environmental SCIENTIST

February 2014
Journal of the Institution of Environmental Sciences

EDITORIAL

A more sustainable energy future?

Energy is fundamental to modern life. We need it to heat our homes, power our iPads, cook our food, drive our cars and manufacture all the goods that we think are needed for life in the 21st century. Yet most people ignore energy until they see the gas or electricity bills or fill up with petrol. Little thought is given to why we use the amount of energy that we do, or where it comes from.

Behind this is a trilemma: how to provide affordable energy with security of supply and – not least – the minimum possible damage to the environment. Politicians seem too willing to focus on only one of these at a time and often ignore good science when the public is obsessed with price; environmental scientists have to find the sweet spot where all three are taken into account.

Despite concerns about the cost of 'green' taxes, high prices are more often a symptom of excessive demand. Rather than increasing supply, our first response should be to ask where energy is being wasted, and how this could be avoided. We should remember that a unit of energy that has been avoided is not just the cheapest, but also the cleanest. We also need to understand why theoretical energy savings often fail to be achieved – the so-called performance gap. Only after we have stopped using unnecessary energy should we focus on its production. Are we generating it where needed, and could decentralised energy production help?

The next step is to look at renewable energy. As costs fall, solar PV appears to be the obvious choice, providing we can manage demand – and the grid – to cope with differing patterns of generation. But other renewables may have hidden environmental costs – will increasing use of biomass, wind or tidal energy affect wildlife and biodiversity? Introducing a monoculture of a non-native grass or flooding the Severn estuary may be good for renewables but less good for ecosystems. And carbon savings from biomass and biofuels might not be immediate: most calculations assume a continuous cycle, but carbon released by burning may not be recaptured in new growth for many years. So, could carbon capture and storage help for biomass as well as fossil fuels?

Even with reduced demand and more renewables, we will need conventional energy sources for many years; these need to be as clean as possible. Should we promote nuclear as a low-carbon source (good) or limit its use because of long-term radiation risks that cannot yet be properly managed (bad)? A shift to lower-carbon fossil fuels will also still be needed. But what should environmental scientists make of shale gas – not just because of much-publicised local environmental effects (often in the greenest and most pleasant places), but because their exploitation adds to the sum of recoverable fossil fuel reserves.

Has increasing gas production helped, or has it simply allowed us to continue to waste energy affordably?

Ian Byrne is Deputy Chief Executive of the National Energy Foundation, which he helped to establish in 1990, and a Cabinet Member of the Society for the Environment (SocEnv). As a Chartered Accountant and a Chartered Environmentalist, Ian tries to ensure that energy and carbon savings are calculated as rigorously as possible, with clear assumptions and due regard to uncertainty. He chairs the International Standards Organization working group writing ISO 17747 Energy savings calculations in organisations, and lives in a home that appeared on national television to showcase its low-energy features.

Cover design by Darren Walker
darrengraphicdesign.com

CONTENTS

environmental SCIENTIST
The Journal of the Institution of Environmental Sciences

Volume 23 No 1
ISSN: 0966 8411 | Established 1971

The environmental SCIENTIST examines major topics within the field of environmental sciences, providing a forum for experts, professionals and stakeholders to discuss key issues.

Views expressed in the journal are those of the authors and do not necessarily reflect IES views or policy.

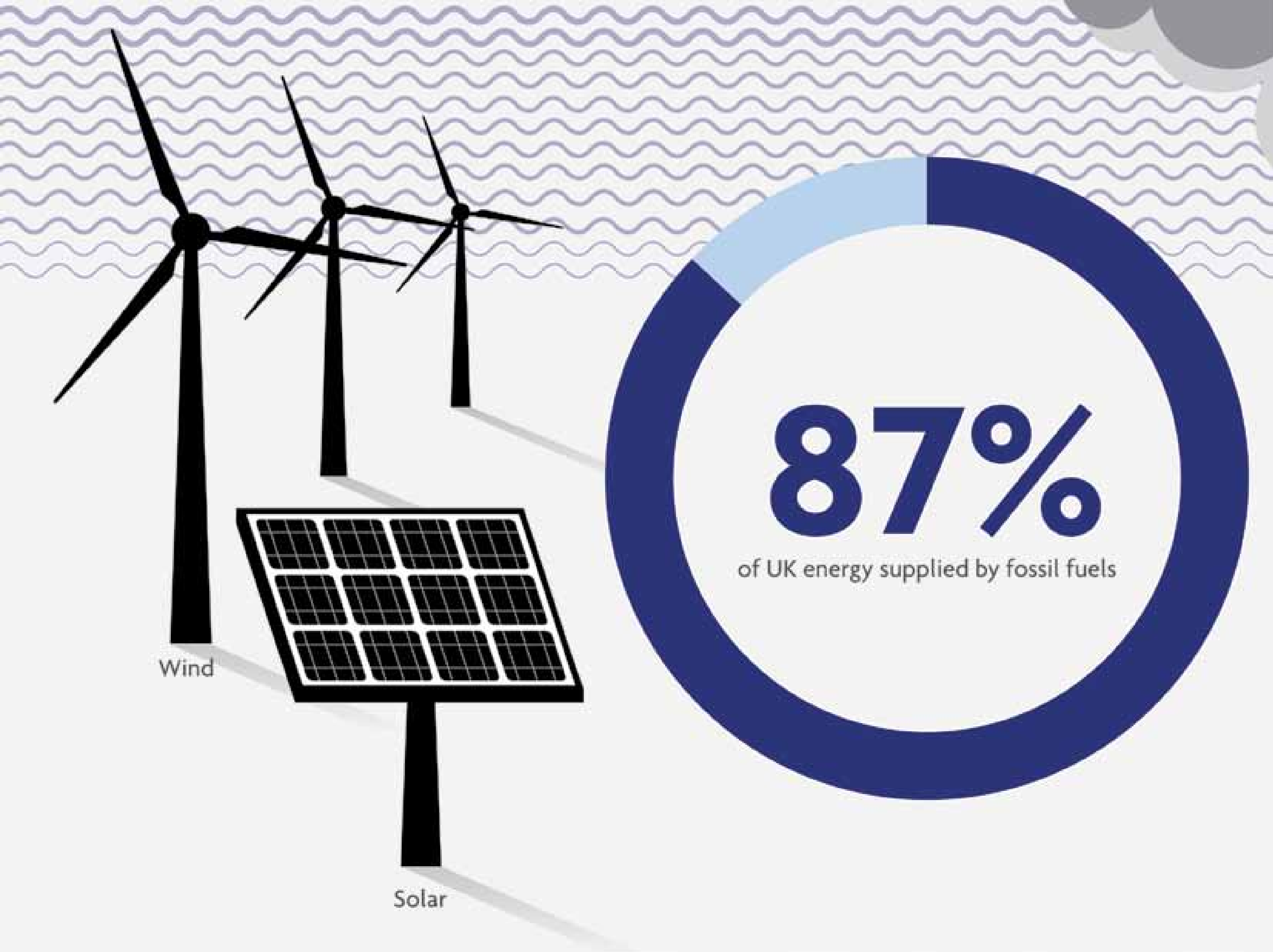
Published by
The Institution of Environmental Sciences
34 Grosvenor Gardens
London
SW1W 0DH

Tel 020 7730 5516
Email enquiries@ies-uk.org.uk
Web www.ies-uk.org.uk

Editors Emma Fenton
Sub-editor Caroline Beattie (beattie.cas@gmail.com)

Designer Darren Walker (darrengraphicdesign@gmail.com)

Printers Lavenham Press Ltd



Mixing it up: the UK and global energy mixes

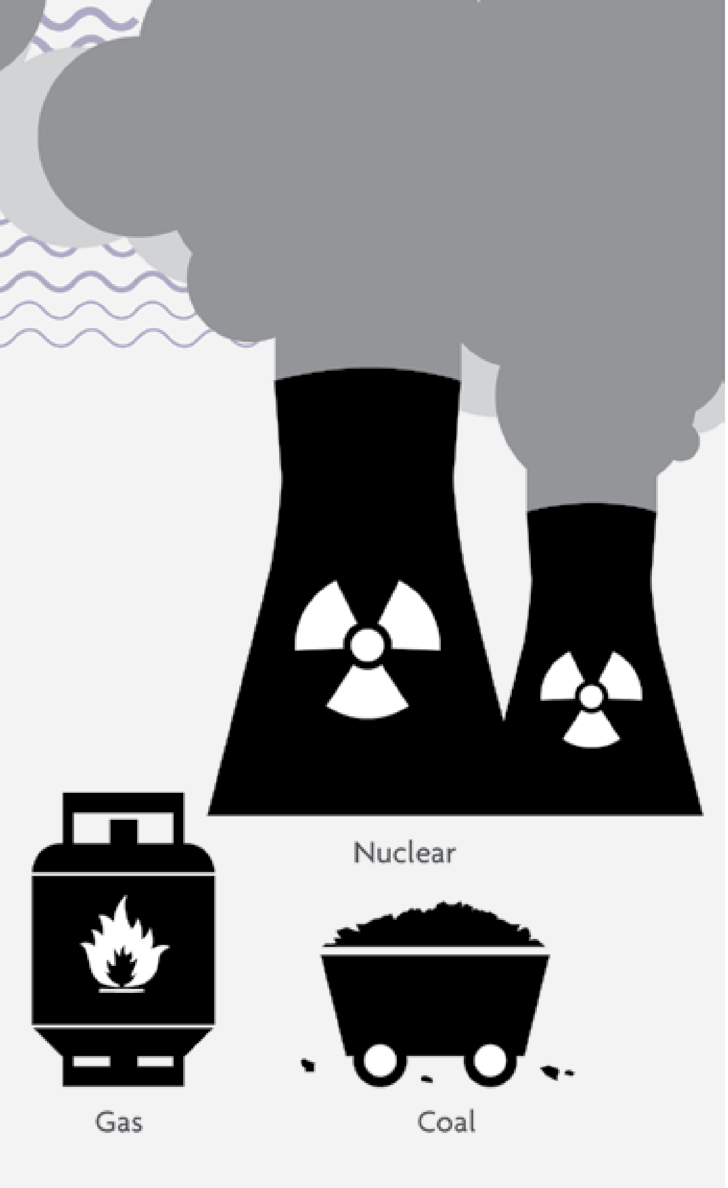
Deane Somerville outlines how the choices for our energy sources came about.

The current and projected global energy mix is heavily weighted toward fossil fuels, which met over 80 per cent of primary energy demand in 2011. Current sources of energy in descending order are petroleum, coal, natural gas, bioenergy, nuclear, hydroelectric, and other renewables[1]. The global population is growing, along with per-capita energy use, resulting in a corresponding accelerated growth in energy demand and therefore energy-related Greenhouse Gas (GHG) emissions.

There are good reasons to encourage even further increases in energy provision: human development goals set by the United Nations Development Programme (UNDP) require universal access to energy as well as improved energy services in developing countries. This involves the provision of reliable energy to over one billion people who currently have no access and to another billion who have intermittent access[2].

GLOBAL AND EU TARGETS

In contrast with rising global energy use, emissions targets have been set in order to limit the effects of human-driven climate change. Approximately two-thirds of global GHG emissions arise from energy use[3]. No global agreement has yet been reached, but



binding EU targets are in place to 2020 and aggressive global targets such as the 450 Scenario exist. Under this scenario, atmospheric concentrations of GHGs should stabilise at around 450 parts per million (ppm) after 2100. This scenario is anticipated to give a 50 per cent chance of limiting the long-term average global temperature rise to 2 °C, which is expected to make the effects of climate change manageable[4].

In light of the current and projected global energy sources and subsequent emissions projections, it is clear that additional changes must be made in order to meet emissions targets as aggressive as the 450 Scenario. As noted by the International Energy Agency (IEA) in their World Energy Outlook 2013, "there is a growing disconnect between the greenhouse gas emissions trajectory that the world is on and one that is consistent with the 2°C climate goal"[1].

The energy industry and policy-makers are faced with the difficult situation of providing significant amounts of energy to a third of the world's population while simultaneously reducing the GHG emissions that are tied to energy generation.

UK ENERGY TARGETS – WHY WE NEED TO CHANGE

The UK energy mix is similar to the global energy mix, with 87 per cent of energy supplied by fossil fuels. In descending order, the UK consumes energy from natural gas, petroleum, coal, nuclear, bioenergy, and other renewables[5]. Electricity is primarily generated by the combustion of fossil fuels, with the remainder provided by nuclear and renewables. Heat and transport energy are also produced mainly from fossil fuel combustion with a small amount generated using electricity.

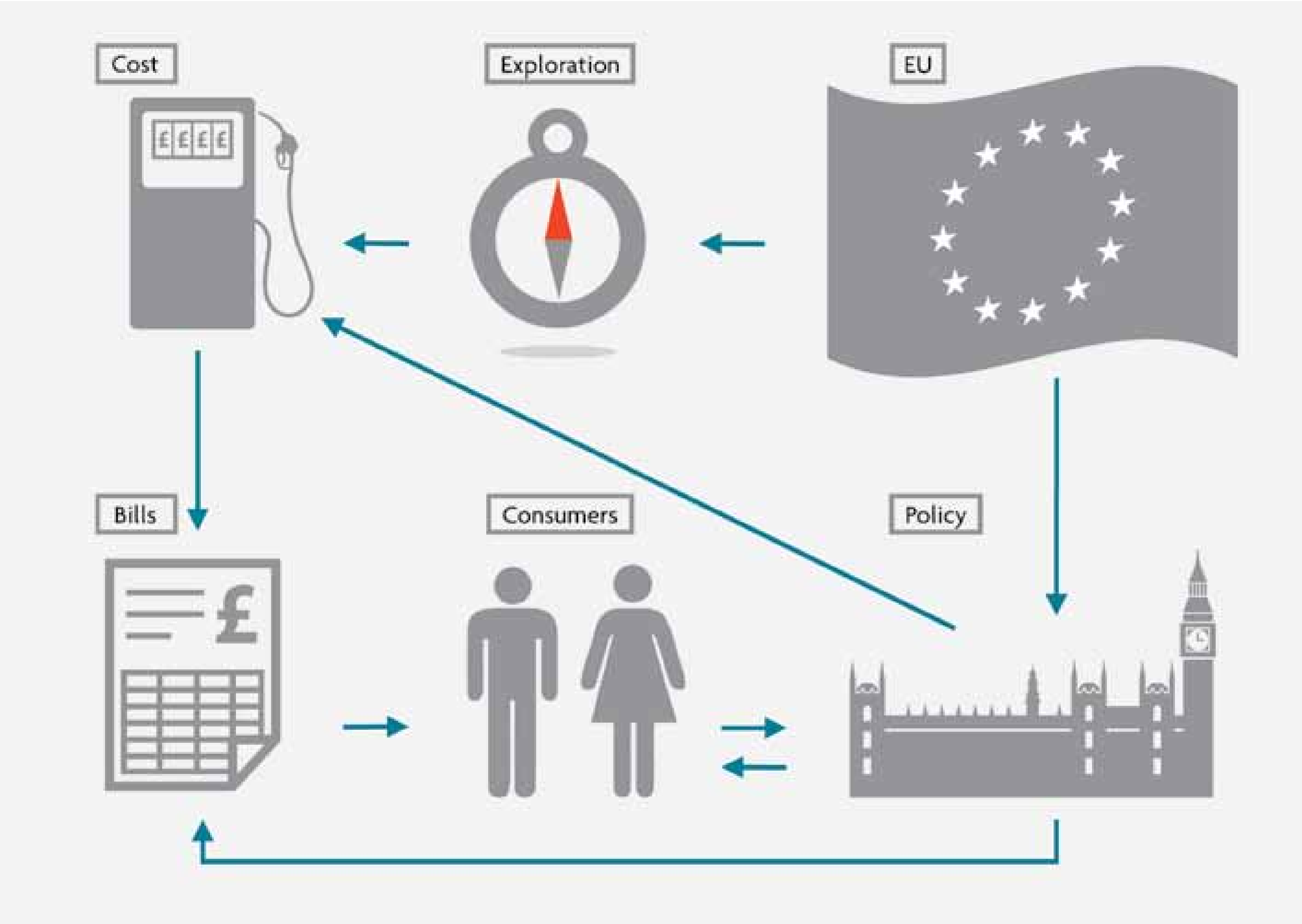
The Climate Change Act was passed by the UK Government in 2008, to set a legally binding target of 80 per cent below base year levels by 2050. The Climate Change Committee (CCC) sets five-year carbon budgets in order to ensure that the UK is on track to meet that target. Government projections from 2012 indicated that the UK expects to fall significantly short of the fourth carbon budget (2023–27) given planned policies, which suggests that the UK will also fall short of meeting subsequent budgets. For budgeted emission reductions to be achieved, additional policy measures will be required.

FUTURE UK ENERGY SYSTEM

In order to reduce overall GHG emissions, the UK Government has placed a large emphasis on electric grid decarbonisation. A low-carbon electricity system is key to the vision of a future decarbonised energy system, especially as heat and transport become increasingly electrified. The future UK energy mix is expected to include an ever-increasing share of renewable energy sources, which will include a significant proportion of intermittent, distributed electrical generation from wind and solar, and potentially wave and tidal. Increasing intermittent, decentralised generation puts new stresses on the electric grid and its operators. To prepare for these challenges, resilient grid infrastructure must be installed, guided by intelligent planning. This planning must take into account the convergence of energy sectors, as transport energy sources are increasingly shifted from fossil fuels to electricity.

Renewable heat has also been promoted through the Renewable Heat Incentive (RHI), which promotes technologies that use electricity more efficiently (heat pumps) and renewable heat sources such as biomass boilers and solar thermal hot water systems.

The UK Government is also using legislation to provide a barrier to continued unabated emissions. Emissions Performance Standards and the Carbon Price Floor, designed to support the European Union's Emissions Trading Scheme, are two such examples that put a price on carbon emissions to make it more difficult for businesses to operate in a non-sustainable manner. Building regulations have also been enacted to deliver 'zero-carbon' new-build homes and non-domestic buildings from 2016 and 2019 respectively.



▲ **Different factors influence policy and fuel choice.**

Energy system decarbonisation in the medium term will likely include increased efficiency of fossil fuel use through combined heat and power (CHP), more efficient internal combustion and hybrid vehicles, and the continued decarbonisation of the electricity sector through additional renewable capacity. Electrification of transport will likely increase, carbon capture and storage (CCS) technology will hopefully be developed through full-scale trials, and energy efficiency measures supported by the Green Deal will help to minimise demand growth. In the longer term, electricity production should be mostly decarbonised through nuclear, fossil fuels with CCS, and a significant percentage of renewables combined with effective energy storage to balance intermittency. Transport and heat will likely be mostly electrified, and fossil fuel efficiency should be maximised in the few industries that require it for process reasons.

FINANCE AND INVESTMENT

The Department of Energy and Climate Change (DECC) estimates that approximately £110 billion of capital investment will be needed over the next decade for the UK electricity system alone. This includes replacement of ageing infrastructure as well as increasing the capacity of that infrastructure. The capacity increases are needed to provide for projected future demand increases that will partially be due to electrification of the transport and heat sectors[6]. According to projections by DECC, overall demand for electricity may double by 2050[7]. Electricity Market Reform (EMR) is designed to ensure that this investment comes to the UK, through implementation of Contracts for Difference (CfDs) to financially support the construction of low-carbon technology, and the Capacity Market to provide incentives for reliable generation. Low-carbon technology uptake is further supported through Feed-in Tariffs.

ENERGY SYSTEMS

All sectors of the energy system are linked. Oil and gas exploration affects fossil fuel prices, which affect electricity pricing, which affects energy consumers from manufacturers to homeowners. Policy affects carbon pricing and emissions standards, which influence pricing and sometimes dictate fuel choice. Public opinion influences politicians and can affect the success of renewable technologies. Computing and data collection technology allows for effective energy management, which in turn affects energy demand and pricing.

As the energy system becomes increasingly decarbonised and reliant on electricity, systems will become even further and more directly interdependent. One of the best tools available for the optimisation of the UK energy system is the increasing availability of detailed energy data provided by smart meters. This information plays a crucial role in balancing the electric grid, but can also be used by energy managers and users alike to monitor and thereby reduce energy use.

Increased energy efficiency will become rapidly more important, as approximately a fifth of existing UK electricity generation capacity is planned for closure by 2020[8]. Data collection and automation of electrical devices through a smart grid and smart device system, sometimes referred to as an 'internet of things', should further emphasise the links within the energy system. Because of the interconnected nature of the energy system, its decarbonisation will require the cooperation of Government, energy producers, and energy users to make a smooth transition.

FUTURE SKILLS

Substantial investment is required in all elements of the energy infrastructure in the UK if the 2050 de-carbonisation targets are to be achieved. Billions of pounds must be invested in physical assets and their systems, user technologies and, importantly, the human expertise to innovate, design, execute and operate the new decarbonised system.

The decarbonisation of the UK energy system cannot happen without an effective and skilled workforce. It is essential that skills development, especially in science and engineering, is fully integrated into the policy package to ensure that the energy industry can implement the Government's strategy.

In many ways the UK's energy future looks positive, due to the experience, knowledge and understanding amongst energy professionals. However, there is currently a decline in the take-up of science and engineering careers by young people and therefore attracting and retaining key skills is crucial to the energy future for us all.

It is the job of all those working in the sector to see that price rises are minimised for consumers in the face of rising fuel poverty, whilst mitigating and adapting to the challenges of a changing climate. This needs a collaborative, communicative approach to ensure the public fully understands the implications of a transition to a low-carbon, resource-efficient energy system. **ES**

Deane Somerville is Knowledge and Information Officer at the Energy Institute (EI). He joined the EI in 2013 after completing an MSc in Energy and Environmental Technology and Economics at City University. The EI is a professional membership body, providing knowledge and good practice to support those working in the global energy sector. Deane is currently working on energy management, heat, and offshore power generation research and knowledge dissemination projects for the benefit of its members and wider society.

To further consider and promote understanding regarding energy systems, Elsevier and the Energy Institute have organised the Energy Systems Conference, which will take place in June 2014. The two-day conference will explore the challenges involved with creating a more secure, sustainable, and affordable energy system. Innovative solutions for reconciling the divergent social, environmental, and economic goals for energy will be discussed, and conference outcomes will be published to provide recommendations for policy-makers and energy leaders.

SOURCES

1. International Energy Agency (2013) World Energy Outlook 2013, IEA, Paris.
2. UNDP. Sustainable Energy. www.undp.org/content/undp/en/home/ourwork/environmentandenergy/focus_areas/sustainable-energy.html (Accessed: 19 January 2014).
3. International Energy Agency (2012) *IEA Statistics: CO^2 Emissions from Fuel Combustion*. IEA, Paris. www.iea.org/co2highlights/co2highlights.pdf.
4. International Energy Agency (2013) *Redrawing the Energy–Climate Map*. IEA, Paris.
5. Department of Energy and Climate Change (DECC) (2013) *Digest of United Kingdom Energy Statistics 2013*. TSO, London.
6. Department of Energy and Climate Change (DECC) (Updated 18 December 2013) *Maintaining UK energy security: Electricity Market Reform*. www.gov.uk/government/policies/maintaining-uk-energy-security--2/supporting-pages/electricity-market-reform.
7. DECC (2013) Consultation on the draft Electricity Market Reform Delivery. [online]. Available from: www.gov.uk/government/consultations/consultation-on-the-draft-electricity-market-reform-delivery. (Accessed: January 2014).
8. Department of Energy and Climate Change (DECC) (2013) *Consultation on the draft Electricity Market Reform Delivery Plan*, URN:13D/139. DECC, London. www.gov.uk/government/uploads/system/uploads/attachment_data/file/238867/Consultation_on_the_draft_Delivery_Plan__amended_.pdf.

Gas production over the last 200 years: friend or foe?

Russell Thomas and **Sharon Churchill** shine a light on the UK's relationship with gas and ask whether it has a future in the UK energy mix.

▲ **Figure 1. Large gasworks. © National grid Gas Archive.**

The gas industry has been in the UK spotlight recently, due to increasing gas prices, shale gas, depleting UK gas fields and a growing dependency on gas for electricity production. The public gas industry celebrated its 200th anniversary in 2012, and this article provides a summary of its history and assesses whether gas has been a friend or a foe.

Whilst gas is expected to be there at the flick of a switch to power your cooker or boiler, the infrastructure that provides this supply is all but hidden from sight below ground. Some of you may be aware of gasholders, the tall cylindrical telescopic storage vessels (see **Figure 1**) that are gradually disappearing from our landscape, but beyond this, little is seen. As many of the developments associated with the gas industry are not obvious, this article shines a light on the industry's past.

Gas has featured in human society for thousands of years, having spiritual significance where 'eternal flames' – burning seepages of gas – formed the centrepiece of religious shrines. The ancient Chinese captured natural gas for heating salt pans. Firedamp was feared in British coal mines for its explosive properties when ignited, but engineers such as Spedding had seen the potential for extracting and burning this gas for lighting purposes[1].

THE MANUFACTURED GAS INDUSTRY

The UK gas industry was not built on natural gas, but on gas manufactured from coal, called town gas.

