 12 Indonesian government planners and economists with key people in the UK who have successfully developed alternative and innovative green technologies. The programme included a week-long UK visit, exploring how small businesses, local communities and researchers are putting environmental sustainability into energy generation and food production systems.

The technical programme started off in rural south-west England, setting the context by learning first-hand about the Transition Town movement from key figures among the network's supporters. In Totnes, a five year old community-led Transition Town project is building capacity and community resilience for a future with less oil and a changing climate. Schumacher College and Riverford Organics, both based in Totnes, also provided opportunities to explore some of the practicalities.

The group then examined a rural hydropower project among the oak woodlands of upland Dartmoor, arguably the closest thing to rainforest in England. This inspiring, award-winning project at Old Walls Farm has been engineered by the industry of the Fursdon family who have owned and farmed the land for generations. They make extensive use of local and recycled resources (for example, stone excavated during the construction of a leat (an artificial watercourse) was used for gate posts and buildings on site) and now supply 80 households with electricity, whilst simultaneously contributing to improving the biodiversity of ancient oak woodland through conservation-focused land management. Successful sustainability has an intergenerational aspect so it is no surprise that the next generation of the family have been drawn into the operation, running Western Renewable Energy which has designed, installed and maintained a range of community-scale hydroelectric power schemes across the UK.

The visitors were intrigued by all aspects of the project, seeing at first hand concrete examples that could be readily translated into an Indonesian context. They could become part of a distributed network of energy generation technology appropriate to their rural communities; systems which also chime with concern for protecting forest biodiversity and ecosystem services.

On the eastern edge of Dartmoor, a further demonstration of how local water and wood resources are being used practically to support the energy requirements of tourism was seen at the River Dart Country Park. The owner has installed two renewable energy systems of great interest to the Indonesians: a fish-friendly Archimedean Screw that uses water diverted from the River Dart to generate electricity, and an award-winning high-efficiency district heating scheme powered by wood-chips from local timber sources. While admiring the wood burner and acknowledging that it was an efficient use of sustainably-managed fuel, with a good audit trail demonstrating compliance with international agreements on timber sources, there was some concern that it might be less appropriate for a region where threats to the rainforest were high on the agenda. However, the simplicity of the highly effective Archimedean Screw technology made it of particular interest to the delegation, since issues of maintenance, durability and ease of repair are central concerns for any projects that might be located in remote and inaccessible locations across the island.

In Exeter, the group was introduced to the novel, portable, wind-powered devices produced by Trade Wind Turbines, an offshoot company from the University of Exeter. These were of considerable interest as potential elements in a mixed portfolio of distributed renewable energy sources for remote rural areas. They also heard from the university about PRIMaRE (Peninsula Research Institute for Marine Renewable Energy), a joint

"[The anaerobic digestion plant] is expected to reduce carbon emissions by 13,000 tonnes of CO_2 per annum, offsetting campus carbon emissions more than three times over."

FURTHER READING

Transition Town Totnes, www.transitiontowntotnes.org.

About WRE Ltd, Western Renewable Energy, www.westernrenew.co.uk/wre/home

Waterleat Walks and Talks, www.waterleat.co.uk/Interest.html

Tradewind Turbines, www.tradewindturbines.com

Wave Hub, www.wavehub.co.uk

Anaerobic digester, Harper Adams University College, www.harper-adams.ac.uk/facilities/anaerobic-digester.cfm

Centre for Renewable Energy Systems Technology, Loughborough University, www.lboro.ac.uk/departments/el/research/centres/crest.

venture with Plymouth University focusing on the huge opportunities from wave and tidal sources around the UK's coastline. PRIMaRE is assisting economic growth in the marine renewable energy industry and supporting the award-winning Wave Hub, an offshore facility for the large-scale testing of technologies generating electricity from the power of the waves which recently opened off the coast of Cornwall. This opened up new possibilities for the Indonesian visitors to explore with their marine authorities.

This experience was matched by a 'virtual' visit to Oban, Scotland where the Director of the new Algal Bioenergy Special Interest Group outlined, via a video-link, the background to this new joint venture (funded by the Technology Strategy Board and the Natural Environment Research Council) which will facilitate the development of marine and freshwater algal production systems. This was something the Indonesians had not previously considered as a potential source of either energy or nutrients, creating new ideas to pursue in the future.

Back in England, Elm Farm Organic Research Centre in Berkshire provided the opportunity to learn more about low input agriculture and agroforestry research activities in the UK. There was particular interest in the agro-forestry research projects, with penetrating questions asked about the extent to which very simple techniques of weed control and growth optimisation had yet to be thoroughly researched and evidenced.