Clayton and his contemporaries experimented with the distillation of coal and found that it generated a flammable gas[1]. Advances in a use for this gas occurred when a group of pioneers, including Lebon, Minckelers and, most importantly, the Scottish engineer Murdoch, found a practical use for the gas in lighting[2]. Murdoch first lit his office in Redruth in Cornwall in 1792, then developed a practical gas-making plant and lit the factory of his employers, Boulton and Watt (B&W).

It was the significant investment of resources in understanding the principles of gas-making by B&W that allowed Murdoch to develop the process into a commercial reality. B&W then built gasworks to light some of the major mills in the country, the first truly effective form of artificial lighting. A major benefit was that gas lighting was much safer than oil lamps or candles, which were easily dislodged, causing fires and loss of life. Town gas was cheaper than oil and candles, reducing lighting costs as well as insurance premiums for the mill owners.

TOWN GAS MAKING PROCESS

At this point it is worth exploring the town gas manufacturing process, and the by-products formed and their properties. The process is described in simplified terms below and shown in **Figure 7**.

Coal was placed within a sealed vessel called a retort, and was heated externally by a furnace. Without air, the heated coal did not burn, but instead moisture was driven off and the large organic molecules within the coal were thermally broken down into smaller compounds. This process released molecules such as hydrogen, water and hydrogen sulphide into the gas as well as the organic compounds that formed the gaseous, oily and tarry phases within the by-products.

The gas leaving the retort was cooled, removing most of the tar and oil compounds trapped in the gas as coal tar. The gas would be washed to remove soluble compounds such as ammonia and phenol which formed ammoniacal liquor, and then the gas would be purified to remove sulphur and cyanide compounds. The treated gas, now called town gas, was stored in a gasholder, ready for distribution through gas mains beneath the streets to customers. Coke remained in the retort, which was removed and cooled by dousing with water (**Figure 2**).

▼ **Table 1. The composition of town gas and the by-products of the manufactured gas process.**

By-product	Characteristics
Town gas	Town gas consisted of carbon monoxide (7 per cent), hydrogen (51.8 per cent), methane (27 per cent), other flammable hydrocarbons (4.7 per cent), oxygen (0.5 per cent) and non-combustible components including carbon dioxide (2 per cent) and nitrogen (5.5 per cent).
Coal tar	Coal tars are a black or brown viscous, non-aqueous liquid consisting of a complex mixture of organic compounds. These included polycyclic aromatic hydrocarbons (PAH), phenolic compounds (eg phenol), benzene, toluene, ethyl benzene and xylene (BTEX) compounds, oxygen, nitrogen and sulphur heterocyclic compounds (e.g. carbazole), and inorganic components (e.g. ammonium and cyanide).
Ammoniacal liquor	The ammoniacal liquor consisted of up to 1 per cent ammonium and lower concentrations of sulphate, phenol, ferrocyanide and thiocyanate.
Purifier waste: foul lime and spent oxide	Foul lime was the waste formed when the gas was passed through hydrated lime, removing most of the sulphur and cyanide from the gas. Foul lime contained approximately 50 per cent sulphur and 6 per cent cyanide. Lime was superseded at the turn of the 20th century by bog iron ore, which was called spent oxide and contained similar amounts of sulphur and cyanide.
Coke	Coke was the useful solid remaining after the gas was extracted from the coal. It was almost a pure form of carbon, although it would also contain some metallic and inorganic components, depending on the original composition of the coal.
Ash	Ash was the waste material remaining after the burning of the coal or coke in the furnace; it contained heavy metals such as lead and zinc.
Air emissions	Primarily carbon dioxide from the combustion of coke, which would have some entrained particulate matter. Odours from tar, ammoniacal liquors and purifier wastes.

The process generated the by-products listed in **Table 1**. The gas industry developed into the utility industry it is today thanks to the German entrepreneur Friedrich Albrecht Winzer. He had the foresight to realise how gas from one or more gasworks could be supplied through pipes under the streets to multiple customers and locations. After several years of effort, Winzer helped establish the Gas Light and Coke Company (GL&C Co) in 1812[1] in Westminster to light the cities of Westminster and London and a part of the Borough of Southwark. It was the world's first gas company and the first public utility, predating the water utilities by many years. By 1814 the GL&C Co had installed 122 miles of gas mains in London, supplying 7 million cubic metres of town gas to 31,000 gas lamps[2]. The development of a new industry brought problems, similar to current concerns over shale gas. People were worried about the passage of gas under their streets, its quality and potential toxicity, and the pollution caused by the gas manufacturing process.

The use of town gas spread rapidly into the provinces. Starting with Preston in Lancashire in 1815, it eventually spread to every city, town and large village in the UK by 1850. Gas lighting was popular as a deterrent against street crime, so much so that for over 20 years the police operated the first gasworks in Manchester. Any sizable town gasworks was created by an Act of Parliament, granting it certain rights, often for the purpose of making the streets safer. Whilst a majority of gasworks remained privately owned, many towns and cities such as Birmingham purchased and owned their gasworks municipally. These municipal gasworks made large profits which were used to fund the construction of municipal buildings and important infrastructure such as sewers. By 1882, 1,840 million cubic metres of town gas was manufactured in Britain. Examples of small and large gasworks can be seen in **Figures 3 and 4**.

TOWN GAS

Town gas was used primarily for lighting until the latter part of the 19th century – electricity did not appear as a credible competitor until the early 20th century. Many town and cities were lit with town gas until the 1950s due to the constant innovation in gas lighting, notably Carl Auer's invention of the gas mantle in 1887. The gas mantle was a small fabric structure impregnated with oxides of thorium and cerium that emitted light when heated. This produced a much brighter light, allowing it to temporarily compete with the electric light.

Other uses for town gas were limited by the available technology, but when the German Robert Bunsen invented the atmospheric gas burner in 1855, it allowed much more efficient use of town gas, making heating applications a possibility. This eventually led to the widespread popularity of town gas used in the home for heating and cooking (**Figure 5**), and in turn improved the quality of life for many, including the poor, whoGgained

▲ **Figure 2. Stokers removing coke from a retort. © National Grid Gas Archive**

access to town gas and gas appliances through the invention of the prepayment gas meter in 1889. Gas lighting in the home was safer; cooking on a gas stove was much cleaner, healthier, more convenient and cost-effective than an open fire; and hot-water heaters made washing and bathing more enjoyable. Gas was even used to power irons, fridges and radios.

Gas became important in industry, as it allowed the production of heat at high and uniform temperatures that could be carefully controlled, which was vital during the two world wars. By 1958, 29 per cent of town gas was used by industry.

COAL TAR

In the early years of the gas industry, coal tar was regarded as a nuisance, and its main use was as a fuel or wood preservative. It could not always be sold, so it was disposed of either on the gasworks or local tips. As a dense non-aqueous liquid, any spillages would seep into the ground and through groundwater until they reached a highly impermeable layer. Soluble chemicals would leach out into the groundwater over time, polluting it with phenol, benzene and naphthalene, for example. As a substance that is both toxic and carcinogenic, coal tar is the most significant source of pollution found on former gasworks.

It was not until chemists started to indentify the useful chemicals present in coal tar that it became valuable. In 1856, the young English chemist William Perkins inadvertently created the synthetic dye industry when he discovered that aniline extracted from coal tar could be used to form brightly coloured dyes and thereby made once-expensive coloured fabrics available to the masses. This was a fundamental discovery, as it made people aware of the rich chemicals that could be produced from coal tar, making it the most important feedstock in the organic chemical industry. From coal tar, it was

▼ **Table 2. The impurities of gas pre- and post-treatment, converted from Stewart[2].**

Gas impurity	Town gas prior to purification (g/m^3)	Town gas after purification (g/m^3)
Naphthalene	2.259–5.718	0.0458
Hydrogen sulphide	8.26–20.57	0.0002
Organic sulphur compounds	0.811–0.917	0.112–0.684
Ammonia	6.84	0.0042
Cyanide compounds	1.376–2.259	0.22–0.45
Nitric oxide	0.002–0.011	0–0.00035

possible to isolate benzene, toluene, naphthalene and phenol, which became vital as the starting point for many other organic chemicals.

Coal-tar-derived disinfectants such as carbolic acid played major roles in reducing deaths from hospital infections. Vital medicines and painkillers such as aspirin and morphine were also produced, as were anaesthetics such as benzocaine, and a wide range of perfumes, essences and flavourings such as vanillin. Pest-control agents developed from coal tar assisted the revolution in increasing food production, although coal tar was also used to manufacture DDT, which caused great environmental damage.

Fuels were manufactured from coal tar and benzol, a light oil washed from the gas, was the forerunner of petrol in Britain. The town gas industry was vital in producing fuels and chemicals (such as toluene) for explosive manufacture during both world wars. Coal tar led to the materials revolution of plastics and polymers in the decades after the First World War, providing the raw material for plastics such as nylon and polystyrene. Until the 1960s, roads were paved with coal-tar-based tarmac, the end use of a large amount of coal tar that enabled a big change in UK transport infrastructure. This list goes on and clearly demonstrates the important technical advances that just one by-product of town gas manufacture brought to society. It cannot be overlooked, however, that many of these industries also created their own legacy of pollution.

AMMONIACAL LIQUOR

The major source of pollution from an operational manufactured gas plant was ammoniacal liquor. This dilute solution of ammonium compounds, phenols and other cyanide and sulphur compounds resulted from washing the gas as part of the purifying process. It was produced in greater quantities than coal tar, so it had to be disposed of more regularly.

The liquor could be a useful fertiliser, sprayed onto fields neat or diluted. However, this was not always feasible and the liquor was often released to the nearest river. Inevitably, such nitrogen-rich water led to the eutrophication of the river and death of organisms within it. In relative terms for the time, this pollution was not as bad as other industries, which produced waste streams rich in toxic metals. Rivers also had to contend with a regular supply of raw sewage from the towns and cities located nearby.

The gas industry eventually built plants where the liquor was converted into sulphate of ammonia fertiliser, an unpleasantly odorous process. The liquor was also concentrated by distillation and taken to large chemical works for fertiliser production.

PURIFIER WASTE

Town gas still contained sulphur and cyanide compounds (see **Table 2**), and the removal of these impurities was essential, as sulphur dioxide would foul the air and damage the interiors of properties when burnt. Bubbling the gas through wet lime was first used, but this produced the foul-smelling waste 'blue Billy' which was taken by cart to be disposed of in rivers, causing nuisance odours and pollution. This was outlawed and replaced by a hydrated lime process; this produced foul lime, which could be used as a fertiliser.

The gas industry switched to an iron-based purification system towards the end of the 20th century, producing a waste called spent oxide that contained cyanide (>6 per cent) and sulphur (50–60 per cent). Spent oxide was sold primarily for use as a feedstock or for sulphuric acid production.

▲ **Figure 3. Small country gasworks in Somerton, Somerset. © National Grid Gas Archive**

COKE AND AIR EMISSIONS

Coke produced in retorts was almost pure carbon; some of it was used by the gasworks to heat the retorts and to produce another gas called water gas. Surplus coke was sold for local domestic or industrial use. Coke was the first smokeless fuel, burning with a blue flame when burnt efficiently and producing much less smoke and soot than coal. As coke was used for heating the retorts and the gas was purified, air pollution was minimised compared to coal-based energy production methods such as electricity.

New gasworks would be built on the outskirts of cities and, thus, the gas industry was able to greatly reduce urban air pollution and smog. However, the industry's carbon emissions would have contributed towards air pollution and climate change.

▲ **Figure 4. Large gasworks in, Torquay, Devon. © National Grid Gas Archive.**

ASHES

When the coke was burnt in the furnaces, the ashes left behind were often used to raise the ground level on site, or sold to others for this purpose elsewhere. The ash was sometimes ground down to be used in concrete production and also sometimes mixed with dehydrated tar to form a low-quality tarmac. The ash contained all the inorganic compounds and heavy metals of the coke such as lead, arsenic and zinc, which could pose a risk to human health.

GAS FROM OIL

Gas was produced primarily from coal until the 1950s, the exception being the production of an enriched form of water gas (WG) called carburetted water gas (CWG). Introduced to the UK in the late 1890s, it could be produced rapidly (in one to three hours) to satisfy peak demand, which coal carbonisation could not. It was made by intermittently combusting and injecting steam into a vessel filled with red-hot coke. When steamed, a poor-quality gas of hydrogen and carbon monoxide was produced, which had no illuminating power. WG could be enriched by injecting oil into the gas to make CWG, which was produced in all the large gasworks in the UK. The CWG process produced water gas tar, a problematic waste tar which in some circumstances was more mobile in the environment than coal tar and could therefore cause more extensive groundwater pollution. This

▲ **Figure 5. An advert for gas stoves. © Russell Thomas.**

has been a particular problem in the USA where the process originated.

The sources of good gas-making coals were decreasing in the UK and their cost was increasing. This badly affected the economics of the gas industry and the quality of the gas. The industry experimented with low-grade coals, but decided to make gas from oil refining by-products when they became available at economic prices. New reforming plants were built across Britain that used butane and naphtha as feedstocks for town gas production. The economic advantages of reformed town gas were the start of the end for the production of gas from coal in Britain. Reformed town gas was much cleaner and produced very little pollution by comparison, though none of the useful by-products.

NATURAL GAS

It was realised that a secure source of natural gas would be preferable, as was the case in France and the USA. Without a local supply of natural gas, the industry started importing liquefied natural gas (LNG) by ship to a reception terminal built at Canvey Island in Essex. Gas was first imported in 1959 from the USA, and 1964 saw the start of regular shipments of up to 700,000 t of LNG per year from Algeria. The Canvey Island project would have developed further if it had not been for the discovery of gas under the North and Irish seas, which was brought ashore by 1967.

In 1966 it was announced that Britain would switch from town gas to natural gas. Without local gas production it was realised that a better gas transport system across the country was required. Feeder 1, a high-pressure gas transmission pipeline, was built in 1966 to transport gas from London to Leeds, signalling the start of the National Transmission System (NTS, **Figure 6**). The NTS has since expanded significantly and is an essential part of delivering and storing gas in Britain. With depleting gas reserves, new LNG import facilities have been built in Milford Haven, Pembrokeshire, and the Isle of Grain in Kent.

In 1966 it was announced that Britain would switch from town gas to natural gas. Without local gas production it was realised that a better gas transport system across the country was required. Feeder 1, a high-pressure gas transmission pipeline, was built in 1966 to transport gas from London to Leeds, signalling the start of the National Transmission System (NTS, Photograph 5). The NTS has since expanded significantly and is an essential part of delivering and storing gas in Britain. With depleting gas reserves, new LNG import facilities have been built in Milford Haven, Pembrokeshire, and the Isle of Grain in Kent.

In order for Britain to switch from manufactured town gas to natural gas, all the fittings used for burning towns gas had to be replaced by sets suitable for burning natural gas. This required the largest engineering feat undertaken in Britain since the end of the second world war. Called "the Conversion Programme", it involved the physical conversion of every gas appliance in the country.

The conversion programme took ten years to complete. Its completion signalled an end to the manufacture of gas in England and Wales, with the switching off of gas production at Romford Gasworks on 26 August 1976. The last gasworks making gas from coal was to be found in the remote areas of Scotland. The last gasworks to close in Britain was the small hand-charged horizontal retort gasworks in Millport on the Isle of Cumbrae, which closed in 1981.

Natural gas does not have the same pollution issues as manufactured gas, although there are environmental costs to exploring and extracting gas, especially in environmentally sensitive locations. Once ashore, the gas is transported via NTS and gas distribution pipelines over gradually decreasing pressures until it arrives at the consumer's home. The main environmental risks from gas infrastructure have been climate change impact from fugitive emissions of natural gas (emissions of gas from pressurised equipment, due to leaks or other unintended releases), which contain methane, a powerful greenhouse gas. Ongoing investment by the gas industry to replace old cast-iron gas mains with plastic pipes has helped to minimise these emissions.

POLLUTION AND REGULATION

There is no denying that the manufactured gas industry did cause pollution to the rivers and water

▲ **Figure 6. Constructing the pipeline for the National Transmission System. © National Grid Gas Archive**

courses, the land in which it operated and to the atmosphere; but was it worse than other industries or the effects of sewage pollution from the general populace? Probably not.

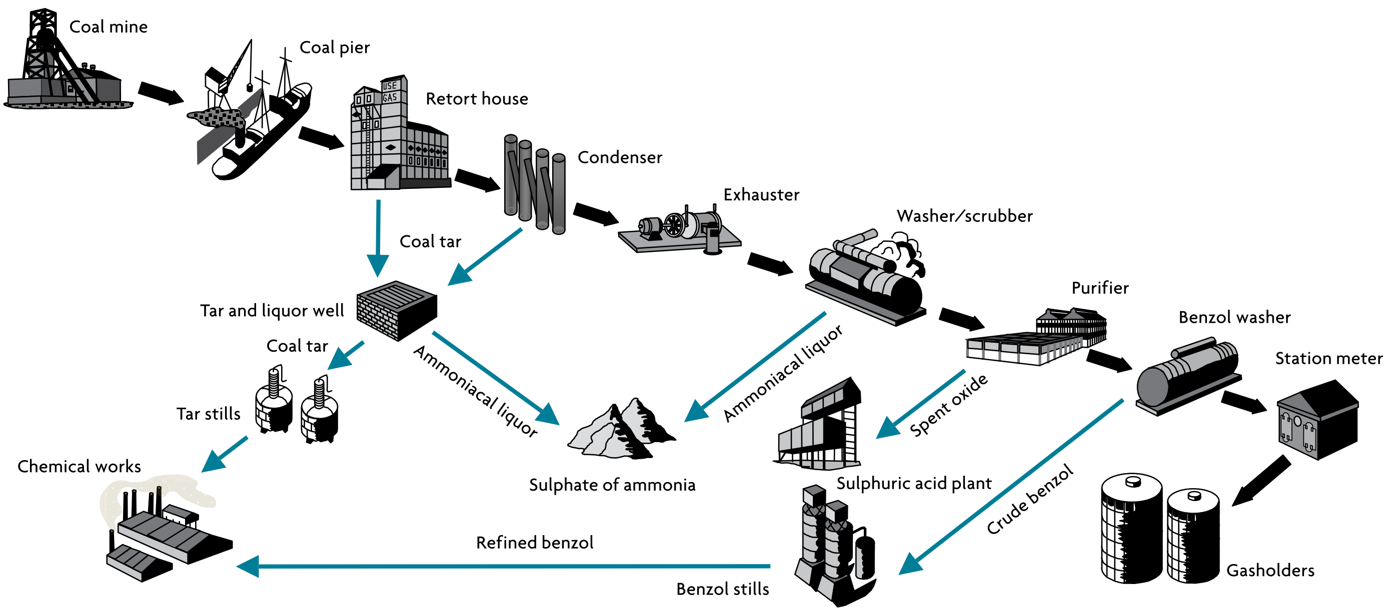
As a natural monopoly and the first utility industry, it was under scrutiny from the outset, being subjected to a select committee review and an associated Royal Society report in 1823. It was regulated through the Gasworks Clauses Act in 1847 (and 1871). This covered all aspects of the gas industry, from pipe laying to pollution. It was one of the first government acts to curb industrial pollution, evidence that pollution was an issue.

The disposal and materials-handling practices of the industry were typical of those used by other industries, and accepted by governments at the time, generally without malevolent intent. The gasworks manager would have been aware of the effects of some of the pollution they could cause, as water pollution incidents were reported from the early gas journals. The activities of the gasworks would often be a reflection of the gas engineer, and some were better than others. Some may have risked prosecution by disposing liquor waste into a clean river at night, while others would have managed their gasworks very efficiently to recover as much value from the by-products as possible and minimise any waste. Many gasworks managers held posts within local government and were careful about harming their reputation.

Many of the rivers running through Britain's industrial heartlands had been seriously impacted by the industrial revolution, and therefore the gasworks were one of many potential sources of pollution entering the rivers. It was a very different case for the over 600 + gasworks in rural areas, where they could have been the major source of pollution and had to ensure they would not destroy sensitive rivers with valuable fish stocks. Whilst the gasworks would try to obtain the best price for the by-products, there were times when they could not be sold and had to be disposed of to waste dumps on site or locally. Such dumps were not well documented and provided unwelcome surprises for many years to come.

HEALTH

As mentioned earlier, the gas industry did much to improve urban air quality. Like most industries, however, the gas industry had well-known occupational illnesses. The main disease was dermal



▼ **Figure 7. The production of town gas from coal. The black arrows show the progress of the gas through the plant and the blue arrows show the processing of the by-products. © Russell Thomas** cancer, but lung and bladder cancer were also later linked to the industry[4]. In 1915, a direct association was made between exposure to coal tar constituents and cancer, when Yamagiwa and Ichikawa at Tokyo University[5] induced cancer in laboratory animals by repeatedly applying coal tar to the skin of rabbits' ears. Work by British scientist Ernest Kennaway[6] in 1930 proved the substances within coal tar responsible for causing cancer, and Robert Doll would later show similar findings when studying workers in the British gas industry[4]. The gas industry introduced protective measures to minimise dermal cancers and by the time that Doll's wide-ranging report was issued in the 1960s, workers in the industry had a better life expectancy than the general public[4].

These very same health issues exist now in the context of contaminated land. Today, the gas industry's environmental legacy is mainly from the polluted soils and groundwater that may remain on former gasworks. This legacy has partly been remediated by the gas industry voluntarily, and other land has since been remediated and built on by private developers. There were over 4,000 former gasworks in the UK. Some closed many years ago, were forgotten about and then redeveloped without proper remediation; this will provide an environmental legacy issue for many years to come.

CONCLUSIONS

The public gas industry has evolved over its 200 years, developing into more than 1,000 different gas undertakings until it was nationalised in 1949. It was reorganised into the British Gas Corporation (1972) then privatised as British Gas Plc (1986), by which time it was a gas exploration, production and distribution company. It survived as a whole until it was demerged in 1997 and the industry has since undergone significant further fragmentation.

Over the past 200 years, the gas industry has invested heavily in innovation, developing better ways to purify gas, discover new types of gas, and improve ways to use gas, reduce pollution and maintain its infrastructure. Who knows what the future holds? Will LNG, shale gas or biomethane be part of the future energy mix, or will gas remain a transitional energy until sustainable energy sources are able to replace it completely?

Against the legacy of water and air pollution, contaminated land and carbon emissions, we need to take into account the positive contribution of the gas industry. It has provided an improved quality of life for a great many people through gas lighting, heating and cooking applications. It has enabled many subsequent industrial and technological developments, and facilitated the development of modern urban life. Many of the materials, pharmaceuticals and chemicals taken for granted today have their roots in the gas industry. All these inventions have made a significant impact on health, life expectancy, lifestyle, personal income, jobs, and how and where we play. Friend or foe? You decide. **ES**

Dr Russell Thomas is a Technical Director for Parsons Brinckerhoff. He has worked in the contaminated land sector on projects restoring the pollution legacy of the manufactured gas industry since 1997. He has also studied the gas industry for many years and is a member of the Institute of Gas Engineers and Managers, and its Panel for the History of the Gas Industry, a body established in the 1970s.

Dr Sharon Churchill currently works for the US Federal Government as an environmental regulatory compliance specialist. She has more than three decades of experience in contamination remediation and is a consultant in environmental contaminant hazard assessment and risk reduction.

SOURCES

1. Thomas, R. A. P. (2013) The History and Operation of Gasworks (Manufactured Gas Plants). www.academia.edu/1029068/The_History_and_Operation_of_Gasworks_Manufactured_Gas_Plants_
2. Stewart, E. (1958) *Town Gas*. Science Museum/HMSO, London.
3. Gasworks Clauses Act, 1847, 10 & 11 Vict. c. 15.
4. Doll, R., Fisher, R. E. W., Gammon, E. J., Gunn, W., Hughes, G.O., Tyrer, F.W., Wilson, W. (1965) Mortality of gasworkers with special reference to cancers of the lung and bladder. British Journal of Industrial Medicine, 22 (1) pp1–12.
5. Yamagiwa, K., and Ichikawa, K. (1918) Experimental study of the pathogenesis of carcinoma. *The Journal of Cancer Research*, Vol 3 (1) pp1–29.
6. Kennawae. (1930) Further experiments on cancer-producing substances. *Biochemical Journal*, 24, pp. 497–504.

Nuclear power: a poisoned chalice?

Stuart Parr reviews the current state and status of the nuclear industry, along with its benefits and disadvantages.

When I was growing up in the 1980s, if you were interested in the environment there was one industry that was Public Enemy No. 1: the nuclear industry. In the UK we had Sellafield (called Windscale at the time) polluting the Irish Sea with radioactive effluent from nuclear fuel reprocessing. Its activities were tarnished by its links to the UK nuclear weapons programme, the legacy of the 1957 Windscale fire and poor political management of the state-run nuclear energy industry[1]. And then there was Chernobyl.

If you had suggested in the 1980s that one day environmentalists would promote nuclear power as a solution to pressing environmental and social problems facing the world, you would have been laughed at, tarred and feathered, or at the very least, considered an anti-social industrialist who cared not a jot for the environment.

The political establishment was also beginning to turn its back on nuclear power. The power solution that was to provide electricity that was "too cheap to meter"[2] was proving to be a millstone. Impending privatisation of the UK electricity industry excluded nuclear power stations and its associated decommissioning and waste-management legacies.