A little further north, Harper Adams University College scientists exhibited some of the exciting opportunities offered by precision farming; the Harper Adams team is bringing robotics into new farming ventures. They also outlined other UK initiatives aimed at bridging the organic/conventional agriculture divide, such as LEAF (Linking Environment and Farming). A surprising highlight was the visit to Harper Adams' newly commissioned anaerobic digestion plant, which combines farm slurry and household food wastes in roughly equal quantities to create energy from waste – a 'fragrant' experience but one that is less nasally-challenging than might be expected – which is certainly generating a large amount of energy for the College and the grid. Commissioned in April 2011, its by-products are used as fertiliser in the College's farm, and it is expected to reduce emissions by 13,000 tonnes of carbon dioxide per annum, offsetting campus carbon emissions more than three times over.

The group finished their tour by examining the advanced high-technology end of new energy options at the Centre for Renewable Energy Research and Technology (CREST), and Intelligent Energy, a Loughborough-based company. There was considerable interest in CREST's rapidly-developing thin-film photovoltaic technology and their electric vehicles. The group were also introduced to the potential for distributed energy systems deriving from Intelligent Energy's advanced fuel cell power systems, as well as the transformation that could accompany wider use of hydrogen-powered motorbikes; these seem likely to become a 'must-have' for the buoyant Indonesian scooter market. As a modern and forward-looking society, innovative clean technologies like these are clearly high on Indonesia's agenda and the delegation concluded their visit with a sense of how to take the best of the new and fuse it with the careful use of precious resources that earlier generations practised.

There is a considerable cultural divide between the UK and Indonesia, but the visit shows there are genuine opportunities to learn from sharing perspectives on some of the UK's most pioneering energy and food production technologies. Innovative research by commercial enterprises, in university departments and in conjunction with third sector organisations, has the potential to support new models of development in the UK and elsewhere in the world. The experience was also inspiring as an exemplar of the creative benefits to be found in having rural and local communities' participation in 'open innovation' and the sharing of ideas, searching for commonality and capitalisation on opportunities. **ES**

Dr Anne Miller is Knowledge Transfer Manager at the Environmental Sustainability Knowledge Transfer Network.

Eco-innovation for a competitive edge

As competitive business pressures and threats to sustainable resource limits intensify and converge, **John Henderson** outlines how the North-West Eco-Innovation Programme is helping entrepreneurial businesses respond positively.

Since Michael Porter first defined his 'Five Forces of Competitive Position' in 1980[1], awareness of the interdependence of economic prosperity and the planet's ecosystem services have massively increased along with society's appreciation of the impact of human activity upon natural capital. Viewing Porter's model (see **Figure 1**) in this light, many relevant factors are evidently influenced by short and long-term threats to key resources such as critical raw materials, energy and water supplies, and ultimately stable, affluent societies. This creates volatility in the balance of competitive forces, most especially in the fundamental supply and demand (buyer) balance. Taking a more positive view, those developing more environmentally sound products and services are employing a relatively new lever to influence competitive forces as conventional routes to competitive advantage become increasingly diluted by globalisation.

Against this background, the North West Eco-Innovation Programme[2] was launched in October 2009 with £1.5m funding by the Northwest Regional Development Agency (NWDA) and £1.7m from the Northwest European Regional Development Fund (ERDF) to help businesses in the region exploit new market opportunities for more environmentally sound products and services. The three-year programme was designed by Lancaster University and is being delivered in partnership with private sector innovation management and technology development specialist C-Tech Innovation Limited. The objective is to provide one-to-one assistance to 480 small and medium sized enterprises, resulting in 240 new environmental products and saving 12,000 tonnes of carbon dioxide. In addition the programme aims to create 107 jobs and safeguard a further 373.

ECO-INNOVATION IN PRINCIPLE

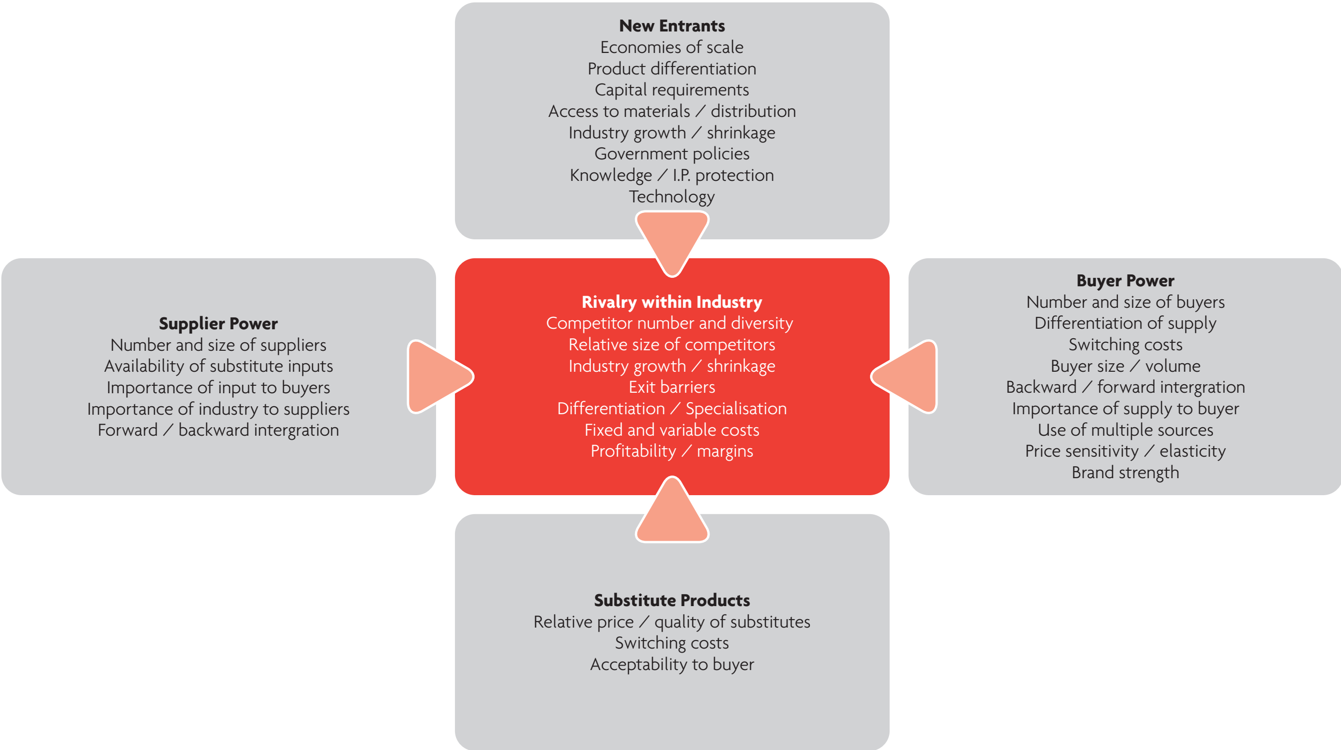
Eco-innovation helps to bring about improvements in products, processes or systems that enhance both the environment and company growth, going beyond the 'greening' of existing businesses by emphasising the need to design out the environmental impact of products during manufacture, use and disposal. The programme supports innovation in a wide range of sectors, and provides access to specialist support including expertise from Lancaster University's Environment Centre and the Lancaster Product Development Unit. Participants are assigned a dedicated project mentor who consultatively creates a bespoke business proposal with the client, typically including steps to:

- Access new markets and opportunities;
- Re-design or develop products or services;
- Identify new applications for products and services in an environmental context;
- Access expertise, mentoring or graduate placement opportunities; and
- Develop ideas through support with research and development.

Businesses are guided through the implementation of the proposal, often progressing a specific high priority activity with the ultimate goal of embedding the innovation process within the company. While it is vital (for successful uptake) to take a business-led approach, it is notable that many of the programme's more substantial developments align strongly with strategic environmental themes such as resource, energy and water efficiency, technologies for renewable energy, and substitution of at-risk materials.

ECO-INNOVATION IN PRACTICE

The dual business and environmental benefits can



▲ **Figure 1: Porter's Five Competitive Forces**
Examples in bold are particularly influenced by materials, energy and other key resource challenges.

be seen in a number of current projects. Furlong Innovations, for instance, has developed a retrofitted downstream flow-control device for domestic combi-boilers which reduces waste of gas, water and time by restricting water flow until a predetermined temperature is reached. Design analysis has estimated a first year carbon saving to investment ratio of 200:1 and typical annual savings of more than £200 and 500 kg carbon dioxide equivalent (CO_2e) per installation. Validation of these figures, testing of Furlong's business model, and help with technical design and development have all contributed to the company winning the Energy Innovation Awards' Consumer Benefit Category 2010.

With the help of a detailed product launch plan, and work to quantify energy, carbon footprint and financial benefits, James Robertshaw and Sons have introduced a range of automated external shading products which prevent overheating due to solar radiation. Reductions in energy consumption (through the use of air conditioning) have been estimated at 50 and 70%, and first year carbon savings of over 40 tonnes CO_2e represent a small fraction of the overall opportunity.

Thanks to a referral from the Eco-Innovation Programme, Centriforce Products Limited, the UK's largest independent producer of recycled plastic sheet, board and profiles, is working fruitfully with Manchester Metropolitan University's Design Department to develop new products made from their recyclates. While product innovation is vital to Centriforce's plans, they also realise that their business model relies on credible environmental performance, and so constantly seek to innovate in their assessment of whole life-cycle impacts. As a result they have been able to move their offering beyond the more obvious benefits of landfill diversion and closed loop recycling[3] to incorporate enhanced durability and lower carbon footprint than virgin plastic and, in some applications, than wood equivalents.