The last nuclear power station to be commissioned in the UK, Sizewell B in Suffolk, took about 14 years to go through design, construction and commissioning, finally sending power to the national grid in 1995. A lengthy public enquiry challenging the safety and environmental impacts of its operation slowed the planning process. Plans for more power stations were therefore shelved: nuclear power was too messy, too expensive and publically unacceptable.

THE REVIVAL OF NUCLEAR POWER

Yet, 30 years later, another environmental issue – climate change – has driven many to reconsider nuclear power and its place in our energy mix. Highly respected environmental scientists, such as the founder of the Gaia hypothesis, James Lovelock, are also promoting its environmental benefits[3]. Governments around the world are looking at developing nuclear power – even in oil-rich countries, such as Saudi Arabia.

Climate change is driven by anthropogenic emissions of greenhouse gases, primarily carbon dioxide (CO_2). The greatest source of CO_2 emissions is burning fossil fuels for energy production. Generating electricity by burning coal generates 1 kg of CO_2 per kWh[4]. Gas would seem a better option, as burning natural gas (mostly methane) generates about 450 g CO_2 per kWh, but methane itself is four times as powerful a greenhouse gas as CO_2, so losses during extraction and transport certainly add to the greenhouse gas figures. Nuclear power and renewable energy are quoted as generating only 5 g of CO_2 per kWh. As nearly all governments are interested in reducing greenhouse gases, it would seem nuclear and renewable energies are the way to go.

As environmental scientists we should re-evaluate the environmental benefits and disbenefits of nuclear power. Are we trying to fix one environmental problem by bringing back an environmental hazard society was moving away from? Can nuclear power solve our impending energy and environmental crises? Or is it still a poisoned chalice that will lead to excessive expenditure and pollution?

THE TRUE COSTS OF ELECTRICITY

Generating electricity from nuclear fuel and from renewable sources is expensive. The current wholesale price for electricity in the UK is about £47.50 per kWh. The UK Government has recently agreed a rate of £92.50 per kWh with EdF for electricity from the planned Hinkley Point C nuclear power station. This price is fixed for 40 years, beginning when the new power station starts generation in 2023. In comparison, offshore wind power schemes built in 2018–19 will receive a guaranteed price of £135 per kWh for 15 years. The prices of nuclear and renewable energy generation could be considered more realistic than that of conventional fossil fuels, which do not account for the externalities of CO_2 emissions released into that global commons, otherwise known as the atmosphere.

What are the other environmental impacts of nuclear? Discharges of radioactivity into the air and water aand solid waste disposal into the ground are the three most obvious. The UK is well placed to understand the impacts of disposals of radioactive waste into the environment, as the UK environment agencies and the Food Standards Agency have been monitoring levels of radioactivity in food and taking environmental samples for a long time. This information has been published for nearly 20 years in the annual Radioactivity in Food and Environment (RIFE) report[5]. This report documents a significant decline in levels of discharges in the environment and levels in food over the past two decades. Currently radioactivity discharged to the air and water from nuclear facilities can barely be detected against the natural background radiation. A flight from the UK to

Mediterranean Europe will expose you to more radiation than living next door to a nuclear power station for a year.

The exception to this is the radiation dose from Sellafield discharges. The UK's centre for the reprocessing of nuclear fuel — one of the world's most hazardous decommissioning sites — still gives measureable radiation doses to the environment, although these doses are significantly lower than they were during the 1980s.

Sellafield will reprocess all the fuel from both the UK's first-generation nuclear power stations, the Magnox stations (all but one of which has now ceased generation), and most of the fuel from the UK's second generation of nuclear power stations (the advanced gas reactors (AGRs), all of which are still generating power. None of the operators of the forthcoming third generation of nuclear power stations are planning to reprocess fuel, a decision is motivated by financial reasons rather than on environmental grounds.

THE SUPPLY OF URANIUM

One of the main mnotivations for reprocessing back in the 1960s and 1970s - other than to generate weapons-grade plutonium - was the prediction that uranium's scarcity would make it expensive. Reserves of uranium have proven to be more plentiful and easier to extract, and thereby cheaper, than had been expected. Operators in the UK now store their used fuel for a period of time before disposing of it.

This solution might initially seem acceptable: no more messy reprocessing, which is a process that generates highly radioactive waste that must then be vitrified before disposal. No more radioactivity discharged into the atmosphere or into the sea. However, spent nuclear fuel still has about 97 per cent of its uranium unused. It also has quantities of plutonium formed within the fuel by irradiation in the reactor which can also be used as nuclear fuel. It seems illogical to throw away perfectly good fuel.

This feature of nuclear power — that in theory you can create a closed fuel cycle by taking uranium fuel, generating power, recycling most of the fuel resulting in extra fuel to generate more power — is a sustainability nirvana. With the addition of fast breeder reactors, fuel could potentially last hundreds of years. Some countries are pursuing such a programme: including India, Japan and Russia (the UK abandoned its programme in the 1990s). Not only do you go someway towards achieving environmental sustainability, but also energy security — a political holy grail— into the bargain.

THE QUESTION OF WASTE

The Achilles' heel of nuclear power and reprocessing, however, is the solid radioactive wastes. These wastes are small in volume compared to conventional wastes — the UK produces about 15,000 m^3 of radioactive waste from nuclear activities every year compared to 80,000,000 m^3 of domestic and industrial waste, of which 5,000,000 m^3

is hazardous waste — but require specialist disposal. Radioactive wastes from the nuclear industry fall into three categories:

- **low-level wastes**, most of which are disposed of at a national repository in Cumbria;
- **intermediate-level wastes**, which are currently stored at the sites that created them as the UK does not have a disposal route for these wastes; and
- **high-level wastes**, which are only generated from reprocessing activities and have to be vitrified converted into a glass-like substance and kept cool in storage at Sellafield.

Since the 1980s, the UK has made several failed attempts to find a disposal site for its intermediate- and high-level wastes. The preferred solution is to bury these deep underground in a 'geological repository'. Most recently, a lengthy process of community volunteerism to identify a geological repository led to just a single site in Cumbria being nominated. The process failed when the three local communities involved could not agree to move forward with the plan. With no disposal route for these wastes, which would also include used fuel from the next generation of nuclear power stations, the nuclear industry remains in an unsustainable position.

A REPUTATION RESTORED?

There is no doubt that nuclear power is going through a rejuvenation across the world. Many nations are investing in this technology for the first time, whilst others are re-examining its viability and environmental and social impacts. The combination of fuel security and potential for CO_2 reductions is highly attractive to many nations. But serious questions remain over emissions of radioactivity into the environment, whilst falling due to improved technologies and better operations, are still controversial. Waste disposal is still difficult, even for low-level wastes. For an environmental scientist, the potential environmental benefits from reprocessing are balanced by the hazards of high-level waste disposal.

The jury is still out whether nuclear power is an environmental panacea, or a poisoned chalice. **ES**

The opinions expressed in this article are those of the author and do not reflect the policies or views of the Environment Agency.

Stuart Parr is an environmental scientist who has worked in the nuclear industry for 15 years. He currently works as a specialist Nuclear Regulator for the Environment Agency.

SOURCES

1. MacKerron, G. (2012) *Evaluation of Nuclear Decommissioning and Waste Management*. Science and Technology Policy Research, University of Sussex.
2. Although sometimes attributed to Walter Marshall, a pioneer of nuclear power in the United Kingdom, the phrase was coined by Lewis Strauss, then Chairman of the United States Atomic Energy Commission, in a 1954 speech to the National Association of Science Writers. Strauss was actually talking about fusion power rather than fission power but his comments were indirect at the time, as the US fusion power programme was classified. From Richard Pfau (1984) *No Sacrifice Too Great: The Life of Lewis L. Strauss*. University Press of Virginia, Charlottesville, Virginia, USA.
3. Speech by James Lovelock to the International Conference in Paris, 21–22 March 2005.
4. Nuclear Industry Association (2008) Nuclear Energy in the Environment. www.niauk.org ()Accessed: January 2014).
5. More information about the RIFE report and copies of it can be found at various locations on the internet, including www.environment-agency.gov.uk/business/sectors/110281.aspx.

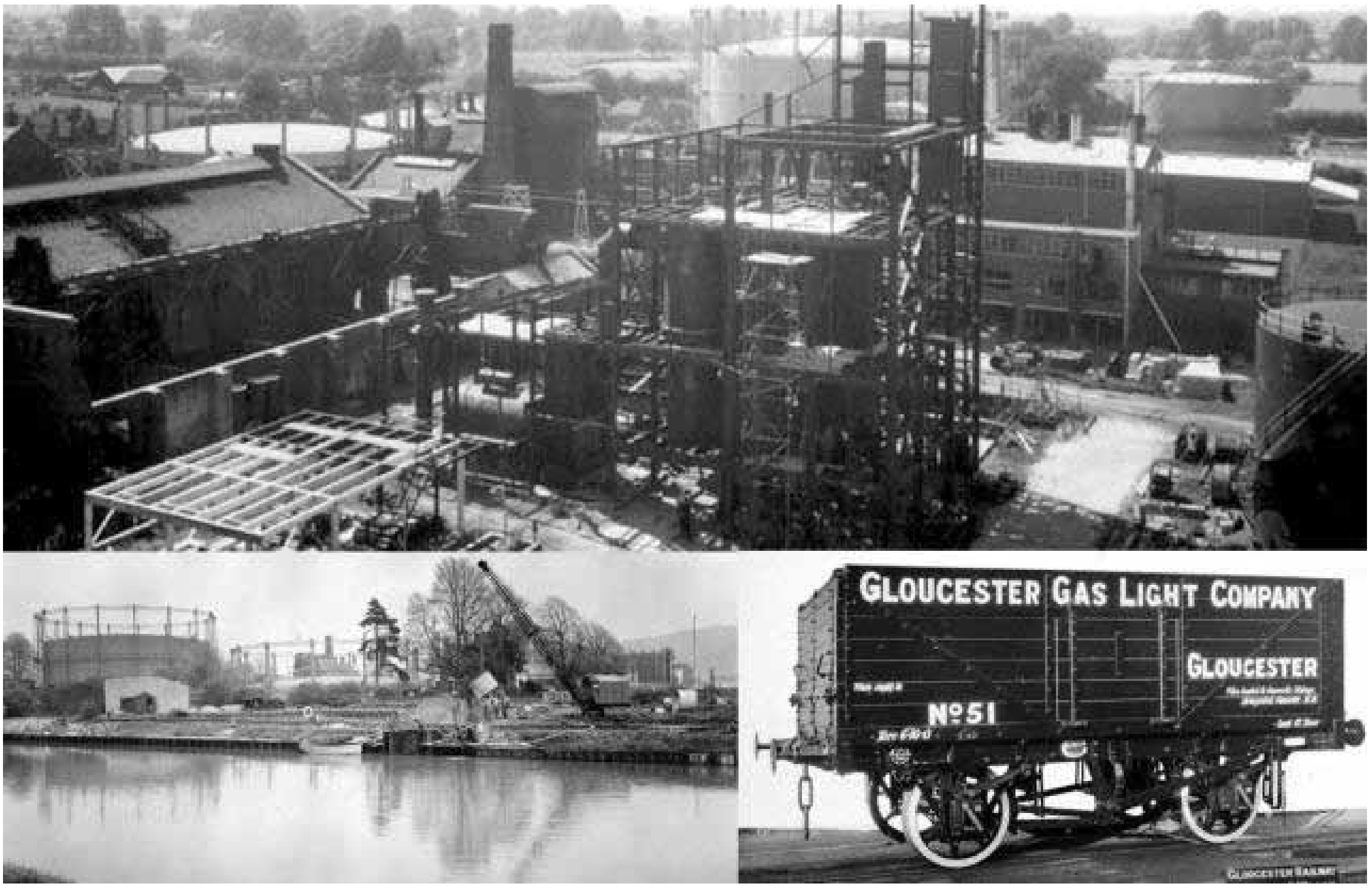
The impact on land of the shifting energy mix

Rachel Tullis of National Grid Property describes the changes brought about by shifts in gas use and the increasing demand for electricity.

The UK energy landscape is ever changing. As the country moves towards a more diverse energy mix that includes renewables, nuclear, clean coal and imported gas, we are witnessing changes to the physical landscape. Not only are we seeing the development of new energy generation and associated infrastructure, but also the decommissioning of the old. In parallel, new mechanisms have been established to allow the continued delivery of traditional sources of energy.

In August 2013 it was reported that UK gas imports hit a record high in the first six months of the year[1]. This increase was partly due to a reduction in North Sea gas production but also to increased demand. Are we witnessing the beginning of a significant shift in where our gas supplies come from? If we are, it is not the first time.

Since the 1970s we have used natural gas, much of it from the North Sea. However, for well over 100 years before that, it was town gas that was at the heart of our energy mix and this was produced from a network of local gasworks located in our towns and cities (see **Figure 1**). The land associated with these gasworks



▲ **Figure 1. Gloucester Gasworks and coal cart (Source: National Gas Archive)** is today represents an opportunity for regeneration. National Grid Property inherited a large number of former gasworks sites and is working to bring many of them back into beneficial use.

THE HISTORY

Town gas, produced from coal, was first used to light streets and factories in the early 1800s. In 1935 there were nearly 1,400 gasworks in the UK.

At the point that the gas industry was nationalised in 1949, the number of gasworks had reduced to 1,050 and this continued to decline into the 1950s[2].

▲ **Figure 2. Remediation excavation on the site of a former gasworks (© The Erith Group)**

THE TRANSITION TO NEW ENERGY

The 1960s saw the development of the National Transmission System (NTS), which allowed for the transport of gas throughout the UK.

Elements of town gasworks were converted to accommodate gas from the NTS and remained operational with associated pipework. For example, many gasholders continued to be used for storage and these have remained a feature in the skylines of UK towns and cities. The remainder of gasworks structures, such as the retort house and purifiers, were demolished to the environmental standards of the time which are not as stringent as today. Contaminated material and rubble was often buried in existing below-ground structures, such as tanks, and/or spread across the wider site. This left a legacy of contaminated brownfield sites across the UK, many of which have remained derelict since.

THE REGENERATION OF LAND

Upon privatisation of the gas industry in 1986, British Gas Plc inherited many old gasworks sites. Subsequently, British Gas Property was born and surplus sites were transferred into its ownership for management, remediation and disposal (see **Figure 2**). There have been numerous mergers and demergers in the gas and electricity industry since, but the property company has remained a constant entity throughout, apart from various name changes.

Currently National Grid Property has a diverse portfolio of approximately 450 former gasworks sites. Since 2003 we have completed approximately 500 remediation projects and currently have a programme, which can be measured in hundreds of millions of pounds, to provide former brownfield land with a brighter future. As we have a large number of sites in our portfolio we run a prioritisation process to bring sites forward for remediation. This is based on evaluation of the number, nature and severity of potential pollutant linkages on a site. We do this based on incoming information from work stages such as desk-based studies and site investigations, re-evaluating throughout the year as new information comes in.

Often remediation can be constrained by operational plant, such as gas mains and gasholders on site. Recent developments allow gas to be stored at high pressure in the pipe network, meaning that gasholders are now surplus to requirements, so many across the country will be demolished in the coming years. We have teams working with National Grid Gas and other distribution networks to unlock other operational constraints to bring sites across the country forward for remediation and ultimately back into beneficial use. By way of example, National Grid owns 400 acres of land in Greater London,

1990		1997		2000		2002		2005
British Gas Property	▶	British Gas Property	▶	Lattice Property	▶	Secondsite Property	▶	National Grid Property

▲ **There have numerous mergers and demergers in the gas and electricity industry but the National Grid Property company has remained a constant entity thoughout, apart from various name changes.**

▲ **Figure 3. Aerial photograph of Battersea. (©Matt Livey)**

with the potential to deliver 12,500 homes in the next 10–15 years, which is a fantastic opportunity for us and London's communities.

THE REGENERATION OF BATTERSEA

The land in Battersea is a great example of such an opportunity. The site on Prince of Wales Drive is five acres in size and contains four gasholders that have reached the end of their operational lives (see **Figure 3**). Preparatory works for their demolition has begun. Once cleared, the site will go on to deliver hundreds of new homes, making a significant contribution to the transformation of Nine Elms on the South Bank as well as creating a vital link between the regeneration area and the existing community (**Figure 4**).

CONNECTING OUR HISTORY TO OUR FUTURE

As we deliver our gasholder demolition and remediation programme across a number of sites, we have a substantial need for suitable fill material. This is needed for the backfilling of remediation excavations and the infilling of in-ground gasholder bases following demolition. Within Greater London we have realised a fantastic opportunity to sustainably source this much-needed fill material from the London Power Tunnels project.

In 2011, National Grid Construction started work on the London Power Tunnels project. This requires creating

▲ **Figure 4. Conceptual design for housing at Battersea. (© MAKE)** tunnels, at a depth of approximately 30 m, to house 400,000 kV cables that will provide safe and secure electricity transmission for Greater London without the need for mass disruption to the road network. The cable tunnels will provide connections between vertical shafts at electricity substations (**Figure 5**).

The total length of tunnelling is in the order of 32 km, and construction is expected to produce approximately 400,000 m^3 of excavated material. Due to tight space restrictions at the excavation shaft heads, there is very little opportunity to store or re-use this material within the project, so the majority of it requires immediate removal from the site. A key objective is to divert at least 90 per cent of this excavated material from landfill. National Grid has recognised the potential sustainability benefits of diverting excavated London Clay and other materials from the tunnelling projects to former gasworks sites that have gasholder bases and remediation excavations requiring backfilling. Approximately one-third of the tunnel arisings will be reused at a number of National Grid Property sites around the London area. This will save 78,000–167,000 haulage miles that would otherwise be used for the disposal and import of materials, which is estimated to equate to savings of 175,000–350,000 kg of CO_2 (estimated figures – contingent on volume of clay and location of sites). So far tunnel arisings have been re-used as backfill on four projects, with another three sites under active consideration.

SUMMARY

National Grid is managing the legacy left by the decommissioning of town gasworks, following the shift to North Sea gas, at a time when environmental matters were not as well understood as they are today. Whilst this represents a significant challenge for us, it is also a huge opportunity to bring brownfield land back to beneficial use across the country.
The London Power Tunnels project has afforded us the opportunity to tackle this legacy more sustainably in the Greater London area and will continue to support our efforts to give former gasworks sites a brighter future over the coming years. **ES**

Rachel Tullis Rachel is Assistant Land Regeneration Manager in National Grid Property. She joined National Grid's Graduate Development Programme in 2011 after completing an MSc[1] Global Water Sustainability at the University of Glasgow and University of Strathclyde.

Rachel currently manages a programme of investigation and regeneration on the National Grid Electricity Transmission portfolio which won Best Scoping or Operation of a Site Investigation at the 2013 Brownfield Briefing Awards.

▲ **Figure 5. London Power Tunnels shaft. (Source: National Grid)**

For more information about the London Power Tunnels project please visit: www.londonpowertunnels.co.uk.

For more information about the demolition of the Battersea Gasholders please visit: www.batterseagasholders.com.

SOURCES

1. Gosden, E. (2013) UK gas imports hit record high of 1 trillion cubic feet in first six months of 2013. *The Telegraph*, 29 August 2013.
2. Gas works, coke works and other coal carbonisation plants, Industry profile, 1995.

CASE STUDY

The impact of windfarms on birds

Nicola Lowndes explores the effects of wind energy generation on avian biodiversity.

Biodiversity has been defined as "The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"[1]. Biodiversity provides ecosystem services including: food, fuel, shelter, clothing, medicine, soil fertilization, water and air purification and carbon offsetting. Furthermore, losses in biodiversity can lead to a loss in genetic diversity, thus reducing the ability of a species to cope with environmental stresses, including climate change[2]. Conserving biodiversity is important not only because of its intrinsic value, but also because of its socio-economic value.

Currently, climate change is considered to pose a serious threat to both people and global biodiversity. The United Nations Framework Convention on Climate Change (UNFCCC) has defined climate change as "climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"[3]. Climate change is exacerbated particularly by the burning of fossil fuels, and currently 80 per cent of global energy demands are met by fossil fuel combustion. With the global demand for energy rising, with increasing human populations and associated growth in development, it is necessary to decrease dependence on fossil fuels and utilise other less damaging forms of energy production[4].

The consequences of climate change will be widespread and will have implications not just for the environment, but also for economic development, availability of resources, population growth and poverty[5]. In order to reduce the risks and impacts of climate change it is globally recognised that greenhouse gas (GHG) emissions must be cut. In light of this, over 100 countries have come to the agreement that global temperature increases must be limited to below 2 °C for mitigation efforts to be successful[6].

Renewable energies are recognised as one of the most important solutions posed to combat climate change, with 14 per cent of current world-wide energy demands being met by renewable energy sources including wind, solar, tidal, geothermal and hydroelectric[7]. That being said, even renewable energy sources have been shown to have potentially negative consequences for environmental conservation and ecosystem biodiversity.

This article will focus specifically on the impacts of windfarms on avian biodiversity, because wind power is more advanced than many other renewable energy sources. Unlike fossil fuels, wind power generates energy without producing the emissions responsible for climate change, including CO_2, NO_X or SO_2[8]. Wind power developments can refer to individual wind turbines, offshore windfarms (OWFs) or onshore windfarms. OWFs are considered the most effective as they are able to produce more energy per unit than their onshore equivalents. This is due to the capacity for larger farms offshore and the steadier, stronger airflows above the sea surface[9].

POLITICAL OBLIGATIONS

As a member of the United Nations (UN) and the European Union (EU), the UK is subject to a number of legally binding obligations and directives aimed at reducing global emissions. The UK is therefore legally bound to adhere to directives including the 2009 EU Renewable Energy Directive. This requires all member states to produce 20 per cent of their energy requirements using renewable energy resources by 2020; it has been estimated that wind power could contribute one-third of this production[7,10]. In addition to these internationally binding policies, in 2008 the UK passed the first long-term legally binding legislation aimed at combating climate change. The Climate Change Act requires a reduction in GHG emissions of 80 per cent below 1990 levels by 2050[11]. Wind power, particular OWFs, are seen as a key part in achieving these targets, with wind power representing the largest contributor to renewable energy in the UK[12].

Taking into account these political obligations, it is key that there is a solid understanding of the impacts of windfarms on biodiversity. Although windfarms have been shown to have detrimental effects on bats and marine mammals, this article will focus on birds, the group considered to be at biggest risk of biodiversity losses related to windfarms. This is in part because many OWFs are erected in shallow waters, where a number of coastal bird species are found, and because the main adverse impacts of windfarms on birds are considered to be direct collision risk, disturbance, disturbance to prey species, and habitat loss[13].

DIRECT COLLISION RISK AND DISTURBANCE

One of the principal arguments against windfarms is the impact they have on bird populations as a result of direct collision with the turbines. Different bird species have differing levels of susceptibility to collision risk: for example, species that fly at a similar altitude to the turbines or species such as birds of prey that forage with their heads down are at higher risk of collision. This was highlighted in November 2013 when charges were brought against Duke Energy Renewables as a result of the deaths of 14 golden eagles (*Aquila chrysaetos*) in the previous three years at windfarm sites in Wyoming, USA. The charges were brought under the Migratory Bird Treaty Act and resulted in the company paying fines of US$1 million. These heavy fines have encouraged the energy firm to prevent this happening again by installing radar technology aimed at detecting eagles in flight and curbing turbines at times of high eagle flight activity[14]. This is undoubtedly a positive step in helping to protect species of concern from the threat of collision.

It is the position of many NGOs that unavoidable, local disturbance of wildlife caused by windfarms is negligible compared with the ecological consequences of climate change[17].

Although direct collision does cause deaths for some species, some have been shown to avoid the turbines[15]. A study by Larsen & Guillemette[16] showed that common eiders (*Somateria mollissima*) avoided flying close to turbines in Denmark. This is positive in terms of collision risk but it could be damaging in terms of disturbance. Avoiding areas with turbines could potentially lead to losses in feeding habitat or further energetic costs leading to higher mortality rates. As a result of these risks, BirdLife International recommends that migratory routes, species and areas of concern are taken into account prior to the development of all windfarms. It also recommends that rigorous monitoring occurs prior to, during and after any installations. Despite these concerns BirdLife still recognises and supports windfarms in their capacity as a sustainable energy source to combat the impacts of climate change[13]. Furthermore, it is the position of many non-governmental organisations (NGOs) that unavoidable, local disturbance of wildlife caused by windfarms is negligible compared with the ecological consequences of climate change[17].

INDIRECT IMPACTS ON PREY SPECIES

There is also evidence of indirect effects on prey species: OWF construction has been proven to cause disruption to birds, marine mammals and fish. The transmission of electricity through cables generates electric and magnetic fields, which have been shown to impact on the orientation and navigation of marine mammals and some fish (i.e. European eels, *Anguilla anguilla*)[18].

Noise pollution from monopile installations is of growing concern. Evidence suggests that at close range noise can cause injury or fatality in some fish species, whilst some species can detect noise at long distances, impacting on intra-specific communications[19]. Perrow *et al*[20] showed that noisy monopile installations significantly reduced herring abundance at Scroby Sands in Norfolk, because herring are hearing specialists and as such are very susceptible to the noise made during construction. This decline corresponded with a decline in the reproductive success of a high conservation priority species, the little tern (*Sternula albifrons*). Construction has also been shown to cause temporary loss in habitat, increased sedimentation in the immediate area, and in some cases the release of potentially harmful substances from the sediments[9].

POSITIVE ASSOCIATIONS

Although the environmentally negative impacts of windfarms are well documented, there are also positive associations. Windfarms act as hard substratum in coastal waters, which are often lacking in other structure. They provide variable surfaces and habitats for the colonisation and growth of benthic organisms, which will in turn attract fish and predatory species[9]. The new habitat created has been shown to increase local species diversity, with stable communities being established a minimum of five years after installation[21]. New habitats and associated communities will have impacts on species interactions and the coastal ecosystem as a whole, and whether these impacts are positive or negative is dependent on the individual farm system[9].

Additionally, wind power does not carry the same risks environmentally as those posed by nuclear and fossil fuel pollution. These include not just the long-term consequences associated with climate change, but also isolated pollution incidents such as the major *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010; this had devastating consequences for the marine and coastal wildlife, as well as the fisheries and tourist industries[22].

CASE STUDY: BLAKENEY POINT

Blakeney Point, located on the North Norfolk coast, is designated as a wetland of international importance under the Ramsar convention, a Special Protection Area (SPA) under the European Community (EC) Birds Directive (Council Directive 79/409/EEC) and a Special Area of Conservation (SAC) under the EC Habitats Directive (Council Directive 92/43/EEC)[23]. Blakeney is afforded these designations in part because it supports large numbers of important breeding birds including little terns, common terns (*Sterna hirundo*) and sandwich terns (*Sterna sandvicensis*); wintering wildfowl, particularly pink-footed geese (*Anser brachyrhynchus*); and wading birds, including ringed

plovers (*Charadrius hiaticula*), sanderlings (*Calidris alba*) and bar-tailed godwits (*Limosa lapponica*)[24].

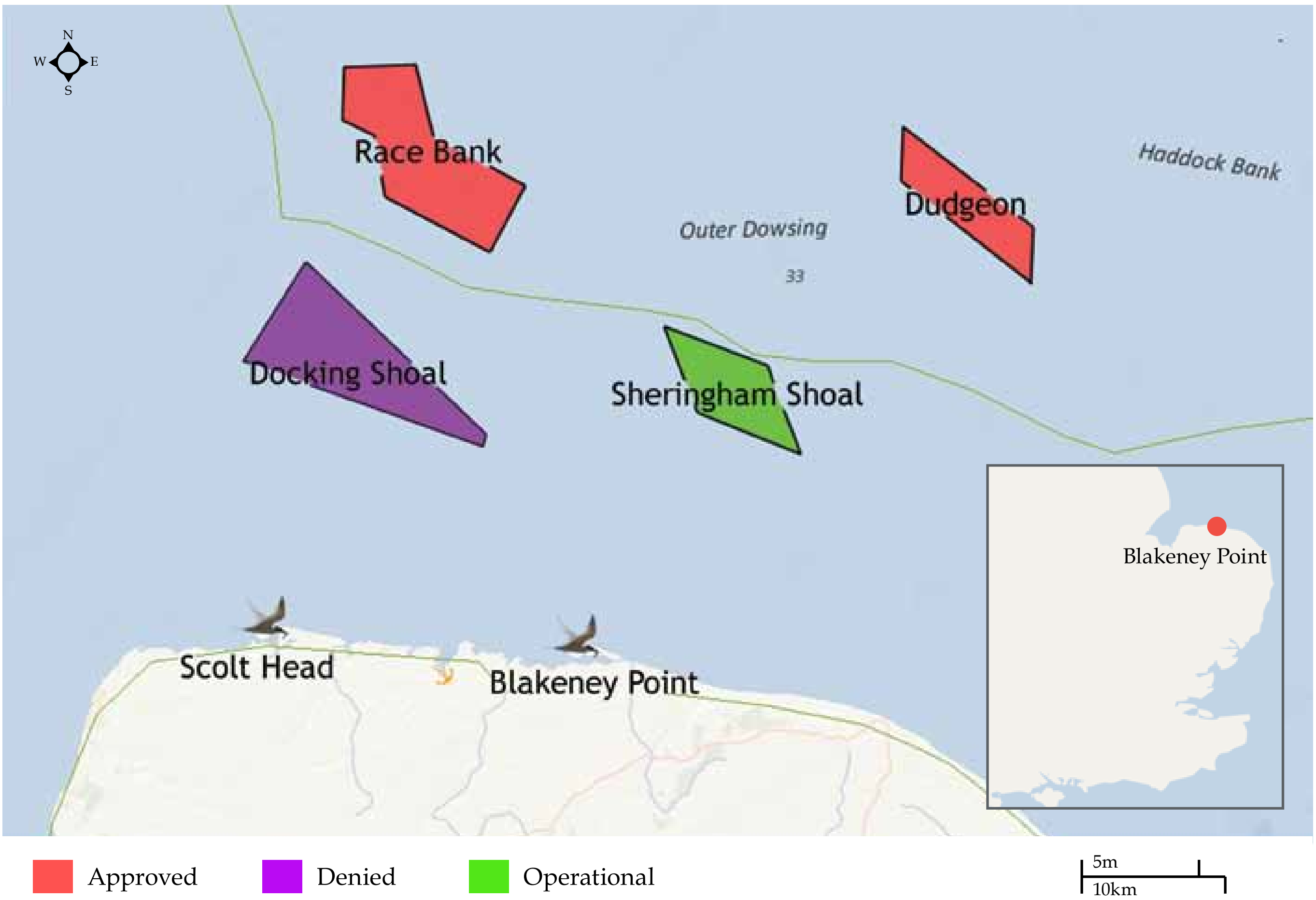
Despite these designations, a recent threat posed to the Blakeney tern colonies (and other avifauna) is that of the construction of a number of windfarms off the coast. Of particular concern is the sandwich tern colony which is considered the most important UK site for this species, in 2011 it boasted 3,572 pairs – approximately 30 per cent of the total UK population[25]. According to a study by Garthe and Hüppop[26], sandwich terns are considered to be highly sensitive to the adverse effects of windfarms when taking into account such factors as flexibility in habitat use, percentage of time flying, flight manoeuvrability and conservation status.

Currently there is one windfarm off the coast of Blakeney, Sheringham Shoal, which became fully operational in 2012[27]. Three further windfarms have been proposed off the North Norfolk coast (see **Figure 1**); of these Race Bank and Dudgeon were approved in July 2012, whilst Docking Shoal was denied by the Government because of its potential impact on sandwich terns[28]. This development was denied partially because the Department of Energy and Climate Change (DECC) felt that its impact would be too great if built along with the other two projects[29]. Docking Shoal was considered to have a larger impact compared to the other sites because of being closer to both Scolt Head and Blakeney Point. Tracking data showed that Docking Shoal was well within the foraging range (average 42.3 km) of sandwich terns, with high collision risk and significant declines in populations being predicted[30,31] (see **Figure 1**).

The refusal of Docking Shoal windfarm was undeniably a positive step for the seabirds of Blakeney Point. However, as Sheringham Shoal windfarm has only been operational for a year, its full impacts on the tern colonies have yet to be established, let alone the impacts of a further two developments. As such the continued monitoring of the birds at these sites is paramount if biodiversity losses are to be prevented.

SUMMARY

Wind energy is a fast-growing renewable energy source that is vital for combating the deleterious impacts of climate change. It is widely accepted that windfarms do cause disturbance and losses in biodiversity to both birds and their prey species. It is, however, also accepted that local impacts of windfarms on biodiversity will be negligible compared with the



▲ **Figure 1. The position of Blakeney Point and Scolt Head Island terneries on the North Norfolk coast, showing the relative positions of Sheringham Shoal, Docking Shoal, Dudgeon and Race Bank windfarms, indicating their current development stage. (Created from data taken from the Global Offshore Windfarms Database[32]).**

ecological consequences of climate change. That being said, it is fundamentally important to find a balance between the potential risks and benefits of windfarms to biodiversity.

Unfortunately, despite recommendations from BirdLife that rigorous monitoring of windfarms sites is undertaken, this is not always the case. With the global demands for energy rising and with strong political obligations aimed at increasing the use of renewable energies, it is more important than ever that avian biodiversity issues remain in focus and not overlooked in a bid to meet these growing demands and obligations. **ES**

Nicola Lowndes gained a First-Class Honours degree in Zoology, followed by an MSc in Conservation from UCL in 2013. She has carried out independent research projects focusing on avian conservation issues at sites of international importance, including Blakeney Point.

REFERENCES

1. UNEP (1992) *Convention on Biological Diversity*: Article 2. UNEP, Rio de Janeiro, 3.
2. Reaka-Kudla, M.L., Wilson, D.E., and Wilson, E.O. (1999) *Biodiversity*. Joseph Henry Press, Washington, D.C.
3. UNFCCC (1994) *Full text of the Convention*. unfccc.int/essential_background/convention/background/items/1349.php (Accessed: 10 November 2013).
4. Asif, M., and Muneer, T. (2007) Energy supply, its demand and security issues for developed and emerging economies. *Renewable and Sustainable Energy Reviews*, 11 (7), pp1388–1413.
5. UNFCCC (2012) *Background on the UNFCCC: The international response to climate change*. unfccc.int/essential_background/items/6031.php (Accessed: 10 November 2013).
6. Meinshausen, M., Meinhausen, N., Hare, W., Raper, S.C., Frieler, K., Knutti, R., Frame, D.J., and Allen, M.R. (2009) Greenhouse-gas emission targets for limiting global warming to 2°C, *Nature Letters*, 458, pp1158–1162.
7. Pryor, S.C., and Barthelmie, R.J. (2010) Climate change impacts on wind energy: A review, *Renewable and Sustainable Energy Reviews*, 14, pp430–437.
8. Denny, E., and O'Malley, M. (2006) Wind generation, power system operation, and emissions reduction, *IEEE Transactions on Power Systems*, 21 (1), pp341–347
9. Petersen, J.K., and Malm, T. (2006) Offshore windmill farms: threats to or possibilities for the marine environment, Journal of the Human Environment, 35 (2), pp75–80
10. The European Parliament (2009) Directive 2009/28/EC of the European Parliament and of the Council, Luxembourg: Official Journal of the European Union.
11. DECC (2012) *The Climate change Act*. www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx (Accessed: 11 November 2013).
12. DECC (2011) *Digest of United Kingdom Energy Statistics* The Stationery Office, London.
13. BirdLife (2005) *Position Statement on wind farms and birds*. BirdLife International, Cambridge.
14. BBC (2013) US firm Duke Energy pays out over wind farm eagle deaths. www.bbc.co.uk/news/world-us-canada-25058346 (Accessed: 23 November 2013).
15. Langston, R.H.W., and Pullan, J.D. (2003) Windfarms and birds: an analysis of the effects of wind farms on birds, and guidance on environmental assessment criteria. Report T-PVS/Inf (2003) 12, by BirdLife International to the Council of Europe, *Bern Convention on the Conservation of European Wildlife and Natural Habitats*.
16. Larsen, J.K., and Guillemette, M. (2007) Effects of wind turbines on flight behaviour of wintering common eiders: implications for habitat use and collision risk, *Journal of Applied Ecology*, 44 (3), pp516–522.
17. Szarka, J. (2004) Wind power, discourse coalitions and climate change: Breaking the stalemate?, *European Environment*, 14, pp317–330.
18. Tesch, F., Wendt, T., and Karlsson, L. (1992) Influence of geomagnetism on the activity of eel, *Anguilla anguilla*, as evident from laboratory experiment, *Ecology of Freshwater Fish*, 1, pp52–60.
19. Inger, R., Attrill, M.J., Bearhop, S., Broderick, A.C., Grecian, W.J., Hodgson, D.J., Mills, C., Sheehan, E., Votier, S.C., Witt, M.J., and Godley, B.J. (2009) Marine renewable energy: potential benefits to biodiversity? An urgent call for research, *Journal of Applied Ecology*, 46, pp1145–1153.
20. Perrow, M.R., Gilroy, J.J., Skeate, E.R., and Tomlinson, M.L. (2011) Effects of the construction of Scroby Sands offshore wind farm on the prey base of little tern (Sternula albifrons) at its most important UK colony, *Marine Pollution Bulletin*, 62, pp1661–1670.
21. Watson, D.I., and Barnes, D.K.A. (2004) Temporal and spatial components of variability in benthic recruitment, a 5 year temperate example, *Marine Biology*, 145, pp201–214.
22. Corn, L., and Copeland, C. (2010) *The* Deepwater Horizon *oil spill: Coastal wetland and wildlife impacts and response*. Congressional Research Service, Washington.
23. Allison, H., and Morley, J. (1989) *Blakeney Point and Scolt Head Island*. The Gallpen Press, Norwich.
24. JNCC (2008) Information sheet on Ramsar wetlands (RIS): North Norfolk Coast. jncc.defra.gov.uk/pdf/RIS/UK11048.pdf.
25. Stubbings, E. (2012) The birds of Blakeney Point: 100 years of National Trust ownership, *British Birds* 105 (9), pp520–529.
26. Garthe, S., and Hüppop, O. (2004) Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index, *Applied Ecology* 41, pp724–734.
27. Scira Offshore Energy (2012) Construction Progress. www.scira.co.uk/construction/construction.php (Accessed: 27 August 2013).
28. BBC (2012) Wind farms off East coast approved by government. www.bbc.co.uk/news/uk-england-norfolk-18735802 (Accessed: 18 July 2012).
29. Danko, P. (2012) Sandwich Tern Sinks Big UK Offshore Wind farm. www.earthtechling.com/2012/07/sandwich-tern-sinks-big-uk-offshore-wind-farm (Accessed: 3 August 2012).
30. BirdLife (2012) Species factsheet: *Sterna sandvicensis*. birdlife.org/datazone/speciesfactsheet.php?id=3265 (Accessed: 28 July 2012).
31. Centrica (2009) Population Viability Analysis of the North Norfolk sandwich tern (Sterna sandvicensis) population. www.centrica.com/f iles/pdf/centrica_en ergy/pva_study.pdf.
32. Global Offshore Wind Farms Database (2012) North Norfolk Coast. www.4coffshore.com/offshorewind/ (Accessed: 21 August 2012).

IES: New members and re-grades

Members	Occupation
Christopher Bassett	Services Engineering Manager
Dorota Bastrikin	Environmental Consultant
Vanessa Bell	Environmental Consultant
Karen Boothby	Geo-Environmental Engineer
Samuel Brough	Operation Manager Scotland
Jennifer Colfer	Environmental Impact Assessment and Land Rights Advisor
Philip Hathaway	Product Designer
Robert Jiagge	Project Geoenvironmental Engineer
Sarah Key	Graduate Environmental Geologist
Chetan Lad	Senior Consultant
Patrick Lambe	Senior Project Manager
Hannah Matthews	Senior Lecturer in Environmental Management
Sonja Trewavas	Principle Environmental Consultant
Christopher Murrell	Site Chemist
Matthew Humphreys	Senior Geoenvironmental Consultant
Sarah Naylor	Pollution Control Officer
Robin Bilton	Energy Account Manager
Barry Roberts	Senior Air Quality Consultant
Christina Downend	Energy & Environment Coordinator
Sarah Watkins	E&B Directorate Advisor
Gary Kass	Deputy Chief Scientist
Olusoji Igunnugbemi	Lecturer II
Leon Stanger	Managing Director
Michael Owens	Principal Consultant
Madison Wing Tang	Project Director
Andrew Collins	Contracter
Maria Luiza Dumitrescu	Environmental Scientist
Stuart Rawlinson	Principal Environmental Consultant & Partner
Hannah Threadgould	Technical Officer Groundwater & Contaminated Land
Sandra Taylor	Education Officer
Ho Yan Cheng	Resident Field Officer
Sandra Taylor	Education Officer
Joanna Wilding	Environmental Public Health Scientist
Paul Latta	Consultant
Graeme Cowling	Senior Environmental Consultant
Charlotte Hawkins	Geo-Envrionmental Scientist

Associates	Occupation
Adam Luke	Graduate
Bright Danso	EMS Adminstrator
Lauren Hall	Environmental Scientist
David Helliwell	Graduate Air Quality Consultant
Bianca Hoad	Graduate
Chantelle Jarvis	Part time Student/Youth Worker
Sophie Lewis	Graduate
Ross Mew	Graduate Air Quality
Adele Miller	Graduate
Martin Mills	Graduate
Laura Moreno Morales	Environmental Scientist
Charlotte Murray	Assistant Geoenvironmental Engineer
Thomas Porter	Graduate
Oliver Rowe	Air Quality Consultant
Jake Stephen	Graduate
Robert Benney	Graduate Environmental Scientist
Grieg Davies	Environmental Scientist
Daniel Struggles	Graduate Consultant
Michel Vedrenne	Research Associate
Timothy Doheny-Adams	Microbiology Laboratory Manager
Daniel Bowden	Environmental Assurance Advisor
Samuel Paine	Graduate
Dare Toba	Environmental Health Principle Officer
Jennifer Roberts	Warm Homes Officer
Paul Allan	Environmental Project Officer
Grant Harrington	Environmental Geotechnical Consultant
Emily Hamlet	Graduate Environmental Scientist
Daniel Millan	Consultant
Harriet Tenner	Graduate
Rebecca Hodnett	Environmental and Waste Management Consultant
Kelly Nash	Graduate
Amy Colliar	Graduate
Mitchell Bown	Graduate
Nicholas Mills	Graduate
Obianuju Nwokolo	Environmental Field Scientist
James Brookes	Graduate Environmental Scientist - Air Quality & Carbon
David Gilfedder	Staff Scientist
Georgina Smith	Graduate

Affiliates	Occupation
Stephen Mills	Company Director
Neil McIntosh	Transport Planner
Alan Shenton	Systems Engineer
Richard Noble	Student/Support Worker

Fellow	Occupation
Stephen Mills	Company Director
Neil McIntosh	Transport Planner
Alan Shenton	Systems Engineer
Richard Noble	Student/Support Worker

Fellow is for esteemed individuals in environmental science and sustainability who are held in high regard by their peers

Member is for those individuals who have substantial academic and work experience within environmental science.

Associate is for individuals beginning their environmental career or those working on the periphery of environmental science.

Affiliate is for individuals with an interest in environmental issues but don't work in the field, or for students on non-accredited programs.

Tidal energy at Strangford Lough: a wave of potential

Joseph Martin describes the innovative technology designed to capture marine energy.

"Weighing 1000 tonnes, with a width of 43 metres from tip to tip and resembling an underwater upturned windmill its makers claim it represents a clean green alternative to climate-destroying fossil fuels. As SeaGen – the world's first and largest commercial scale tidal stream energy generator – was laid down in Strangford Lough, Northern Ireland, yesterday, the company behind it claimed this form of tidal power has the potential to supply up to 10% of the UK's energy within a decade."[1]

Five years on, the device has continued to lead the way in tidal current technology, having generated 7–8 GWh of electricity since it went into operation. Recent studies by the developer, Marine Current Technologies (MCT), have concluded that the project has had no significant environmental impact and similar installations are now planned for a number of other sites across the UK.

MARINE ENERGY – A VAST RESOURCE

Marine energy has a huge potential, but it is only now that technologies are being developed that can take advantage of this resource. The technologies include tidal stream and tidal barrage technologies that capture the energy of the daily tides, and wave technologies that capture the energy in waves. The sea is a challenging environment to work in, due to its changeability and the corrosive effects of seawater. Another of the main determining factors in wave and tidal stream development is location and climate. The UK tidal stream resource represents approximately half of the European resource and 10–15 per cent of the global resource[2].

Designed by engineer Peter Franklin, the SeaGen S was built and assembled at Belfast's Harland and Wolff shipyard – the birthplace of RMS Titanic – and therefore was in good company as the world's first tidal stream energy generator.

SeaGen S works by having two rotating blades that turn at 14 revolutions per minute in normal operation, driven by the tides going in and out. The blades are sited in the top third of the water, where the currents are at their

▲ **The SeaGen S being assembled at the Harland and Wolff shipyard in December 2007. (Source: Maritime Journal. © Mercator Media 2014)[9]** strongest, thus maximising energy capture. The rotors drive a generator that sends electricity along a cable that then links into the National Grid across the Lough in Strangford village[1]. A key innovation of the SeaGen S is that it can be raised out of the water for adjustments and repairs when required. This undoubtedly helps to reduce maintenance costs and set it apart from other rival underwater turbine technology.

THE ENVIRONMENT AT STRANGFORD LOUGH

Strangford Lough is recognised worldwide for its remarkable wildlife and landscape. Its environment is also of immense value to the people who live and work there and who visit the lough for recreation. The lough has been designated as a Special Protection Area and is a candidate for Special Area of Conservation under the Birds and Habitats Directives respectively[3]. The lough is also only one of three Marine Nature Reserves in the UK.

An Environmental Statement (ES) was submitted in 2005 to support the licence application. Once SeaGen S had been installed, MCT implemented a £3 million environmental monitoring programme (EMP), including marine mammal monitoring and bird and benthic ecology surveys. The EMP progressively demonstrated the benign nature of the development, and at the end of the programme in 2012 it was concluded that no major environmental impacts had been detected[4].

Stakeholder engagements have been carried out and consultations have allowed views and opinions of the local community to be aired. The EMP, which ended in 2008 included views from those with a vested local interest. David Erwin, the Chairman of the SeaGen Scientific Group and Stakeholder Liaison Group commented: "This is the most comprehensive study of the environmental impact of marine energy devices undertaken anywhere in the world. Given my long association with the Lough, I was always confident that SeaGen could operate without any significant impact and I'm delighted that the results of five years, painstaking work by some of the world's most-respected experts in their fields have shown this to be the case"[5].

▲ **A computer-generated model of the underwater rotors in operation.**

THE FUTURE OF TIDAL ENERGY IN THE UK

The Strangford Lough scheme looks to be very much a precursor for what is to come across the UK. In March 2013 plans went on display for four SeaGen tidal devices at Kyle Rhea (Isle of Skye, Scotland) [6]. The Welsh Government has also given its approval for the development of the Skerries Tidal Steam Array, which will also be operated by MCT and is expected to supply up to 10,000 homes[7].

More recently, engineers from the University of Edinburgh and Oxford have revealed findings of a report that estimates that the Pentland Firth, between mainland Scotland and Orkney, has enough potential tidal power to generate 1.9 GW of electricity, helping to meet Scotland's 2020 targets for renewable generation[8].

The Strangford Lough project is a scheme that has sparked renewed vigour among scientists and engineers to come up with even more innovative design solutions to meet demand for tidal and wave power throughout

▲ **The tidal turbine at Strangford Lough (Source: Alternative Energy Website / Marine Current Turbines)[10]**

the UK. The challenge for governments and the energy industry is to harness tidal power and at the same time balance the needs and requirements of the local communities and the environment. ES

(A video explaining SeaGen S technology and how it operates is available at: www.youtube.com/watch?v=OIoHgTQ4LlA.

Joseph Martin An environmental scientist within AECOM Belfast, Joseph Martin works primarily on environmental imapact assessments (EIA), air quality calibrations for Belfast AURN (Automatic Urban and Rural Network), ecological bat surveys, GIS Mapping and CEEQUAL sustainability assessments. Joseph also has a background in renewable energy technologies, having worked as an advisor within Action Renewables in Belfast.

REFERENCES

1. McDonald, H. (2008) Tidal power comes to Northern Ireland. *The Guardian*, 31 March. www.theguardian.com/environment/2008/mar/31/tidal.power.
2. Hitchin, P. (2012) Riding a Wave of Potential, *Power Engineering International*. 20 (1). www.powerengineeringint.com/articles/print/volume-20/issue-1/features/riding-a-wave-of-potential.html.
3. Department of the Environment (DOE), *Strangford Lough Management Scheme*, Public Information Booklet (May 2001) www.doeni.gov.uk/niea/strangfordmanagementscheme.pdf. [Accessed 28th January 2014].
4. Sea Generation (2013) *Environmental Aspects*. Sea Generation. [Online]. Available from: www.seageneration.co.uk/environmentalaspects.php. [Accessed 4th January 2014].
5. Marine Current Turbines (2008) SeaGen Tidal Turbine gets all-clear from environmental & scientific studies. www.marineturbines.com/3/news/article/56/seagen_tidal_turbine_gets_all_clear_from_environmental___scientific_studies (Accessed: 28th Jan 2014).
6. Marine Current Turbines (2013a) Kyle Rhea Tidal Array Project: Public Exhibitions. www.marineturbines.com/News/2013/03/12/kyle-rhea-tidal-array-project-public-exhibitions (Accessed: 4 January 2014).
7. Marine Current Turbines (2013b) Skerries Tidal Array secures planning consent from Welsh Government & funding from UK Department of Energy. www.marineturbines.com/News/2013/02/28/skerries-tidal-array-secures-planning-consent-welsh-government-funding-uk-department. (Accessed: 4 January 2014).
8. Amos, I., and Gardner, C. (2014) Pentland Firth tides 'can power half of Scotland'. *The Scotsman*, 20 January. www.scotsman.com/news/environment/pentland-firth-tides-can-power-half-of-scotland-1-3274462. (Accessed: 20 January 2014).
9. *Maritime Journal* (2007) UK Tidal Energy Welcomed in Canada. Maritime Journal.com. www.maritimejournal.com/news101/industrynews/uk_tidal_energy_welcomed_in_canada.
10. Taylor, P. (2007) Alternative Energy Website - SeaGen Tidal Power Installation. Alternative Energy www.alternative-energy-news.info/seagen-tidal-power-installation/ (Accessed: 28th January 2014).