2D Heat Limited has been able to pursue vital product development and test work in support of their patented electric heating element technology. Using a spray-on coating process, elements can be incorporated into the body of an appliance. This results in not just exciting new design possibilities, but more energy and materials efficiency than conventional systems. The resultant energy savings enabled the company to recently secure £180,000 of additional investor funding.

ADVANCING INTO THE FUTURE

Despite these and similar successes, the programme enters the final year of funding in its current format at a time of substantial uncertainty for public sector support of business competitiveness, and yet there is clearly an ongoing appetite for mechanisms that enable the best entrepreneurial businesses to flourish. This is not a marginal issue; the Northwest of England

Top: **Plastic furniture from recyclate**
Bottom: **Plastic bales**
Photo credit: John Henderson

The removal of the regional model of economic development is certainly not the end of the road for business support. The more diversified and localised Local Enterprise Partnership based approach on the one hand, and the consolidation of national level innovation support on the other, will undoubtedly mean that innovation-driven businesses, their knowledge partners, and those who organise to support the growth potential they represent, will all have to imaginatively explore new ways of working in the future. In this context, the Technology Strategy Board's new model of Technology Innovation Centres (TICs) (centres providing a focus for business and research into specific technologies with potentially large global markets) is particularly relevant. At the time of writing, Resource Efficiency is one of ten candidate topic areas for three potential TICs. It is hoped that the case for a visible and prestigious focal point for activities linking research excellence and effective commercialisation in this vital area will be effectively made and sympathetically received if the impetus created by programmes like North West Eco-Innovation is to be sustained in the future. **ES**

"Reductions in energy consumption (through the use of air conditioning) have been estimated at 50 and 70%, and first year carbon savings of over 40 tonnes CO_2e represent a small fraction of the overall opportunity."

alone has been allocated €755 million (approximately £643 million at the time of writing) from the ERDF between 2007 and 2013.[4] Key targets for the North West Operational Plan include creating 26,700 net additional jobs and generating £1.17bn additional annual Gross Value Added by 2015, and supporting a 25% reduction in addition CO_2 emissions generated by the ERDF Programme.[5] These (and similar outcomes in other parts of the country) are being delivered by a diverse range of interventions, many of which face similar uncertainties to the Eco-Innovation Programme.

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IES: New members and re-grades

Members	Occupation	
Nicholas Atherton	Technology Manager – Land Quality	M
Ntsako Baloyi	Projects Manager	M
Samantha Buck	Project Manager	M
Alastair Curran	Technical Officer	M
Trevor Curson	Group Director	M
Carol Flux	Development Manager	M
Katie Foster	Geo-Environmental Engineer	M
Andrew Gilbert	Hydrologist	M
Robin Graham	Contaminated Land Officer	M
David Harrison	Senior Consultant – Air Quality	M
Donna Hawkins	Environmental Geoscientist	M
Chinny Iroegbu	Senior Specialist Scientist	M
Mark Kerwick	Inspector	M
Declan Lawlor	Environmental Officer	M
Rachael Martin	Remediation Scientist	M
Alex Minchell-Bewick	Senior Environmental Consultant	M
John Moore	Curriculum Manager	M
Charlotte Peacock	Managing Director	M
Maria Perez	Long-Term Visitor	M
Anna Savage	Senior Air Quality Consultant	M
Hannah Sydney	Geotechnical Engineer	M
Lindy Tam	Assistant Consultant	M
Stuart Tillett	Geoenvironmental Engineer	M
Associates	**Occupation**	
Claire Barrett-Mold	PhD Student	A

IES: New members and re-grades

Anna Bunney	Marine Research Assistant	A
Sophie Davis	Volunteer Events Promoter	A
Thomas Green	Graduate	A
Charles Howard	Graduate	A
Saferio Inganga	Chief Environmental Research Officer	A
Wai Lam	Assistant Environmental Officer	A
Chung Lau	Graduate	A
Charles Makin	Graduate Air Quality Consultant	A
Robert Thomas	Air Quality Consultant	A
Anna Thomson	Land Quality Assessor	A
Affiliates	**Occupation**	
Faye Warrender		Af

Fellow

Fellowship is for esteemed individuals in the fields of environmental science and sustainability who are held in high regard by their peers

Member

Full membership is a professional designation for those working in the field of environmental science, which confers that you have reached a certain standard within your career

Associate

Associate membership is for individuals who hold a relevant degree or equivalent qualifying experience.

Affiliate

Affiliate membership is for individuals with an interest in environmental issues but who don't work in the field.

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