Bring home the revolution

Steven McNab and **Jessica Holt** describe the energy revolution that could bring renewable energy to the people.

Are we on the verge of a new decentralised, community-based and owned energy revolution? Driven by grassroots activism to date, this approach was given formal backing by the Government in its announcement of a Community Energy Strategy on 27 January 2014. This announcement sets out a broad strategy which includes the launch of a £10 million Urban Community Energy Fund and plans for an information resource for community groups. Whilst the announcement has been generally well received, commentators have noted that more detail is needed for the policies to really have an impact. Others wonder if this will even create a dent in the current system.

Decentralised energy is the generation and distribution of energy closer to the locations where it is consumed, 'embedded' in the lower-voltage supply grid network[2]. It takes a number of forms and is often, but not exclusively smaller scale low carbon or renewable by design (**Box 1**).

BOX 1: TECHNOLOGIES

The most common generation technologies used and energy-efficiency interventions seen in community renewables:

- Solar PV – roof top and ground mounted
- Onshore wind
- Biomass
- Run-of-river hydro
- Anaerobic digestion (AD)
- Energy efficiency
- Solar thermal
- District heating
- Heat pumps
- Behavioural change and education programmes
- Bulk buying and mass energy-supplier switch programmes

Two things are clear: (i) renewables are a certain feature of the long-term energy supply mix; and (ii) the landscape of energy generation in the UK is shifting with a greater emphasis on local generators. A wide range of community participation and ownership models have been designed and tested – some highly complex, others far more straightforward and replicable. These have proven to work soundly and confidence levels are high, so the structures are now being applied to multi-megawatt projects. The supporting system is motivated and professional, involving community-based social enterprises (Wey Valley Woodfuel or Repowering) and highly professional charities (Pure Leapfrog or Energy Savings Trust) that support local energy champions and community groups and a range of advisory businesses.

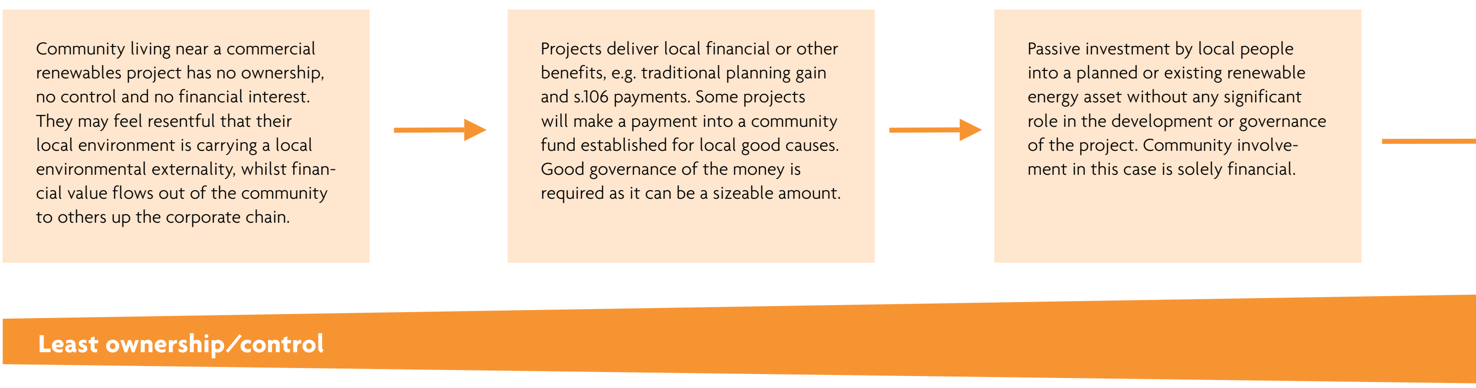
Whilst most renewable energy projects deliver overarching energy and environmental goals, many also deliver a range of valuable social benefits, including local employment, education and training, along with the reduction of fuel poverty. Examples of indirect benefits include some pupils involved in school-based projects reporting adoption of energy efficiency measures in the home, even influencing parental behaviour. The technical benefits are an increase in the efficiency of the supply system and reduced transmission losses (the grid loses eight per cent on average)[1].

In the last decade the amount of community energy produced in the UK has increased by over 1,300 per cent, but is still only around 60 MW – a tiny 0.3 per cent of all energy produced from renewables. In Germany that figure stands at 46 per cent[3]. Recently, the projects in the UK have become far larger and a wider range of financial institutions have become engaged.

THE 'TRADITIONAL' RENEWABLE ENERGY PROJECT MODEL

So far, the development of decentralised renewable energy has been led by utility companies or specialist commercial developers who develop projects and will often sell them on after a period of operation. Other projects have been developed by large energy-using companies seeking to reduce their exposure to energy price rises and fluctuations or in pursuit of environmental objectives (Iggesund, IKEA and Vodaphone, have all deployed large-scale decentralised generation).

The assets are often held by the corporates that developed them, utility companies or low-risk, long-term investors attracted by the relative stability of often index-linked



▲ **Figure 1. The continuum of control in energy participation models.**

Government-subsidised revenues (the subsidy making up a substantial proportion of the overall project revenues).

FINANCIAL SUPPORT

Given the huge support given to the fossil fuel industry and the fact that the external cost of carbon emissions are not effectively internalised, newer renewable technologies have required support to compete in the privatised energy markets. Despite recent party politicisation of the debate, the renewable energy sector operates in an unbalanced market where the subsidies available to it are dwarfed by those provided to the fossil fuel industry. The 2013 IEA World Energy Outlook report stated that the global cost of fossil fuel subsidies expanded to US$ 544 billion in 2012, support provided to the renewable sector totalled only US$ 101 billion[4].

There is a range of subsidies available that now vary significantly by technology type (see **Box 2**). The more established technologies that can more readily compete receive lower levels of subsidy. As economies of scale are realised, the price of deployment reduces and so the subsidy is reduced. The price of deploying solar PV has shown the most dramatic reductions through time, as has onshore wind. The UK is seeing a significant benefit from mass deployment of solar in Germany and other countries, which has significantly driven down the deployment costs for us in the UK. This is in contrast to the cost of deploying nuclear generation, for example, which has increased over the same timeframe in particular due to safety concerns.

PLANNING CHALLENGES

All but the smallest micro-generation projects with permitted development rights are required to secure express planning permission or a Development Consent Order for the largest projects, and sometimes other environmental consents. Some will require an Environmental Impact Assessment. The planning system should ensure that any negative impacts (externalities) are very carefully weighed against the benefits. The specific adverse impacts that can arise vary greatly between technology types. For example, Anaerobic Digestion (AD) may create concerns over traffic and odour, biomass over airborne emissions, and wind over visual impact, flicker, radar impact and impact on birds. Even relatively low impact ground-mounted solar PV has generated debate about the loss of agricultural land and visual impact. Many of these issues can be overcome with technical solutions and careful site selection.

Whilst there is a strong policy presumption in favour of renewable energy developments, as more energy has been developed closer to communities, the reality of the physical and visual impacts have sometimes impacted upon local attitudes. The planning system should shine

BOX 2: GOVERNMENT SUBSIDIES[5]

ROCs – Renewable Obligation Certificates – provide incentives for large-scale renewable electricity generation (over 5 MW) by requiring UK suppliers to source a proportion of their electricity from eligible renewable sources. Energy market reform is phasing out ROCs and replace them with a new form of feed-in tariff (FIT), a 'FIT contract for difference' which should provide a stable level of support for the life of a project.

FIT – Small-Scale Feed-in Tariff – pays energy users who invest in small-scale, low-carbon electricity generation systems for the electricity they generate and use, and for unused electricity they export to the grid. FIT is available for projects up to 5 MW, unless they are community projects in which case the ceiling is 10 MW.

RHI – Renewable Heat Incentive – provides incentives for the production of useable heat from certain renewable energy generation technologies. Can be used with ROCs on certain combined heat and power projects.

LEC – Electricity produced from designated renewable sources is exempt from the Climate Change Levy and is entitled to Levy Exemption Certificates (LECs). For larger projects, other 'embedded benefits' (savings in grid charges from the generation being used locally) can be captured in the power purchase agreements through which the power is usually sold.

Active investment by local people into a planned commercial renewable energy asset where the community plays a role in ensuring that the development meets local needs, supports it through the planning process and acquires an ongoing interest in the asset through some re-investment of funds generated by the asset for community benefit.

Full community ownership, in which the generation asset may be orignated by the community and is owned through a legal entity that is specifically incorporated to promote and maintain local control, such as an Industrial & Provident Society for community benefit. These legal entities include various features to protect community control such as an asset lock and a requirement for all profits surplus to those required to repay investors to be deployed for community benefit.

Despite community ownership such projects are built by fully commercial entities and should be as a robust as fully commercial assets.

Most owernership/control

- **Greater returns**
- **Greatest social impact**
- **Greater risk and resource requirement**

a spotlight on these and ensure that the impacts are mitigated to an acceptable level, or otherwise, that the strategic benefits outweighs those local impacts.

The primary forum for a local community to voice their support or concern is the public consultation stage. Most host communities break into three broad groups.

- **Active supporters** who generally like renewables and will accept a degree of local impact (e.g. because they see climate change, fracking impacts or nuclear legacy issues as a greater evil, are advocates of green power, or who quite like wind turbines as symbolically beckoning in a new age of local energy).
- **Active objectors** who dislike a project on some basis (e.g they do not like big energy companies, do not like change, do not like noise, believe turbines spoil the view, disturb birds and bats, renewables are intermittent and so inefficient and our money is better spent on XY or Z).
- A **silent majority** who do not express views either way (perhaps they live farther away and are not negatively impacted, are determined fatalists, or just live too busy lives and do not care sufficiently either way).

However the local argument develops on a specific scheme, successive opinion polls clearly demonstrate that UK public opinion is very strongly supportive of renewable energy. For example, DECC in 2013 reported that "Three-quarters of people (76%) continue to support the use of renewable energy sources to generate the UK's electricity, fuel and heat, similar to the September 2012 figure of 79%." (DECC, 2013, p4)[6]

Before-and-after' analysis of windfarms has shown that communities that were concerned hosts and objectors convert to be largely supportive of the projects. However, there has been increasingly negative press coverage of NIMBY cases and some analysts observe negative media amplification of these issues, with substantially negatively skewed reporting.

PURE LEAPFROG

So far Pure Leapfrog has provided free professional support to around 70 community energy projects and affordable loans to more than 50, including the following award-winners:

- Student Switch Off (behaviour change and energy efficiency)
- MOZES – Meadows Ozone Energy Services Limited – (PV, community park)
- Bath and West Community Energy: solar, hydro and wind
- Repowering (Brixton Solar Energy)
- Ashton Hayes Going Carbon Neutral (microgrid design, community shop, PV, biofuels)
- Bristol Community Energy Co-Op (wind)
- Wey Valley Solar Schools (LEDs and PV)
- SolarAid (micro solar accross Africa)
- Project Dirt (environment and community projects)

"Community energy groups often require support in overcoming legal barriers, negotiating a dynamic landscape, and lack of access to finance. We resolve them by providing template contracts with a proven track record of success, the channelling of high-end affordable professional support and access to finance on terms that support community groups to deliver their ambitions."
Alex Germanis, Head of Projects at Pure Leapfrog.

'BUY-IN' RATHER THAN 'BOUGHT OUT'

One way to address some of the negative externalities is identify and to compensate for them. This can be

BOX 4: PURE LEAPFROG SUPPORT

Leapfrog's long-term vision is to put community energy at the heart of the UK's future sustainable energy mix. Our immediate goal is to ensure that over 20 per cent of the UK's on-shore renewable energy capacity will be owned by communities by 2020. We work to level the playing field by offering community energy revolutionaries professional support and affordable finance.

We set out to derisk UK and international low-carbon and renewables projects using the skills of our day jobs (as lawyers, engineers, environmental consultants, accountants, PRs etc) to prove, by building a body of case-study exemplars. We have helped around 70 so far.

To date, we have issued close to £1 million of loans, primarily to projects in the bottom 50 per cent of the country economically. These projects will generate a surplus of over £6 million, reducing fuel poverty, cutting energy bills for schools and community centres, and creating new jobs in social enterprises.

We look forward to supporting:

- community-owned and managed local grids
- community Energy Services Companies (ESCos) supplying the local community and exporting surpluses of power and heat
- whole communities or groups of housing associations organising to bulk purchase energy
- mass roll-out of microgeneration and energy efficiency
- community forestry projects encouraging biodiversity, creating local jobs and providing good British biomass
- managing the community-benefit pots for big projects to enhance the overall impact and ensure good governance

cynically seen as bribery, but environmental economists describe this as applied externality theory. The approach, promoted by developers and Government policy, has to date, focused on 'community benefit' payments by developers to local communities. These began as relatively informal payments for onshore wind but have become mandatory (a payment per MW installed is now UK policy).

Even in situations in which local communities do not have an ownership share in the generation assets, some ask for contributions to energy bills, or PV arrays on the local schools. Although the level of community benefit provided by a project is not a formal planning consideration (it cannot be in law), parish councils and other local stakeholders are able to influence the planning process if they feel positively disposed towards the project. Witness the high level of enthusiasm around Sellafield for what many would consider to be a 'bad neighbour' development – popular essentially because it is a highly prized employer in the area.

However, this approach still sees renewable energy as a negative externality to be tolerated if the rewards are sufficient. The alternative approach, now being promoted by the Government, is to enable local communities to buy in to a project rather than being bought off (see **Figure 1**). The engagement and support of local communities from the beginning of a project's development is becoming increasingly important to secure planning consent. One Pure Leapfrog client, a community energy group, organised a substantial flurry of hundreds of letters in support of a large wind farm development in return for the right for the community to buy into the equity of the project and share in the benefits. This is a classic example of the shift from NIMBY to YIMBY.

FINANCE OPTIONS

A community hoping to develop its own project or invest in a share of a commercial one will need to raise the funds to develop the project or to invest because the subsidies will be insufficient without a significant contribution of equity and/or debt.

The following are some of the popular sources of finance for community projects:

Local share issues: local communities have raised millions of pounds through local share issues. Share issues usually pay investors a rate of return of 4–9 per cent, with investor capital locked in for 10–15 years. Enterprise Investment Scheme tax relief can boost returns significantly. For example, Pure Leapfrog has underwritten local share issues in Brighton, Leominster and Lewes where the community provided the capital to install solar panels on community properties. Westmill Solar[7] is another great example of a larger-scale (5 MW) PV project with 1,600 members in its co-operative ownership model, where a local authority pension fund subsequently acquired a large tranche of bank debt through a green bond;

Loans: Pure Leapfrog is a senior secured lender, providing finance to projects without diluting local ownership and control while keeping our interest rates affordable. Examples include a loan to Staffordshire Sunny Schools, which will install 1 MW of solar panels across 25 schools, and loan facilities for two community energy cooperatives in Bristol to enable them to grow their assets and improve returns both to investors and the community without the costs of a further share issue. Traditional financial institutions and impact investors may be interested but they may see the community angle as an additional risk. Triodos, The Co-Operative Bank, Barclays, Lloyds, RBS and the UK Green Investment

BOX 5: WHAT IS FUEL POVERTY?

According to the Government, a household is considered to be in fuel poverty if:

- they have required fuel costs that are above average; and
- were they to spend that amount they would be left with an income below the official poverty line. (DECC, 2013)[12].

It has been estimated that there were 2.3 — 2.8million fuel poor households in England 2013[10].

Bank all have some interest;

Green bonds: for example, Wedmore Community Power Cooperative offered the opportunity to invest in shares, two-year bonds paying 3.5 per cent or seven-year bonds paying 4.5 per cent;

Crowdfunding: there are various crowdfunding platforms that enable individuals to invest in community energy projects. For example, Abundance Generation offers investment in debentures that pay 5–9 per cent, and Ethex offers investors the ability to invest either as debt or equity[8];

Tax relief on investments: two key tax structures provide tax relief for community energy investments: Enterprise Investment Scheme (EIS) and Venture Capital Trust (VCT). In addition to income and capital gains tax benefits, some forms of investment are also exempt from inheritance tax; and

Grants and philanthropy: these are typically not available in conjunction with FITs and ROCs. Private philanthropy may be available from large companies or generous foundations such as Tellus Mater, the Ashden Trust and the Calouste Gulbenkian Foundation.

"We want communities to develop their own renewable energy projects. Unfortunately, we are seeing altruistic, well-intentioned individuals being run into the ground almost with the sheer scale of effort involved"

House of Commons Energy and Climate Change Committee Local Energy Sixth Report, evidence from Anthony Weight, the Sustainable Development Co-ordinator of Cornwall Council.

DELIVERY CHALLENGES

Community-owned projects can be complicated, and this has kept the brakes on large-scale roll out for some time but the pathfinder projects are leading the way. Other issues do require Government support – there are some absurd 'state aid' issues that have killed off several brilliant community-based projects, for example,

because of prior support from a local authority or an award-giving body of the Big Lottery Fund. The rules on becoming a second local supplier create high barriers to entry. But these are being broken down. It is exactly these issues that Pure Leapfrog aims to address (**Box 4**).

WHAT'S IN IT FOR THE REST OF US?

So why is community energy important in a wider context? To answer that question it is worth briefly taking stock of the current state of UK energy. In 2013 energy prices rose by 6–11 per cent, meaning an increase in annual fuel bill of around £123[9]. With an estimated 2.39 million households already living in fuel poverty[10] (see **Box 5**) and energy prices projected to continue rising[11], community investment in decentralised energy can reduce prices, promote energy security, cut carbon output and allow communities all over the UK to thrive and become more financially resilient.

Importantly, by creating a connection between local generation and local use of energy, community energy also encourages users to take responsibility for their energy consumption. This contrasts with the current system, in which we energy consumers each expect to be able to draw out of the system unlimited amounts of power, often without regard for the consequences whether for the environment or energy system.

Evidence from Germany shows that where community-owned energy generation is embraced at a cultural level, larger-scale changes can follow. For example, once an existing local grid contract has expired, municipal authorities can invite bids not only from other large energy companies but also from communities who wish to run their local grid. This is called an 'energy co-operative' and they are growing fast, with over 136,000 citizens owning shares in German energy co-operatives and 650 co-operatives producing renewable energy[13].

THE FUTURE

It has been suggested that decentralised energy could provide 17 GW of capacity by 2030[1], for which medium- to large-scale projects (10–50 MW) must be incentivised. The current FIT and ROC regimes assist community and commercial developer groups alike, but communities often require support that goes beyond direct financial assistance: support is needed to organise locally, to negotiate with major engineering companies to help navigate the tricky and time-consuming planning process, to facilitate grid connection and to mitigate financial risks by increasing technical know-how and reducing political uncertainty.

The blueprints for workable community participation models are available, but the pot of public money to support these projects is finite. What is stopping your community getting hold of its share and taking hold of a more stable energy future?

To quote a 90s advertising slogan: "Don't you just love being in control?" **ES**

The views expressed are the authors' own, as are any mistakes or inaccuracies.

Steven McNab is an environmental, planning and climate change lawyer specialising in renewable energy development and managing environmental social and governance risks with a passion for community energy projects. (steven.mcnab@simmons-simmons.com or 0207 825 3171)

Jessica Holt is a trainee solicitor at Simmons & Simmons who advises on environmental and planning aspects of corporate deals and renewable energy projects.

Acknowledgements
Thanks to Robert Rabinowitz, COO and Alex Germanis, Head of Projects, and the team at Pure Leapfrog for comments, data and case study inputs as well as stalwart support every day to the community energy revolutionaries.

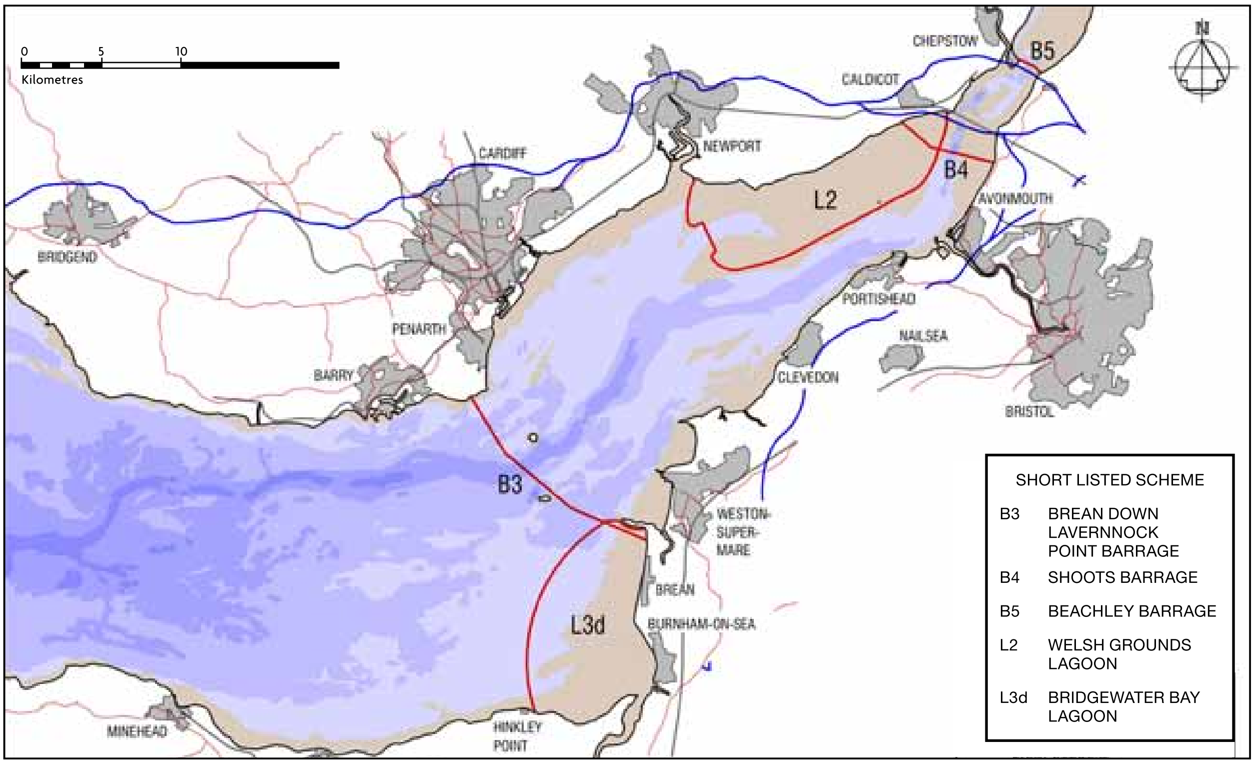
Dedicated to the memory of David Green and the EcoIsland vision.

REFERENCES

1. House of Commons, Energy and Climate Change Committee (2013) *Local Energy: Sixth Report of Session 2013–14*, Volume I. HC180. The Stationery Office Ltd, London. www.publications.parliament.uk/pa/cm201314/cmselect/cmenergy/180/180.pdf.
2. ARUP (2011) *Decentralised Energy Masterplanning: A manual for local authorities*. Arup, London.
3. Harnmeijer, J., Parsons, M., and Julian, C. (2013) *The Community Renewables Economy: Starting up, scaling up and spinning out*. ResPublica, London. www.respublica.org.uk/item/The-Community-Renewables-Economy-Starting-up-scaling-up-and-spinning-out-zlbz.
4. IEA (2013) World Energy Outlook 2013 Factsheet: How will global energy markets evolve to 2035? IEA, Paris. www.worldenergyoutlook.org/media/weowebsite/factsheets/WEO2013_Factsheets.pdf.
5. DECC Increasing the use of low-carbon technologies. DECC, London. www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies (Accessed: 24 January 2014).
6. DECC (2013) DECC Public Attitudes Tracker – Wave 7: Summary of key findings, URN 13D/272. DECC, London. www.gov.uk/government/uploads/system/uploads/attachment_data/file/254725/summary_wave_7_findings_decc_public_attitudes_tracker.pdf.
7. Westmill Solar Co-op. www.westmillsolar.coop/home.asp (Accessed 24 January 2014).
8. See, for example, www.trillionfund.com/ or www.abundancegeneration.com/ (Accessed 24 January 2014). 9.
9. BBC (2013) British Gas to raise prices by 9.2%. BBC Business News, 17 October 2013. www.bbc.co.uk/news/business-24562930. 10.
10. DECC (2013) *Fuel Poverty Report – Updated August 2013*. DECC, London.
11. Carbon Energy (2013) National Audit Office warns energy bill hikes to last 17 more years. www.carbon-energy.co.uk/news/national-audit-office-warns-energy-bill-hikes-to-last-17-more-years/?year=2013&month=11.
12. DECC (2013) Fuel poverty statistics. www.gov.uk/government/collections/fuel-poverty-statistics (Accessed: 24 January 2014).
13. DGRV (2013) *Energy Cooperatives: Findings of survey conducted by the DGRV and its member associations [online]. Available from*: www.dgrv.de/weben.nsf/272e312c8017e736c1256e31005cedff/41cb30f29102b88dc1257a1a00443010/$FILE/Energy_Cooperatives.pdf.

Why did the Severn Barrage fail and what does that mean for tidal energy in the UK?

Peter Kydd reviews the issues affecting barrage and lagoon projects in the UK.



▲ **Figure 1. The shortlisted options for the Severn Tidal Power Feasibility Study. (Source Parsons Brinckerhoff, Options Definition Report, April 2010)**

In April 2008, when Parsons Brinckerhoff were appointed by the UK Government to lead a consortium of consultants studying the engineering and environmental components of the Severn Tidal Power Feasibility Study[1], we had no idea what would emerge from it. Aside from the Sustainable Development Commission's (SDC) report in 2007[2], no studies had been undertaken on tidal range power schemes since the 1980s and early 1990s. Even then, the SDC's report relied heavily on evidence from the previous studies, supplemented by expert opinion and the contemporary legal landscape. In simple terms, it concluded that the topic was worth further study and that, in principle, a large tidal power scheme would be in the public interest subject to it complying with environmental legislation, and that the long-term benefits of such a scheme were retained by the public sector.

The two-year Government Feasibility Study followed shortly afterwards, with the following primary objectives:

- to generate electricity from the renewable tidal range resource of the Severn Estuary in ways that will have an acceptable overall impact on the environment and economy both locally and nationally, will meet our statutory obligations and provide benefit to the UK; and

- to deliver a strategically significant supply of renewable electricity, which is reasonably affordable compared to other sources and represents value for money in the context of the UK's commitments under the forthcoming EU Renewable Energy Directive and Climate Change Act and our goal to deliver a secure supply of low-carbon electricity[1].

FEASIBILITY STUDY PHASE 1

The first phase of that study focused on identifying different projects that could potentially meet these objectives. The second, more detailed, phase focused on a shortlist of these options to determine the optimal engineering solutions and their environmental and economic effects.

The term "strategically significant" was interpreted to mean a scheme with an installed capacity of 1,000 MW or more, although one smaller option was studied (a 625 MW barrage at Beachley) because of its location, just upstream of the River Usk, to review whether this location had any benefits for the Severn's fish population.

The shortlist comprised five options, shown in **Figure 1**. There were two large land-connected lagoons and three barrages, including the alignment (B3) from Lavernock Point near Cardiff to Brean Down near Weston-super-Mare, commonly called 'the Severn Barrage'.

Tidal range projects make use of the potential energy in the tides by storing water within a basin at the high-tide level and releasing it when the tide has dropped. The energy generated is proportional to the difference in levels and the flow of water through the turbines.

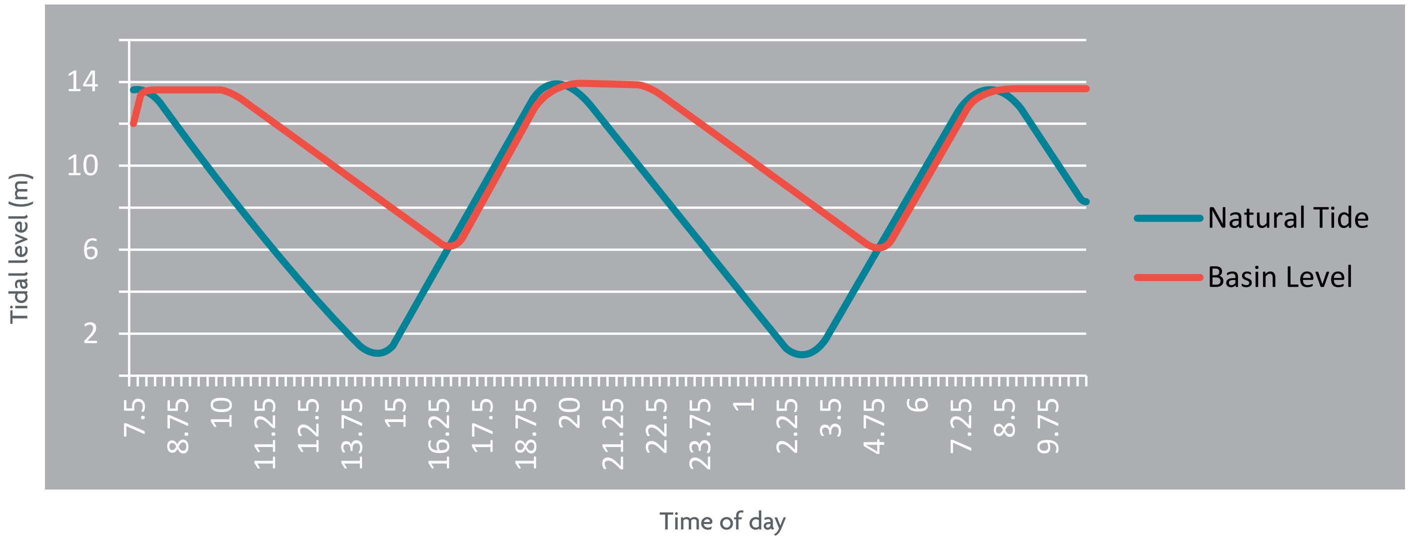
FEASIBILITY STUDY PHASE 2

Phase 2 of the study investigated the different operational modes of the projects on the shortlist and the effects they would have on the environment and other users of the estuary, such as the ports. The different operational modes were ebb only (generating twice a day on the ebb tide as per **Figure 2**) and ebb and flood (generating four times a day on the ebb and flood tides, as per **Figure 3**).

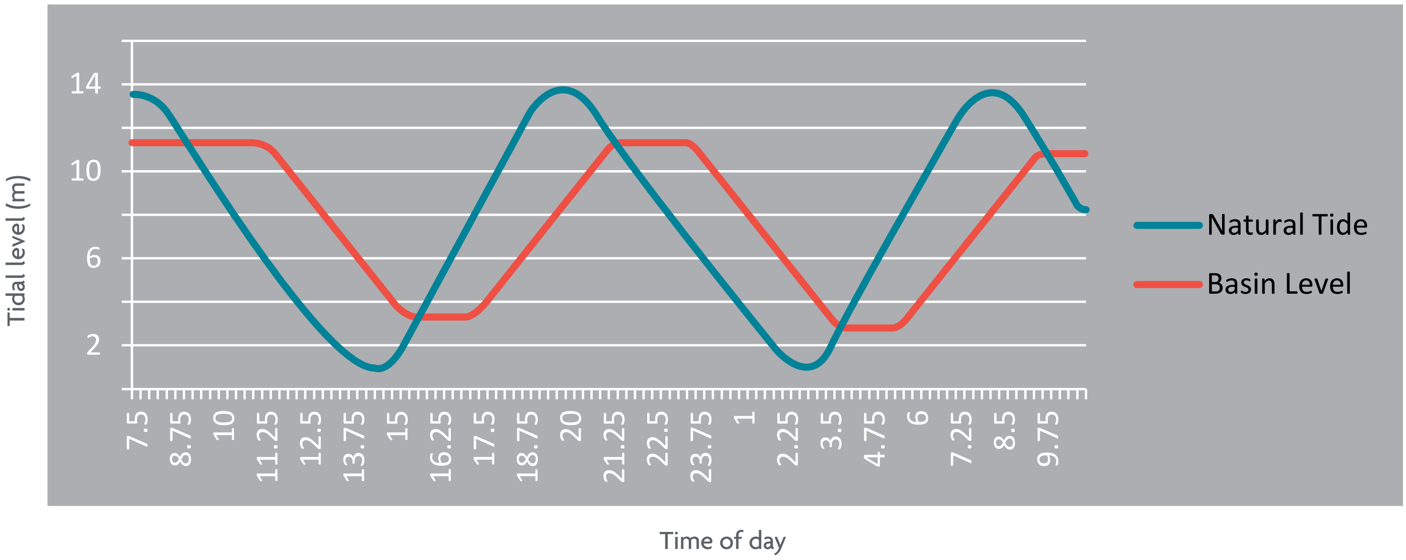
The same turbine types were specified for all five options for ease of comparison. This was a bulb turbine that can operate in both ebb and flood modes and can also pump. Pumping can be used to augment energy output by pumping water into the basin when the sea and basin levels are at the same level and generating when the difference in levels is larger. However, energy consumed and generated from pumping was excluded for two reasons. Firstly it could not be guaranteed in a future operating environment, and thus its costs and effects on the environment would be variable. Secondly, for the larger options, the benefits of pumping to generate additional energy were not clear cut, with some experts citing that the benefit of raised water levels from pumping would be confined to the area of water closer to the barrage, thus reducing how much additional energy it could generate from pumping.

CONCLUSIONS FROM THE 2010 STUDY

In addition to the Government's conclusion that "it does not see a strategic case to bring forward a tidal energy scheme in the Severn estuary at this time, but wishes to keep the option open for future consideration"[1], a



▲ **Figure 2. Variation in natural tide and tidal basin water levels on spring tides in ebb only operating mode. (y-axis is tidal level (m above Chart Datum), x axis – Time in hours), Source Parsons Brinckerhoff).**



▲ **Figure 3. Variation in natural tide and tidal basin water levels on spring tides in ebb-and-flood operating mode.(y-axis is tidal level (m above Chart Datum), x axis – Time in hours), (Source Parsons Brinckerhoff).**

number of interesting conclusions emerged from the Severn Tidal Power Feasibility Study[3] These were:

- the effect of new environmental legislation on process, requirements and costs since the previous studies in the 1980s;
- the increase in shipping to the Port of Bristol since its privatisation in the early 1990s;
- the uncertainties in environmental impacts and associated mitigation measures, particularly in relation to fish;
- confirmation that a large barrage would increase high-tide levels at least as far as Cornwall and Pembrokeshire along the Bristol Channel; and
- the benefits of land-connected lagoons (reduced environmental and economic impacts by comparison with barrages) – these had hitherto been dismissed due to their relatively long impoundment lengths that increase capital costs.

As the Government published the various reports produced for the Severn Tidal Power Feasibility Study, it also confirmed that private developers could continue to propose schemes for the Severn[4].

Shortly afterwards, Corlan Hafren, a consortium of private investors, academics and consultants, submitted an outline proposal to the Department of Energy and Climate Change (DECC). Unfortunately, their proposals were not published, other than some images on a website that appeared to show the Cardiff–Weston Barrage studied by in the Government's Feasibility Study, augmented by a new road and rail crossing. Road and rail crossings had been considered in the early stages of the Government's Feasibility Study but had been rejected as they were not included in current transport policy and Network Rail had no plans to augment or replace the Severn Tunnel.

THE HAFREN POWER PROPOSAL

In 2012, Corlan Hafren became Hafren Power, with a different consortium mix and a new proposal based on an approach similar to Atkins and Rolls Royce's in the Severn Embryonic Technology Scheme (SETS) – a match-funded programme initiated by DECC to encourage investment in new turbine technologies that could be used in the Severn in future years.

Unfortunately, very little detail was published by Hafren Power until the Energy and Climate Change Committee announced that it would hold an Inquiry into 'A Severn Barrage' based on Hafren Power's proposals to Government in October 2012. Hafren Power submitted written evidence which was published by the Committee shortly afterwards, alongside some 70 other written submissions from interested parties, some in favour but others against the Hafren Power proposals. Many mentioned that there were no details of the proposed Hafren Power scheme in the public domain. Aural evidence sessions were heard in early 2013 and the Committee published its report in June 2013[5].

In addition, Hafren Power published an edited version of its business case[6] in May 2013. This provided the first insight into the Hafren Power proposals for most, although the business plan had been shared with the Energy and Climate Change Committee as part of an earlier confidential evidence submission. The proposal described in the business plan was for an 18 km fixed tidal barrage between Brean in England and Lavernock Point in Wales. It was estimated to cost £25 billion and have 1,026 very-low-head (VLH) bi-directional turbines, generating approximately 16.5 TWh/year on both ebb and flood tides.

Particular points made by the Select Committee in their report were:

- the lack of robust supporting evidence led to a sense of mistrust on the part of some stakeholders, made worse by the uncertainties surrounding a possible Hybrid Bill;
- the revenue per kWH (the strike price) required by Hafren Power is unknown;
- Hafren Power have failed to overcome the serious environmental concerns that have been raised;
- construction of such a large-scale barrage would inevitably create jobs but could also lead to job losses in local businesses and in particular the ports industry;
- while a tidal barrage could offer decarbonisation and energy security benefits, the Hafren Power project in its current form has not demonstrated sufficient value as a low-carbon energy source to override regional and environmental concerns; and
- stronger public governance of these resources would offer the opportunity to develop alternative technologies and strengthen the evidence base before building a large-scale facility.

The Government published its response[7] in September 2013, largely in line with the Committee's conclusions and agreeing that there were alternative approaches, such as those proposed by RegenSW in their balanced technology approach[8].

WHY IS THERE NO SEVERN BARRAGE?

On one hand, it could be argued that the best time for developing the tidal resource from the Severn was in the post-war years up to the point at which the electricity market was privatised. There was less environmental regulation, and the ports in the Severn were less successful than they are today. On the other hand, if Severn tidal power was too expensive by comparison with other power generation, the gap should be closing as environmental legislation makes fossil fuel more expensive and the world looks for cleaner forms of reliable power generation.

Although the Severn Barrage may look an attractive option to many, it has a number of issues that I believe are at the root of the problem. The first of these is its size. At over £20 billion, it is a significant investment, and unlike many other infrastructure investments, it cannot be phased. The main cost is in the barrage itself and this has to be completed before any tidal power generation can take place. As a consequence, there is a different risk profile than, for example, an offshore wind farm, which can be developed incrementally.

Its size also has some other implications. For example, the basin area that a Severn Barrage would impound is much greater than is required for power generation, and it is the basin area that suffers many of the adverse environmental impacts, with loss of habitats and changes to the natural environment. This is one of the reasons why land-connected lagoons out-perform barrages in terms of environmental impacts, as the basin area of a lagoon is tuned to its energy output and is therefore smaller for a given power output when compared with a barrage.

Another issue is the fact that it blockades an estuary. This has a number of adverse impacts. First, as the barrage represents an impedance to incoming tidal flows, the proportion of flow not passing through the turbines is deflected back to sea, raising water levels downstream of the barrage. Even with the high-flow turbines being proposed by Hafren Power, this remains a problem and their own analysis shows raised water levels along the shorelines of the Bristol Channel, potentially increasing flood risk. Second, migratory fish have to pass through the barrage and other fish species may inadvertently pass through the barrage. There is still much research that needs to be undertaken relating to fish passage through structures and turbines in saline water so this area remains uncertain. Third, the barrage presents an additional problem for shipping. Not only do they have to pass through the barrage but also the water regime upstream of the barrage will be different, with lower high-water levels (particular in ebb and flood generation mode) that will compromise larger vessels being able to transit port locks. Although the port locks could be reconstructed, this could not be efficiently done without temporarily closing the port operations, with associated loss of trade, income and jobs. Ships would also have to pass through an additional set of locks on the barrage itself. For container vessels seeking to minimise transit times that select their offloading ports on this basis, the prospect of having to transit locks could lead to them seeking alternative port destinations.

The Hafren proposals also sought to utilise a new turbine design, capable of passing much higher water flows and lower power densities to address environmental concerns. However, their timetable for implementation was ambitious, considering that the turbine design had not been tested, even as a prototype. A long period of testing would have been required to resolve the many uncertainties in the interface between the natural environment and the turbine characteristics.

In my view, it is the combination of these issues that represents the fundamental problem. There are many others that have been cited, relating to compensation of habitats, the strike price and the high proportion of the Levy Control Framework funding that would be required. Whilst difficult issues, I do not believe they are obstacles as such and one could argue that, for example, the experience of creating new habitats would be advantageous as the UK seeks to replace habitats that would be lost as a consequence of sea-level rise. In terms of subsidies, a tidal range project would typically have a long life, in excess of 120 years, and whilst it requires a subsidy for the initial 30 years or so, it would actually have a downward influence on the wholesale cost of electricity for the other 75 per cent of its life, something that should benefit our future generations.

So the key issues are size, impedance and uncertainty. Focusing on how these may be overcome should help us move from a situation where we have many thousands of pages of reports written over several decades but no Severn power generation, to a more sustainable vision of generating power that could actually contribute to carbon emissions reduction, security of supply and long-term economic benefit whilst respecting the environment and its inherent value.

THE FUTURE FOR TIDAL ENERGY IN THE UK

The Severn Estuary, as the UK's largest tidal power resource, has the most scope for resolving how we deal with the issues of size, impedance and uncertainty outlined above. However, there are many more locations in the UK that have tidal range potential, including North Wales and the North West. What follows is relevant to all potential tidal range sites in the UK, although the

vision is couched in Severn Estuary terms to demonstrate the practicality of alternative options to a barrage in the Severn.

SIZE

It is clear that the Government wants to maintain a market-based mechanism for the UK electricity sector and that the private sector is reluctant to tie its investment into a single large-scale investment such as the Severn Barrage, which is nearly double the size of a large nuclear station. Size is therefore predominantly about reducing capital costs to a level where they are within the comfort zone of the project developer and their investors. As the largest PFI project in the UK is about £6 billion[9], this suggests a natural upper boundary. Fortunately, there have been a number of land-connected lagoon projects proposed for the Severn with lower capital costs than this. They include the Swansea Bay Tidal Lagoon[10], an 11 km^2 impoundment generating 400 GWh/yr which is currently going through the UK planning regime, and the Stepping Stones Tidal Lagoon[11], impounding 18 km^2 and generating 1,200 GWh/yr, which is at conceptual design stage.

Tidal lagoons can be sized so that the basin area is tuned to the energy generated, but because the ratio of impoundment wall to basin area is not linear, the smaller the lagoon, the longer the impounding wall is per unit of energy. Thus smaller lagoons are relatively more expensive. For the bathymetry of the Severn, the most economic schemes will tend to have an area of between 15 and 90 km^2. Using these areas, the amount of energy generated per km of impounding wall is reasonable, although the larger areas will result in schemes that exceed the £6 billion level (a benchmark cost would be about £100 million per km^2 of basin area.

IMPEDANCE

A further benefit of tidal lagoons is that they do not impede the estuary in the same way as a barrage, so that shipping can pass up the estuary as they do currently with no additional locks to pass through or loss of high-water level. The fact that major lock structures are not required also leads to capital cost savings. The Government's Feasibility Study also showed that the size of a tidal lagoon in the Severn Estuary reduces the risk of far-field effects such as the downstream increase in high-water levels caused by a barrage.

Migratory fish also have the freedom to pass up the estuary but may also get attracted into the high flows into the turbines. However, that is a more manageable problem to solve than provision of fish passage through a barrage. It also suggests that adopting an incremental approach, starting with a smaller lagoon and understanding the behaviour of fish in practice, would benefit the development of subsequent schemes in terms of managing fish close to a tidal lagoon.

UNCERTAINTY

Although there will always be uncertainty within a highly dynamic marine environment, the ability to undertake research on live projects operating in the Severn would help inform the development of subsequent tidal power projects. The Severn can accommodate a number of different tidal lagoon projects of different sizes, so there could be a real prospect of building a smaller project first, and learning from this to inform the development of a second project, and so on. This would help reduce uncertainty in areas such as habitat creation or loss, fish impacts and siltation, as well as creating a more sustainable supply chain (in terms of jobs sustained over many years).

SUMMARY

As will be evident from the above, the future for tidal power in the UK should be clearer following the lack of progress made by the recent Severn Barrage submission to Government. In particular, it suggests that an incremental approach, based on the development of tidal lagoons, will not fall foul of the fundamental problem associated with the barrage, particularly in terms of size and impediment to other users of the estuary. An incremental approach, based on learning from one project and applying it to the next, in an environment where there is clear strategy and governance, could see a sustained pipeline of tidal power projects in the UK, and resolve uncertainties. Such an approach would also encourage innovation, particularly in terms of optimising lagoon siting and exploring ways in which the cost of construction can be reduced.

Both the Swansea Bay and Stepping Stones projects include innovative, albeit different, approaches to reducing the cost of the wall. At Swansea Bay, they are exploring the use of sand-filled geotubes for the embankment construction, whereas the Stepping Stones project utilises pre-cast caissons, mass-produced to the same design and dimensions, and floated into position. The Stepping Stones project also features a crest height at the same level as high-water level so the reinforced concrete structure can be safely overtopped. Further innovations are possible, both in terms of further refinement of the wall design, use of natural environment features within the lagoon designs, refinement of turbine designs and using lagoons for testing new turbine types.

Of the three technically feasible lagoons studied to date in the Severn (Swansea Bay, Stepping Stones and Bridgwater Bay), over 5 GW of capacity would be created, and there is scope for further lagoon development that could potentially double this. These options utilise existing technology and are therefore feasible today but also provide a platform for new technology developments that may emerge in the future. Having a structured plan to develop the Severn's tidal power resource in this way could produce as much or more power than a Severn Barrage when complete, but would avoid the difficulties of committing to a single large project from the outset. Instead it would provide a solution that could be developed incrementally, working with the environment and both the regional and national economies. **ES**

Peter Kydd BSc(Edin) CEng FICE is a Chartered Civil Engineer and Director of Strategic Consulting at international consulting firm Parsons Brinckerhoff. He also chairs the South West Marine Energy Park and led the consortium of consultants engaged by Government to undertake the Severn Tidal Power Feasibility Study between 2008 and 2010.

REFERENCES

1. DECC (2010) Severn Tidal Power: Feasibility Study Conclusions. decc.gov.uk/en/default.aspx?n1=3&n2=51&n3=58&n4=60&n5=171.
2. SDC (2007) *Turning the Tide: Tidal Power in the UK*. www.sd-commission.org.uk/publications.php?id=607.
3. Kydd, P. (2009) Severn Tidal Power Feasibility Study. Parsons Brinckerhoff, London. regensw.s3.amazonaws.com/1275397577_424.pdf.
4. Stacy, K. (2010) Chris Huhne: The Severn barrage will be built. *Financial Times*, 24 November 2010. blogs.ft.com/energy-source/2010/11/24/chris-huhne-the-severn-barrage-will-be-built/#axzz2ndGE4bPB.
5. House of Commons, Energy and Climate Change Committee (2013) *A Severn Barrage? Second Report of Session 2013–14*. HC 194 [Incorporating HC 879, Session 2012–13]. www.parliament.uk/business/committees/committees-a-z/commons-select/energy-and-climate-change-committee/inquiries/parliament-2010/a-severn-barrage/.
6. Hafren Power. Hafren Power plans to build an 18 km barrage to harness the huge tidal range of the Severn Estuary. www.hafrenpower.com/ (Accessed: 8 January 2014).
7. UK Parliament (2013) A Severn Barrage?: Government Response to the Committee's Second Report of Session 2013-14 – Energy and Climate Change. www.publications.parliament.uk/pa/cm201314/cmselect/cmenergy/622/62204.htm.
8. RegenSW, Bristol City Council, West of England Local Enterprise Partnership, Bristol Tidal Energy, South West Marine Energy Park, Marine Energy Matters. *Bristol Channel Energy: A Balanced Technology Approach; Discussion Document*. (2012) regensw.s3.amazonaws.com/bristol_channel_energy_balanced_technology_approach_20121127_dc91be5efc7914f8.pdf.
9. M25 Connect+ Consortium. www.connectplusm25.co.uk/aboutus.html.
10. Tidal Lagoon (Swansea Bay) plc. Harness the power of Swansea Bay. tidallagoonswanseabay.com/ (Accessed: 8 January 2014).
11. Kydd, P. (2012) Stepping Stones Tidal Lagoon: An outline proposal for a new tidal range project in the Severn Estuary. Parsons Brinckerhoff, in association with Black & Veatch, London. regensw.s3.amazonaws.com/120831_stepping_stones_tidal_lagoon_presentation_for_bristol_tidal_forum_ead4881f6fce116d.pdf.

Biomass and carbon dioxide capture and storage

Jasmin Kemper and **Tim Dixon** assess the future for the capture and storage of greenhouse gases.

The use of biomass for biofuel production and for energy production processes, such as combustion and gasification, results in the emission of the greenhouse gas (GHG) CO_2. Carbon capture and storage (CCS) describes processes that capture CO_2 from large point sources, transport it via pipelines or ships and finally inject it into geological formations deep underground.

Biomass with CCS (bio-CCS or BECCS) is one of the few negative emissions technologies because capture and long-term storage of the CO_2 emissions from biomass combustion and decay effectively result in net removal of atmospheric CO_2. Potential benefits include the capacity to compensate for historical emissions by removing them from the atmosphere and the ability to reduce the overall costs of climate change mitigation by offsetting the emission sources that are more difficult to abate, such as from aviation.

It is important to understand the potential of the technology, as well as drivers and barriers, which can accelerate or limit the implementation of bio-CCS. For this reason, the IEA Greenhouse Gas R&D Programme (IEAGHG; see Box) has commissioned a number of studies to provide an assessment of the potential of bio-CCS technologies[1,2] and a review of how current GHG accounting rules deal with negative emissions[3].

TECHNICAL, REALISABLE AND ECONOMIC POTENTIAL

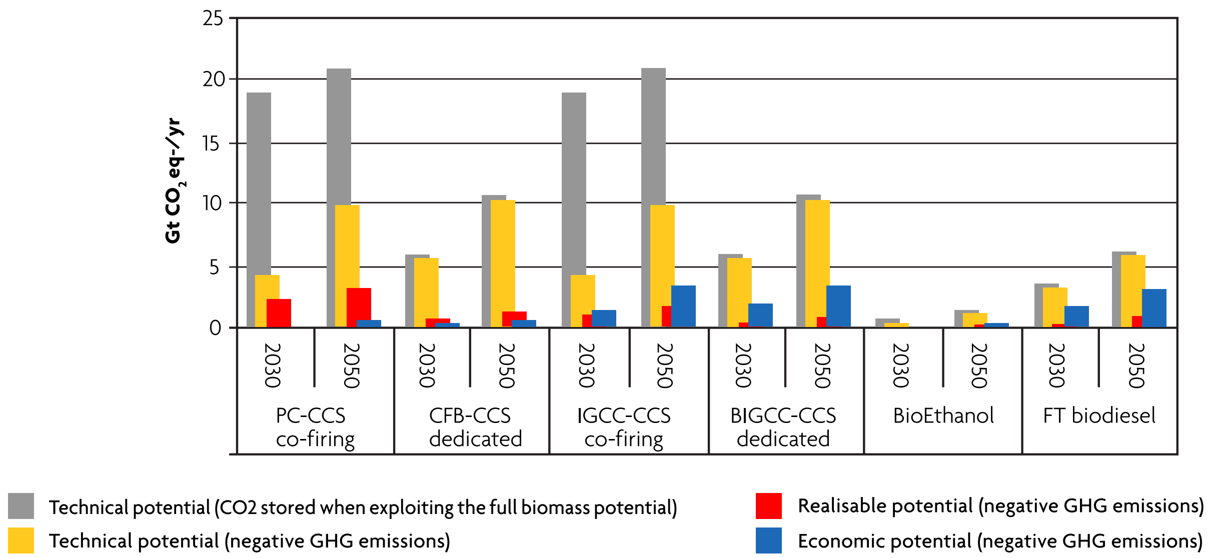
The first study published in 2011[1] evaluated six routes from two major sectors, large-scale electricity generation and biofuel production, regarding their *technical*, *realisable* and *economic* potential. The technical potential was determined by the net energy conversion efficiency (including the energy penalty) and the carbon removal efficiency of the bio-CCS route. The realisable potential adds limitations to the technical potential by including energy demand, capital stock turnover and possible deployment rate. The economic potential considers the costs of biomass resources, biomass conversion and CCS for selected bio-CCS routes[1]. **Figure 1** illustrates the results.

The technical potential for bio-CCS technologies is large and could result in negative emissions of up to 10 Gt of CO_2-equivalent ($GtCO_2eq$) annually per route in 2050. This number is significant when compared to the global energy-related CO_2 emissions of over 30 Gt in 2010[4]. The highest potentials are for biomass integrated gasification combined cycle with CCS (BIGCC-CCS) and circulating fluidised bed combustion with CCS (CFB-CCS), each achieving negative emissions of 10.4 $GtCO_2eq$ in 2050. The potential of the biofuel routes is comparatively lower - from 0.6 to 6 $GtCO_2eq$ - because in biofuel routes a significant proportion of CO_2 remains in the product, in the residues or is emitted further along the value chain.

Pulverised coal fired power plants with CCS (PC-CCS), co-firing biomass, have the largest realisable potential in both the medium and long term, leading to negative emissions of 2.3 and 3.2 $GtCO_2eq$ respectively. The reason for this is the assumption in the study that all new power plants will be equipped with CCS after 2020 and existing ones will undergo retrofit. This flexibility explains why the absolute realisable potential is considerably higher for co-firing than for dedicated biomass combustion. However, dedicated routes have higher relative negative emissions per unit energy and require less storage capacity to achieve negative emissions.

The economic potential, assuming a CO_2 price of 50 €/t, could result in negative emissions of up to 3.5 $GtCO_2eq$ annually per route in 2050. For the best performing routes, BIGCC-CCS and IGCC-CCS, about one-third of the technical potential appears to be economically attractive (this is under the assumption of a strong technical development). Compared with the gasification routes, the economic potential of PC-CCS and CFB-CCS routes is negligible. The costs for these routes are generally higher than for corresponding reference technologies, so a CO_2 price of more than 50 €/t needs to be in place to make them commercially viable. With respect to the biofuel routes, Fischer–Tropsch biodiesel (FT biodiesel) shows a relatively high economic potential of 3 $GtCO_2eq$ in 2050, whereas the potential for bioethanol is very small. As capture costs for bioethanol routes are relatively low, they can still provide early economic opportunities for bio-CCS.

Another aim of the study was to identify drivers and barriers for the deployment of bio-CCS technologies. The CO_2 price can act as both a driver and an obstacle. If storing CO_2 from bio-CCS does not create sellable allowances and/or the price is too low, then there is no economic potential for negative emissions and therefore no incentive for bio-CCS technologies. In addition, the relatively immature state of some bio-CCS technologies, such as BIGCC, is a potential barrier because it leads to a higher financial risk. The availability and costs of bio-CCS will also depend on the reliable supply of low-cost, sustainable biomass. A possible driver might be the more positive public perception of bio-CCS compared to fossil fuel CCS because of its link to renewable energy.



▲ **Figure 1. GHG emission balance for global technical, realisable and economic potential per bio-CCS route for 2030 and 2050[1]. (Co-firing shares are 30 per cent in 2030 and 50 per cent in 2050. Note that numbers are not additive, as potentials were assessed on a route-by-route basis with direction of available biomass to one route at a time.)**

ADDING GASIFICATION AND ANAEROBIC DIGESTION

A follow-up study published in 2013[2] evaluated the potential of two additional technology routes for biomethane production in combination with CCS: gasification and anaerobic digestion. At the same time, it considers different types of feedstock: energy crops (EC) and agricultural residues (AR), biogenic municipal solid waste (MSW) and animal manure and sewage sludge. This study only distinguishes between technical and economic potential. As in the first study, the technical potential refers to the potential that is technically feasible and not limited by economics, but in contrast to the first report, this study defines the economic potential as the potential at competitive cost compared to the reference natural gas, including a price for CO_2. **Figure 2** shows the main results for global technical and economic potential in terms of negative emissions achievable for 2030 and 2050.

With the ability to remove up to 3.5 $GtCO_2eq$ in 2050, the gasification route has the largest technical potential. The substitution of natural gas with biomethane can lead to an additional reduction in GHG emissions of 4.4 $GtCO_2eq$. These numbers are again significant when compared to the global energy-related CO_2 emissions of over 30 Gt in 2010[4]. Among the anaerobic digestion routes, only production based on energy crops and agricultural residues reveals a significant technical potential of up to 2.1 $GtCO_2eq$ in 2050.

The economic potential for biomethane production with CCS depends mainly on the prices for CO_2 and natural gas, and is only a fraction of the technical potential. The majority of the routes only become economically viable at natural gas prices over 11 €/GJ and CO_2 prices of at least 20 €/t. An exception is anaerobic digestion using animal manure/sewage sludge or municipal solid waste. These routes are already economically viable at a natural gas price of 6.7 €/GJ, and they can each lead to negative emissions of about 0.4 $GtCO_2eq$ in 2050.
As for the six routes in the earlier study, the availability and cost of sustainable quantities of biomass will play an important role. A main driver for the gasification

route is the existence of a large-scale infrastructure for transporting biomass, natural gas and CO_2. Due to their smaller scale, which results in higher connection costs, the digestion-based routes are more likely to become a niche application. For these routes, the presence of CO_2 utilisation options can act as a driver for a business case. In general, only regions that have favourable natural gas prices, CO_2 prices and infrastructure will be able to use biomethane production with CCS to its full potential.

ACCOUNTING FOR NEGATIVE EMISSIONS

Some low-carbon policies and associated GHG accounting rules do not appropriately recognise, attribute and reward negative emissions. An ongoing IEAGHG study[3] is currently reviewing the following GHG accounting and monitoring, reporting and verification (MRV) rules:

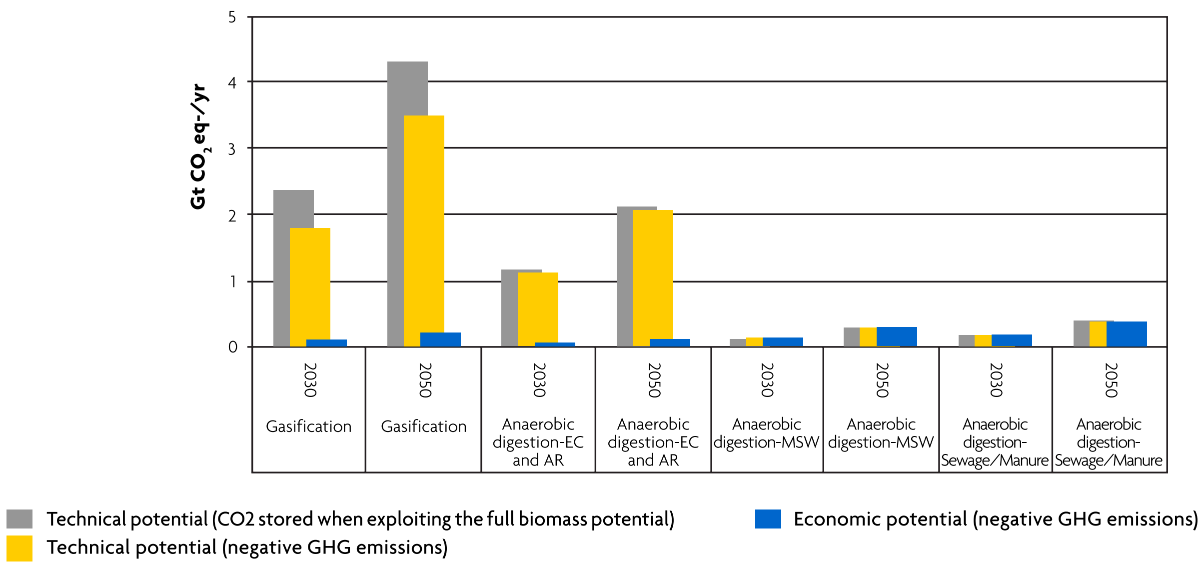
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories;
- Kyoto Protocol Clean Development Mechanism (CDM) and Joint Implementation (JI);
- EU Emission Trading Scheme (EU ETS), Renewable Energy Directive (EU RED) and Fuel Quality Directive (EU FQD);
- US Greenhouse Gas Reporting Program (US GHGRP);
- California's cap-and-trade scheme (California ETS) and Low Carbon Fuel Standard (LCFS); and
- Australia's Carbon Pricing Mechanism (CPM). However, the Australian Government introduced repeal bills in November 2013, aiming to abolish the carbon tax scheme from 1 July 2014.

Many of the above accounting rules potentially allow for negative emissions from bio-CCS to be recognised. This is either achieved by net-back accounting at a portfolio level or by generating project-based credits. However, regional cap-and-trade schemes do not generally recognise and attribute negative emissions. The EU ETS, for instance, prevents the recognition of negative emissions from bio-CCS, because an installation's GHG inventory can only consider fossil carbon for deductions. In addition, the EU ETS exempts installations exclusively using biomass from the scheme. In similar ways, the Australian CPM does not cover emissions from biomass combustion and the California ETS does not recognise negative emissions. These are the flaws of some GHG accounting schemes. There are ongoing discussions about the EU ETS and California ETS about how to amend the schemes and overcome these loopholes. Currently there are no incentives for capturing and storing biogenic emissions, i.e. negative emissions, over just emitting them, i.e. zero emissions.

INCENTIVISING NEGATIVE EMISSIONS

Several challenges exist around appropriately rewarding negative emissions. There is a perception that negative emission technologies, such as bio-CCS, deliver a 'double dividend'. First, through the displacement of an existing fossil CO_2 source and second, by capturing and storing these emissions. Therefore, the question of 'double crediting' arises. Because cap-and trade schemes do not fully take account of this double dividend at the moment, bio-CCS would compete with other abatement technologies on a per-tCO_2 basis.

Sustainability issues present both a wider issue for large-scale biomass energy development and also for GHG accounting rules. One example is land use change (LUC) effects that bioenergy crop cultivation can



▲ **Figure 2. GHG emission balance for global technical and economic potential per bio-CCS route for 2030 and 2050[2]. (Note that numbers are not additive, as potentials were assessed on a route-by-route basis with direction of available biomass to one route at a time.)**

trigger. In terms of GHG accounting, a zero-emissions assumption for biomass combustion or decay is contingent on the growth and harvesting of that biomass being in equilibrium. Where LUC causes land degradation and subsequently a loss of biological carbon stock, the zero-emissions assumption is no longer valid. To overcome this, the monitoring systems for these land management activities need improvement from their current patchy and/or poorly implemented status. Importing biomass, especially from developing countries where monitoring is weak, into jurisdictions where GHG credits can be generated for its use, seems disputable without better GHG accounting systems being in place. LCFS, such as the one in California or the EU, tackle this issue by considering all emissions along the biofuel value chain, including – to an extent – LUC effects.

"In general, only regions that have favourable natural gas prices, CO2 prices and infrastructure will be able to use biomethane production with CCS to its full potential"

CONCLUSION AND OUTLOOK

Biomass in combination with CCS shows significant potential to reduce GHG emissions by 2050. The main drivers, or barriers (depending on the point of view), are the price of CO_2 and the price and availability of sustainable biomass. Setting an incentive or a reward for bio-CCS remains a task for policy-makers, and it will be a complex and challenging one. If policy-makers and regulators do not accurately address sustainability concerns, like land use change, the credibility of negative emissions claims could suffer, especially as bioenergy crops are competing for land with food production and for storage resources with other CCS technologies. The EU and USA are now considering measures to take upstream emissions into account and to clarify the sustainability requirements for biomass. In this regard, the parity of treatment of biomass fuels and fossil fuels, the latter of which do not need to account for upstream emissions in their value chain, will be an area requiring major discussion. **ES**

Acknowledgements

The authors would like to thank Dr Joris Koornneef of Ecofys, Dr Paul Zakkour of Carbon Counts and related co-workers for carrying out the studies on the global potential for bio-CCS and on the accounting of negative emissions.

Dr Jasmin Kemper is a Project Officer at IEAGHG. She joined the Capture & Integrated Systems team in 2011. Jasmin has managed technical studies on CO_2 dehydration, pipeline transportation and accounting for GHG emissions from bio-CCS. Other work areas include IEAGHG's network on carbonate and chemical looping technologies, sustainability, public perception and non-CO_2 GHGs. She received her PhD in engineering on the evaluation of amine-based solvents for post-combustion CO_2 capture.

Tim Dixon is the Technical Programme Manager for IEAGHG. He has been at IEAGHG since 2008, and is responsible for ensuring that IEAGHG provide the evidence base to support the growing regulatory and policy developments for CCS. Previously he worked in CCS, emissions trading and related areas for the Government's Department of Trade and Industry and for AEA Technology. He was UK negotiator for the London Convention and OSPAR CCS amendments, and for CCS in the EU ETS. He still assists the UK government in the UNFCCC, and was the negotiator for the UK and EU on CCS in CDM.

SOURCES

1. IEAGHG. (2011) *Potential for Biomass and Carbon Dioxide Capture and Storage*. Report 2011/06. July, 2011.
2. IEAGHG. (2013) *Potential for Biomethane Production with Carbon Dioxide Capture and Storage*. Report 2013/11. September, 2013.
3. IEAGHG. Biomass and CCS – Guidance for Accounting for Negative Emissions. Volume in press.
4. IEA. (2012) *CO_2 emissions from fuel combustion*. OECD/IEA, Paris.

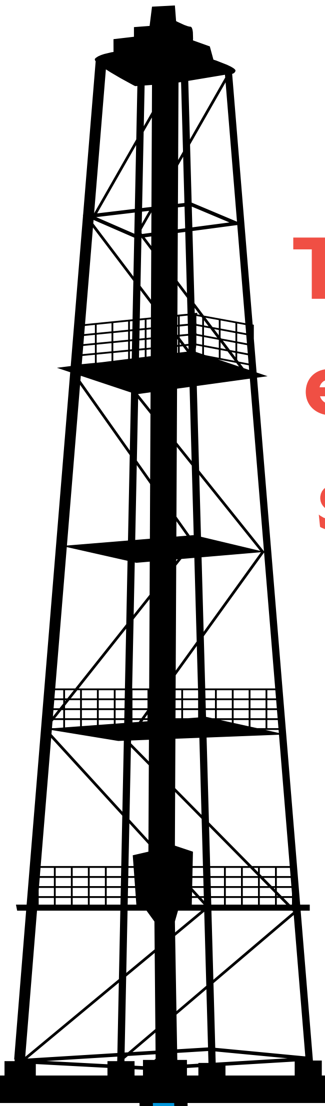
ABOUT IEAGHG

The IEA Greenhouse Gas R&D Programme (IEAGHG) is an international collaborative research programme established in 1991. IEAGHG studies and evaluates technologies that can reduce greenhouse gas emissions derived from the use of fossil fuels. The programme aims to provide its members with definitive information about the role that technology can take in reducing greenhouse gas emissions. IEAGHG takes pride in being an informed and unbiased source of technical information on greenhouse gas mitigation.

The programme's main activities are:

- to evaluate technologies aimed at reducing greenhouse gas emissions;
- to help facilitate the implementation of potential mitigation options;
- to disseminate the data and results from evaluation studies; and
- to help facilitate international collaborative research, development and demonstration activities (R,D&D).

More information and cited reports available at www.ieaghg.org.



The management of environmental risk for shale gas exploitation

Ian Davison assesses the implications of developing shale gas in the UK.

The exploitation of hydrocarbon gases trapped in shale rocks has developed rapidly in North America over the last two decades. New developments in drilling and production technologies have enabled the commercial development of sources of gas that were once considered inaccessible[1]. Conventional oil and gas production uses the natural permeability of reservoir rocks and formation pressure to bring hydrocarbons to the surface. However, shale gas and other 'unconventional' hydrocarbon gas sources like coal-seam methane are trapped in rocks of low permeability, and therefore fracturing the rock is required to liberate the gas and allow it to be brought to the surface[1].

Technologies such as accurate directional drilling, high fluid volume fracturing, special production fluids and multi-pad wells[2] have enabled the exploitation of shale gas resources, but collectively they have attributes that require managing to avoid degrading the natural environment[1]. The techniques used to fracture the shale and the environmental impacts caused by extraction methods and by-products have caused major concerns for populations in areas underlain with hydrocarbon-rich shale[3]. At the same time, gas consumers in North America have benefited as the resulting surfeit of gas entering the market has significantly reduced gas prices[4].

In the USA, regulation has lagged behind the rapid exploitation of these resources and has resulted in incidents of pollution and environmental issues being felt by proximal communities[3]. This has led to concerns over whether the short-term economic benefits of cheap fuel are worth the long-term environmental impact[5].

UK REGULATION GUIDELINES

Within the UK, shale gas exploration is at an early stage, with a small number of companies (Cuadrilla and iGas) presently undertaking investigatory operations. The regulation of operations is being undertaken by the Environment Agency (EA) and the Health and Safety Executive (HSE) under the auspices of the Department for Energy and Climate Change (DECC). The protection of the environment requires that the inherent risks in undertaking the exploitation are understood so that mitigations can be formulated and framed in regulation for practical application[6].

The UK Government (Defra) has produced guidelines for environmental risk assessment that provide the basis on which risk assessment and management of environmental risk should be carried out within the UK[7]. Alongside this document, the HSE have a similar document focusing more on human risks[32] where they develop the concept of 'as low as reasonably practicable' (ALARP) for actions to reduce the risk to human health in the workplace. By 'reasonably practicable', they mean that actions to prevent risks must be weighed "against the trouble, time and money needed to control it". This requires that people assessing risks use their judgment along with a body of guidance and past judgments[33]. For environmental risks, the Defra guide states that the ALARP principle should only be considered where it is deemed appropriate to balance cost and benefit. The regulatory principle, 'best available technique' (BAT), is preferred, as it allows for the fact that risks can be managed better over time due to advancing technology and new techniques[24].

An environmental risk assessment is initially done to prove to regulatory authorities that the originator has undertaken due diligence to ensure that unwanted circumstances do not occur. It is also a business tool for reducing the operational overheads from accidents and a health and safety tool for reducing threats to human health. In an environmental risk assessment, the scale of the risks can range from macro-considerations (the impact of greenhouse gases) or specific (a leaking valve). The target audience for risk assessments is the regulator and the organisation itself, as it continues to review and refine its risk analysis and mitigation measures. The source of the risk information can be a risk manager within an organisation but effective risk identification and mitigation requires involvement from all stakeholders involved in an operation[7] if it is to avoid being parochial and subjective.

The issue of subjectivity in risk analysis has drawn risk analysis into increasingly detailed investigations of operations and processes. The expert committee based hazard identification (HAZID) bowtie method, which details potential threats along with preventative and mitigation measures, is being considered for use within shale gas operations[8]. Another option for taking subjectivity out of risk analysis is through quantitative statistical assessment methods, rather than the more normal qualitative method. Quantitative methods, such as Monte Carlo risk analysis, use a probabilistic approach to focus where action should be taken. Remediation decision making (RDM) focuses on an assessment of monetary liability to determine where action should be taken[9]. A further method called 'fuzzy logic' uses the process of linguistic reasoning to determine whether or not action should be taken[10].

THE QUESTION OF SCALE

In his report to the European Commission, Broomfield[1] showed that the risks to the environment were not from individual wells but from the wider-scale exploitation of an area. Examples in the USA feature extensive amounts of land taken from its natural state for use as well pads, access roads and gas distribution hubs. Environmental issues like 'land take' are easily observable with technologies like Google Earth, but less noticeable are emissions, transport damage, waste management and risks to the underground environment.

The UK Government has recently voiced its support for shale gas exploitation[11] and the larger companies like Centrica and Total have now taken an interest in exploration[12]. The advent of larger companies, along with plans for incentives for local communities hosting shale gas drilling[13] holds the potential for development activities to ramp up quickly. Presently the Cuadrilla operations in the West Lancashire area are at a relatively low level, although with the identification of good gas plays, a multiplicity of drilling and support installations all at different stages of development will be required, as demonstrated by an investigation by the New York Department of Environmental Conservation (NYDEC)[14]. The regulation of Cuadrilla's activities at present is very intensive[15] but a question remains as to whether regulation and oversight by regulatory authorities can be maintained with significantly higher development activity in multiple areas and by many companies.

THE REGULATORY REGIME

The process by which companies obtain permission to undertake individual stages of shale gas exploitation are significantly complicated and prone to delay and blocking by local concerns, mostly relating to the industrialisation of the environment[16]. Local planning authorities generally consider local issues when considering development permissions and regulatory bodies granting permits consider the individual processes being undertaken rather than a wider view[17].

The wider view of large-scale developments is usually undertaken through a strategic environmental assessment (SEA)[18]. The SEA examines the wider environmental issues as well as balancing aspects of sustainability against national priorities and aims to inform ministerial decisions[19]. In 2010, DECC commissioned an environmental assessment relating to its 14th onshore licensing round[20], although consultation on this was suspended following seismic tremors from trial fracturing in West Lancashire[21]. In May 2013 the Government commissioned a new SEA for the 14th licensing round process. However, a national-level SEA relating to onshore exploration may not be the best vehicle for the particular issues raised by unconventional gas exploitation. Other SEAs relate to regional strategic decisions, such as the SEA for the Thames Estuary Plan, and evaluate regional issues while engaging the public in decisions that will affect their environment[22]. A regional-scale SEA would provide a framework for planning decisions within areas affected by shale gas exploitation and allow effective public consultation.

THE PRACTICE OF RISK ASSESSMENT

Risk assessments for extractive industries are an EA-determined requirement originating from the mining waste directive[23], the format of which is loosely defined within Defra's environmental risk assessment guidelines (*Green Leaves III*)[24] and covered by the EA's H1 Horizontal guidance notes[25]. Risk assessment is part of the process by which operators show that they have applied the best available technique in dealing with the by-products and legacy of their development activity[26]. Recent examples from Cuadrilla show improvement, with increased levels of auditable detail on mitigation methods.

However, a concern would be that not all risks that could have an impact on the environment are being released into the public domain. The EC directives 96/82/EC and 2012/18/EU for the control of major accident hazards involving dangerous substances (Seveso II and III Directive) set in place requirements for safety management systems and emergency planning for large installations and for public access to that information[27]. While the Seveso Directives are aimed at large industrial installations, it might be argued that shale gas exploitation is really a dispersed large industry and so the same level of rigour should be applied. The processes used to reduce risk, like HAZID bowtie exercises, could be transferable to the shale gas industry and provide significant reassurance to communities with the rigour and detail of this approach. Arguably the HAZID approach is a best available technique for environmental risk assessments and should be considered by the regulatory bodies for shale gas risk management.

THE UK EXPLOITATION DECISION

The US energy security concern has assisted shale gas exploitation over the past decade[28] and pushed environmental concerns over the activity into the background[29]. However, the experience of US communities' involvement with the nascent shale gas industry has caused widely publicised concerns within potentially affected UK communities. The potential for shale gas to change the economic landscape of the UK has been recently highlighted by significantly increased British Geological Survey (BGS) figures of 'gas in place' reserves[30] and the improved US economic situation[29].

In spite of this, until recently the UK Government has been reluctant to expediently exploit these resources due to its commitment to international carbon agreements and perceived environmental risks[31]. Broomfield[1], in his review of the management of shale gas risks within the EU, stated that current legislation was adequate for the supervision of the industry while exploitation was at a low level, but that additional regulation might be required for regulating the widespread effects of the activity. DECC has determined that gas will be an increasing component of the UK's energy provision up to 2030[31], and accordingly the Government needs to support the regulatory authorities to allow them to monitor the industry effectively. The recent announcement of a reduction in the EA's funding does not support this[34].

"The regulatory authorities need adequate numbers of appropriately skilled people overseeing operations at each stage to ensure that undue risks are not taken."

The smooth development of the shale gas industry within the UK is dependent on making accurate assessments of the risks operators take in exploiting the resource. Risk assessors need standard tools with consistent definitions with which to define the impact and the likelihood of risks so that regulators can confidently authorise development activity. The regulatory authorities need adequate numbers of appropriately skilled people overseeing operations at each stage to ensure that undue risks are not taken and that appropriate remedial actions are taken when issues occur. Finally the public needs to have full access to risk information so that they can see best available techniques being diligently used and can hold operators to account. ES

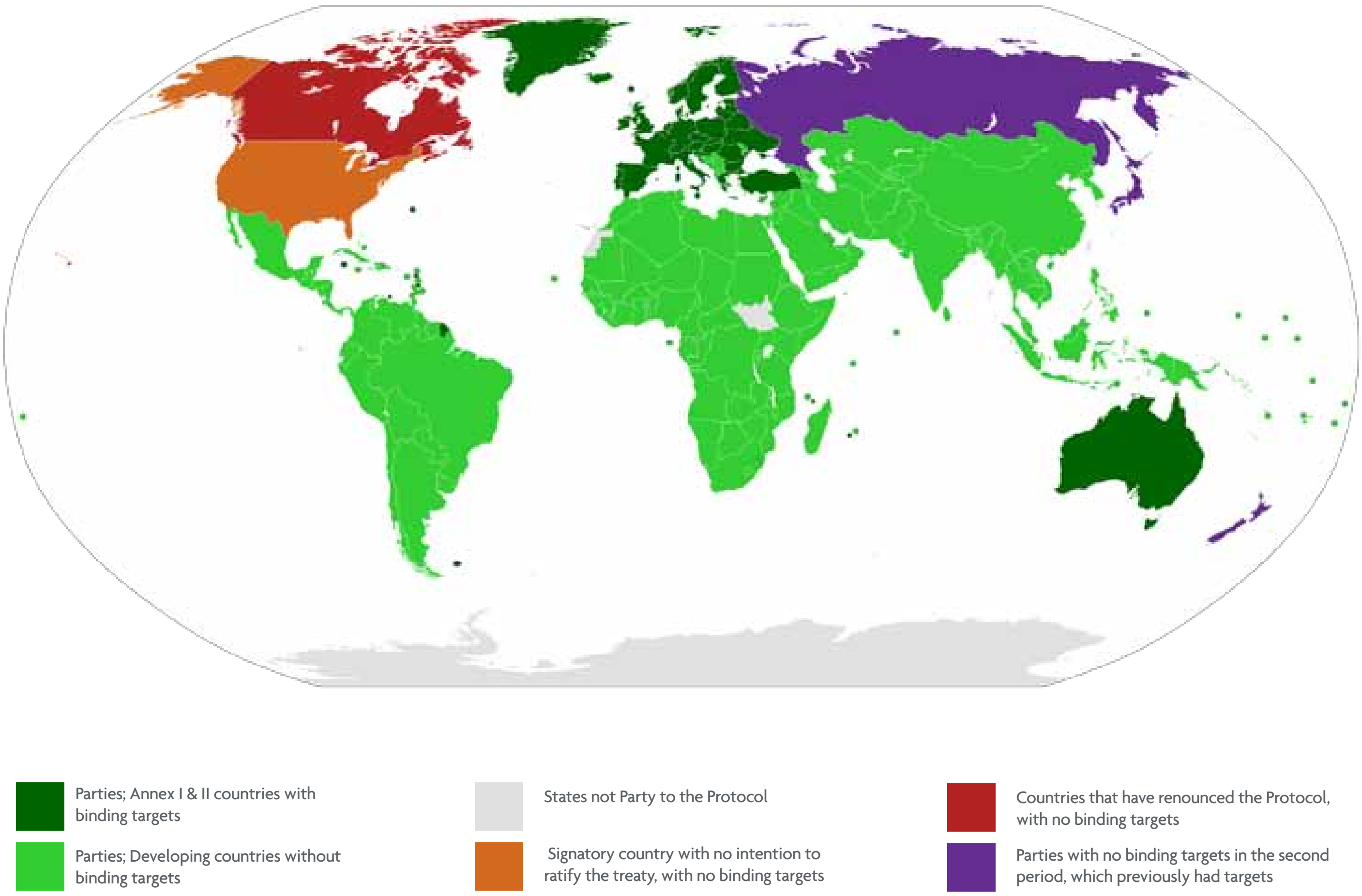
Ian Davison is an environmental manager working for the QSS Group, a safety, quality and environmental consultancy based in Derby. He recently completed his masters degree in environmental management at the University of Derby, for which the subject of his masters thesis was the management of risks from shale gas exploitation.

SOURCES

1. Broomfield, M. (2012) *Support to the identification of potential risks* for *the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe: Report for European Commission DG Environment Issue 17*. ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf.
2. Ingraffea, A. (2011) *Facts on Fracking GAD Luzerne County*. www.youtube.com/watch?v=mSWmXpEkEPg (Accessed: 2 February 2013).
3. Spence, D.B. (2012) Federalism, Regulatory Lags and Energy Production, University of Pennsylvania Law Review 2012, *University of Texas Law and Econ Research Paper No 222*, Social Science Electronic Publishing. papers.ssrn.com /sol3/papers.cfm?abstract_id=2017280.
4. Guarnone, M., Rossi, F., Negri, E., Grassi, C., Genazzi , D., and Zennaro, R. (2012) An unconventional mindset for shale gas surface facilities, *Journal of Natural Gas Science and Engineering*, 6(1), pp14–23. ScienceDirect. talis-list.derby.ac.uk:2108/science?_ob=ArticleListURL&_method=list&_ArticleListID=-89490554&_sort=r&_st=13&view=c&_acct=C000054125&_version=1 &_urlVersion=0&_userid=1665738&md5=115a8bb3b9860f2f7aec48c1b2ee1b2f&searchtype=a.
5. Rahm, B.G., and Riha, S.J. (2012) Toward strategic management of shale gas development: Regional, collective impacts on water resources, *Environmental Science and Policy*, 17, pp12–23. Science Direct. talis-list.derby.ac.uk:2108/science/article/pii/S1462901111001948#.
6. EA (Environment Agency) (2012a) *Monitoring and control of fugitive methane from unconventional gas operations*. a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/scho0812buwk-e-e.pdf. EA (Environment Agency) (2012b) *Guidance Note: Regulation of exploratory shale gas operations*. a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/LIT_7284_231c35.pdf.
7. EA (Environment Agency) (2013a) *Shale Gas – North West – Monitoring of Flowback Water*. www.environment-agency.gov.uk/static/documents /Business/6th_Dec_-_Shale_gas_-_North_West_-_Monitoring_of_flowback_water_-_update_(3).pdf.
8. DECC (Department of Energy and Climate Change) (2009) *Guidance Notes for Onshore Oil and Gas field development Plans*. www.gov.uk/government/uploadssystem/uploads/attachment_data/file/15707/onshore ogfdpguide.doc. DECC (Department of Energy and Climate Change) (2011a) The Unconventional Hydrocarbon Resources of Britain's Onshore Basins – Shale Gas. og.decc.gov.uk/ assets/og/bo/onshore-paper/uk-onshore-shalegas.pdf.
9. Defra (2011) *Guidelines for Environmental Risk Assessment and Management: Green Leaves III*. www.gov.uk/government/uploads/system /uploads/ attachment_data/file/69450/pb13670-green-leaves-iii-1111071.pdf.
10. Cuadrilla (2013g) Email to Ian Davison, 14 June.
11. Pritchard, P. (2000) *Environmental Risk Management*. Earthscan Publications Ltd, London.
12. Darbra, R.M., Eljarrat, E., and Barcelo, D. (2008) How to measure uncertainties in environmental risk assessment, *TrAC Trends in Analytical Chemistry*, 27 (4), pp377–385. Science Direct. www.sciencedirect.com.ezproxy.derby.ac.uk/science/article/pii/S0165993608000356.
13. Davey, E. (2012) *Written Ministerial Statement by Edward Davey: Exploration for shale gas*. www.gov.uk/government/speeches/written-ministerial-statement-by-edward-davey-exploration-for-shale-gas.
14. Macalister, Y., and Monaghan, A. (2013) Fracking gets major boost from Centrica, *The Guardian*, 13 June. www.guardian.co.uk/business/2013/jun/13/fracking-boost-centrica-blackpool.
15. Harvey, F., and Carrington, D. (2013) Fracking communities should get incentives, says minister, *The Guardian*, 18 March. www.guardian.co.uk /environment/2013/mar/18/fracking-communities-incentives-minister.
16. NYDEC (New York Department of Environmental Conservation) (2011a) *Revised Draft SGEIS on the Oil, Gas and Solution Mining Regulatory Program*. www.dec.ny.gov/energy/75370.html.
17. POSTNote (2011) *Unconventional Gas*. gov.uk/government/uploads/system/uploads/attachment_data/file/79189/ungaspostnote.pdf.
18. Lean, G. (2013) Fracking faces tough foes in leafy Sussex, *The Daily Telegraph*, 28 June. www.telegraph.co.uk/earth/energy/10148552/Fracking-faces-tough-foes-in-leafy-Sussex.html.
19. Royal Society (2012) *Shale gas extraction in the UK: a review of hydraulic fracturing – Royal Society of Engineering*. royalsociety.org/uploadedFiles/Royal_Society_Content/policy/projects/shale-gas/2012-06-28-Shale-gas.pdf.
20. Feldmanna, L., Vanderhaegena, M., and Pirotte, C. (2001) The EU's SEA Directive: status and links to integration and sustainable development, *Environmental Impact Assessment Review*, 21, pp203–222. ScienceDirect. www.sciencedirect.com.ezproxy.derby.ac.uk/ science/article/pii/S0195925501000713.
21. DECC (Department of Energy and Climate Change) (2013c) *Offshore Energy Strategic Environmental Assessment (SEA): An overview of the SEA process*. www.gov.uk/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process.
22. OOGL SEA (Onshore Oil and Gas Licensing / *Strategic Environmental Assessment) (2010) Strategic Environmental Assessment for a 14th and Subsequent Onshore Oil & Gas Licensing Rounds*. www.gov.uk/government/ uploads/system/uploads/attachment_data/file/66721/onshore-er.pdf.
23. DECC (Department of Energy and Climate Change) (2013d) *Oil and gas: licensing rounds*. www.gov.uk/oil-and-gas-licensing-rounds.
24. Jones, C., Baker, M., Carter, J., Jay, S., Short, M., and Wood, C. (eds) (1999) Strategic Environmental Assessment and land Use Planning. Earthscan, London.
25. DECC (Department of Energy and Climate Change) (2010) *Environmental Permitting Guidance The Mining Waste Directive*. www.gov.uk/government/uploads/ system/uploads/attachment_data/file/69323/pb13636-ep2010miningwaste.pdf.
26. Defra (2013) *What we do*. www.gov.uk/government/ organisations/department-for-environment-food-rural-affairs.
27. EA (Environment Agency) (2013d) *Horizontal Guidance: H1 Environmental Impact Assessment*. www.environment-agency.gov.uk /business/topics/permitting/36414.aspx.
28. EA (Environment Agency) (2004) *Guidance for the Recovery and Disposal of hazardous and Non Hazardous Waste*. www.environment-agency.gov.uk/static/documents/Business/sgn_issue_4_968872.pdf.
29. European Commission (2012) *Chemical Accidents (Seveso I, II and III) – Prevention, Preparedness and Response*. ec.europa.eu/environment/seveso /index.htm.
30. Baker Institute Rice University (2010) *Research: Shale Gas and U.S. National Security*. www.bakerinstitute.org/programs/energy-forum/research/research-shale-gas-and-us-national-security.
31. Haug, M. (2012) Shale gas and renewables: divergence orwin-win for transatlantic energy cooperation?, *Journal of Transatlantic Studies*, 10 (4), pp358–373.
32. BGS (British Geological Survey) (2013) *New shale gas resource figure for central Britain*. www.bgs.ac.uk/shalegas/#ad-image-0.
33. Lilley, P. (2013) Britain can't afford to surrender to the greens on shale gas, *The Spectator*, 11 May. www.spectator.co.uk/features/ 8905731/the-only-way-is-shale/.
34. HSE (Health and Safety Executive) (2013a) *ALARP at a glance*. www.hse.gov.uk/risk/theory /alarpglance.htm.
35. HSE (Health and Safety Executive) (2013b) *Risk Assessment*. www.hse.gov.uk/risk/risk-assessment.htm.
36. The ENDSreport (2013) *Environment Agency job cuts bigger and quicker than expected*. www.endsreport.com/41255/environment-agency-job-cuts-bigger-and-quicker-than-expected.

What would be the consequences of the UK not meeting its Kyoto carbon targets?

Paulina Poplawski-Stephens assesses whether the UK will meet its Kyoto targets, and what will happen if it fails to do so.



▲ **World map showing Kyoto protocol participation, adapted from © Wikimedia. Created by L.Tak.**

In 1997, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol, the international act binding nations around the world to reducing carbon emissions. The Kyoto Protocol entered into force on 16 February 2005 when 184 Parties of the Convention ratified it. Those countries took on binding targets for the first commitment period (KP1) that ran from 2008 to 2012.

So what would happen if the UK failed to meet its targets? In the first instance, we must approach the question by looking at the European Union's obligations in the UNFCCC's Kyoto Protocol. This is because, in May of 2002, the EU as a whole ratified KP1, taking advantage of a scheme under the Protocol known as a 'bubble', in particular Article 4 of the Kyoto Protocol which allows Parties to form agreements to fulfil their

Table 1. The 1997 EU Parties to the Kyoto Protocol and their emissions reduction targets

	Target for 2008–12 (percentage change from base year 1990)
EU-15	−8
Austria	−13
Belgium	−7.5
Denmark	−21
Finland	0
France	0
Germany	−21
Greece	+25
Ireland	+13
Italy	−6.5
Luxembourg	−28
Netherlands	−6
Portugal	+27
Spain	+15
Sweden	+4
United Kingdom	−12.5

Article 3 commitment jointly. This means that all EU member states in the 'bubble' will be considered compliant with their 2008–12 commitments if their total combined emissions were less than or equal to the assigned amount in Kyoto units, each of which is 1 tonne of CO_2-equivalent (CO_2e) emissions. This corresponds to a combined reduction target of 8 per cent by 2012.

This 8 per cent target was redistributed among the 15 'bubble' states (also called the EU-15) – the countries that were EU members in 1997 when the Kyoto Protocol was adopted. These member states were Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland (**Table 1**). The redistribution is better known as the EU burden-sharing agreement, which sets different emissions limitation and reduction targets for each member state. It also effectively splits each national Kyoto target into an emissions budget for the Emissions Trading System (ETS) sectors and another emissions budget for the sectors not covered by the ETS (e.g. agriculture, buildings, transport, waste).

KP1: 2008–12

At this point in time, the EU is able to predict its own KP1 compliance with a strong level of confidence, as the latest EU reporting data includes greenhouse gas (GHG) emissions for the 2008–12 period. GHG emissions from the ETS have been verified up to 2012, plus the EU has early estimates from member states of their 2012 GHG emissions.

The EU-15 is on track to have done better than its 8 per cent reduction target. According to the European Environment Agency (EEA), total average emissions of the EU-15 in the 2008–12 period have declined by 12.2 per cent compared to base-year (1990) levels. Furthermore, planned use of Kyoto mechanisms[1] – assigned amount units (AAUs), certified emissions reductions (CERs) and emissions reduction units (ERUs) – as well as estimated removal units (RMUs) from LULUCF (land use, land-use change and forestry) will have contributed to additional emissions reductions in the EU-15.

Based on the facts, the EU-15 will easily sail into the second commitment period with a KP1 overachievement, although 'achievement' is probably not the best description. Emissions reductions in the EU's ETS (responsible for about half of the emissions profile) were primarily driven by the recession, which reduced demand for industrial products and lead to a decline in production and therefore CO_2e emissions. The use of permitted project-based credits (CERs, ERUs) equating to 1,048 million tonnes CO_2e emissions[2] played a secondary role in the ETS sectors' performance.

ANOTHER SCENARIO

But let us consider the unlikely hypothetical scenario that that circumstances arise that render the EU 'bubble' defunct. The default position in this case then becomes the carbon performance of the 15 member states individually at the end of the first commitment period. In this scenario, what is the risk of the UK not meeting its individual binding target?

According to EEA reports, since 1990 the UK's GHG emissions have fallen by 28 per cent. More so, EU-15 data shows that it is thanks to the UK's performance that the EU is nearing the KP1 finish line in such good shape. The UK is on track for meeting its KP1 binding target on the basis of domestic reductions alone (despite the UK holding one of the lowest shares of renewable energy in 2011) as the UK Government reported to the European Commission this year that it had no intention of using Kyoto mechanisms for the commitment period.

OVER OR UNDER?

However, the EEA warns that their analysis of the data can only be seen as a preliminary indication. This is because each Party's 2012 annual reports will only be officially submitted to the UN on 15 April 2014, and then the UN's experts will undertake a rigorous review of the EU-15's and UK's reports. This could take up to a year, and therefore the UK's carbon inventory will likely only be finalised in 2015. In the end, despite promising data analysis from the EEA, it is the UN's Compliance Committee that has the authority to decide whether the EU-15 'bubble' or the UK is under or over its assigned carbon budget.

If the UK's actual emissions exceed its assigned amount of Kyoto units for that commitment period, the Compliance Committee will give the UK 100 days to make up any shortfall in compliance by acquiring AAUs, CERs, ERUs or RMUs through emissions trading. This 100-day time frame is better known as the 'true-up period'. At the end of the true-up period, if UK's inventory reveals that there is a deficit in its assigned budget, the matter is handed over to the 'enforcement branch', which is responsible for determining whether a Party with a binding target is not in compliance with its emissions targets, the methodological and reporting requirements for GHG inventories, and the eligibility requirements under the mechanisms.

The enforcement procedure has several steps. After a preliminary examination, competent intergovernmental and non-governmental organisations may submit relevant factual and technical information to the enforcement branch as part of a consultation period. In this way, enforcement bases its deliberations on reports from external stakeholders but also the UN's expert review teams and its subsidiary bodies (namely the body for scientific and technological advice and the body for implementation), Kyoto Protocol Parties, etc. The UK will have the opportunity to make formal written submissions and request a hearing where it can present its views and call on expert testimony.

The enforcement branch's decision is final and binding, and the UK would only be able to appeal if it felt it has been denied due process. Should the enforcement branch rule against the UK, the UN Compliance Committee will then publicly declare the UK as non-compliant and will also make public the consequences to be applied.

SO WHAT HAPPENS NEXT?

In 2011, when Canada's environment minister, Peter Kent, confirmed that Canada was legally withdrawing from the Protocol he also crudely described the international agreement as having "very few teeth beyond international diplomatic censure"[3].

Canada chose to withdraw because it had calculated that it would have to pay approximately CAN14 billion in buying emissions reductions from other Kyoto protocol countries to meet its target. However it could have also chosen to not meet its target and be declared non-compliant, because under the enforcement procedure, its carbon deficit (plus an additional penalty deduction of 30 per cent from its assigned amount) would have been carried over to the second commitment period.

Enforcement includes naming and shaming, having to submit a compliance action plan and suspension from making transfers through emissions trading until reinstated. But, as far as real emissions reductions are concerned, the UK would be given time until the end of the next true-up period (after 2020) to rebalance its carbon budget.

The international enforcement machinery in its current state is weak. The UK, should it not meet its targets, has a 100-day window to buy its way out of non-compliance through emissions trading. And unfortunately, based on CER prices today[4] and the predicted AAU surplus of some EU member states[5], these mechanisms represent a negligible financial fear factor and a disproportionately low carbon cost – not to mention a controversial means of achieving emissions reductions[6]. If after trading it still has a deficit, the UK can carry its responsibility over, rendering first-period actions inconsequential until the end of the second period.

KP2: 2013–20

There is another sticking point. The second commitment period is enshrined in the Doha Amendment. The Amendment was agreed at the UN Climate Change Conference in Doha, Qatar in December 2012 and comprises a number of amendments to the Kyoto Protocol. Importantly, it establishes a second commitment period with legally binding emissions targets for the years 2013–20.

However, only Bangladesh, Barbados, Mauritius, Monaco and the UAE have ratified the Doha Agreement, as of 27 December 2013[7], although the 28 member states of the EU and Iceland intend to jointly ratify the Amendment along with Australia, Liechtenstein, Norway and Switzerland. Nevertheless, those Parties will not be enough for the Amendment to take legal effect in international law – it needs 144 of the 192 Parties to the Kyoto Protocol[7]. This means that, for the time being, there exists a post-KP1 enforcement loophole.

THINKING WITH OUR SCIENCE GOGGLES ON

Despite the international agreement being where it is, is, the EU and the UK, assuming the global leadership role in tackling climate change, must continue to support ideas like reason and empirical research as the basis for understanding the world.

The Intergovernmental Panel on Climate Change (IPCC, the UN's scientific panel) says that "human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system[9]". The IPCC's fifth assessment report, to be published in full in October 2014, is expected to further underline the certainty that warming is anthropogenic.

The Parties to the UNFCCC will join the negotiation table in 2015 in Paris at the 21st Conference of the Parties, which should result in a make-or-break decision – the global community will choose to either support the scientific consensus or undermine it. 2015 will be the year of the ultimate push for a post-2020 binding agreement to prevent dangerous anthropogenic interference in the climate system, and successful adoption of a new agreement by global leaders will remind the laggards that science remains at the head of the negotiation table. ES

Paulina Poplawski-Stephens has worked in the climate change sector for six years in consulting, auditing and carbon credit procurement. She is currently based in Paris and works with ClientEarth's Climate and Energy Team. She completed her legal studies in London and her environmental science studies at the University of Guelph, Canada.

SOURCES

1. UNFCCC. The Mechanisms under the Kyoto Protocol: Emissions Trading, the Clean Development Mechanism and Joint Implementation. unfccc.int/kyoto_protocol/mechanisms/items/1673.php (Accessed: 7 January 2014).
2. European Environment Agency (EEA). *Trends and projections in Europe 2013. Tracking progress towards Europe's climate and energy targets until 2020*. EEA Report. No.10/2013.
3. Carrington, D, Vaughan, A. (2011) Canada condemned at home and abroad for pulling out of the Kyoto treaty. The Guardian, 13 December. www.theguardian.com/environment/2011/dec/13/canada-condemned-kyoto-climate- treaty.
4. See, for example, www.eex.com/en/Market%20Data/Trading%20Data/Emission%20Rights/Certified%20Emission%20Reductions%20Futures%20%7C%20Derivatives (Accessed: 7 January 2014).
5. Ruthner, L., Johnson, M. Chatterjee, B., Lazarus, M., Fujiwara, N., Egenhofer, C., du Monceau, T., and Brohe, A. (2011) *Study on the Integrity of the Clean Development Mechanism* (CDM). Report ref: CLIMA.B.3/ETU/2010/0020r. AEA, Stockholm Environment Institute, Centre for European Policy Studies, CO2logic. ec.europa.eu/clima/policies/ets/linking/docs/final_report_en.pdf.
6. EEA Report (ibid). Czech Republic, Estonia, Lithuania, Slovenia, Latvia, Hungary, Romania and Bulgaria have reported surplus AAUs to the European Commission.
7. UNFCC (2012) Doha Amendment. www.unfccc.int/kyoto_protocol/doha_amendment/items/7362.php (Accessed: January 2014)
8. The Marrrakech Accords and the Marrakech Declaration. 2001. Annex: Procedures and mechanism relating to compliance under the Kyoto Protocol IX. PROCEDURES FOR THE ENVIRONMENT BRANCH www.unfccc.int/files/meetings/cop_11/application/pdf/cmp1_23_7_procedures_and_mechanisms_compliance.pdf
9. IPCCC (2013) *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Summary for Policymakers*. IPCC, Geneva. www.climatechange2013.org/images/uploads/WGI_AR5_SPM_brochure.pdf.

Bournemouth University

MSc Green Economy

Study from anywhere in the world

Unique

- The only course of its type in the world.

Flexible

- Delivered entirely by distance learning (full/part-time)
- Can be taken as Continuing Professional Development (CPD) units
- Combine your studies with paid or voluntary employment.

Topical

- The development of a green economy is a political and socio-economic imperative
- Acquire the knowledge and skills to enable the transition to a green economy.

Interdisciplinary

Course content includes:

- Carbon management
- Green technologies and renewable energy
- Biodiversity and ecosystem services
- Sustainability science
- Environmental law and social justice
- Sustainable development.

Business critical

- Scope for a professional placement in a workplace
- Job opportunities across many sectors of the economy
- Combine the course with work-based learning.

Find out more...

Visit:
www.bournemouth.ac.uk/green-economy

Contact:
askBU Enquiry Service
Tel: +44 (0)1202 961916
Email: askBUenquiries@bournemouth.ac.uk
www.bournemouth.ac.uk/askBU