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Environmental Chemistry Group **www.rsc.org/ecg**

Bulletin

'Dire combustion and confused events'. Shakespeare's imagery in *Macbeth* also mirrors the complexity of the pyrolysis of organic waste – one of the topics in this year's ECG DGL & Symposium. **Image Credit:** Sommai/Shutterstock.com.

In this issue

The conversion of waste into chemical products and energy, for example by pyrolysis and gasification, was the theme for this year's **Distinguished Guest Lecture & Symposium** held on March 14th 2012 at Burlington House, London. The guest lecture, entitled "Fuels, chemicals and materials from waste," was given by **Professor Paul T. Williams**, University of Leeds. Other speakers covered the UK government position on energy from waste, the production of high-value chemicals, the planning and environmental impacts of pyrolysis and gasification, and the anaerobic treatment of municipal organic waste in composting facilities. A meeting report and articles based on presentations at this meeting may be found on pages 3-12 of this issue.

Also

Reports from a meeting on **Contaminated Land Risk Assessment**, the **First UK Solar to Fuels Symposium**, and the **ESED awards ceremony**; an article on the role of **"Big Society"** reprinted from the *Journal of Environmental Monitoring*; and details of upcoming meetings on the ***Silent Spring* 50th Anniversary** and on **Health and Hydrogeology**.

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Energy, waste and resources – three sides of the same coin?

A report of the Environmental Chemistry Group 2012 Distinguished Guest Lecture and Symposium, held in the Chemistry Centre at Burlington House on Wednesday, March 14th 2012.

The 2012 Distinguished Guest Lecture was given by Professor Paul Williams (University of Leeds), and around sixty people attended. Biographical information for the DGL and supporting speakers together with their slides and abstracts for the presentations are available at http://www.rsc.org/Membership/Networking/InterestGroups/Environmental/2012-distinguished-guest-lecture.asp.

The first paper ("Energy from Waste: a policy perspective") was delivered by **James Cooper**, Head of Energy-from-Waste Policy, DEFRA. He described the UK government's role and ambitions with respect to energy-for-waste as being part of the strategy "to achieve a more sustainable approach to the use of materials and an improvement in the services offered to households and businesses in relation to waste collection and disposal whilst delivering environmental benefits and supporting economic growth." Household recycling rates have increased from 11% in 2000/2001 to 40% currently. Energy from Waste (EfW) is seen as one way to hit increasingly stringent targets for reduced waste disposal *via* landfill. More EfW will also help to meet local and national renewable energy targets. To do this consistently it is expected that efficiencies will have to increase to balance a predicted decrease in feedstock: "More energy out of less waste" is needed. The waste market in the UK accounts for ~0.7% of GDP and in a green economy there will be opportunities to grow this sector; the production of reformed biofuels from waste incineration is one such possibility receiving close attention. To be successful, all next-generation EfW processes must be able to respond and adapt to continuing changes in environmental legislation regarding emissions, products and feedstock mix. For further information see the Government Review of Waste Policy in England 2011; http://www.defra.gov.uk/publications/2011/06/14/pb13540-waste-review/.

The second speaker, **David Brignall** (Wardell Armstrong), spoke on "Pyrolysis and gasification – planning and environmental impacts". He described how the use of gasification [a process that converts carbon-based materials at temperatures above 700 °C to produce syngas (a gas mixture containing varying amounts of carbon monoxide and hydrogen) and solid residues] and pyrolysis (the thermochemical decomposition of organic materials at elevated temperatures without oxygen, producing chars, oil and syngas) satisfied the need for reduced landfill disposal, renewable Combined Heat and Power (CHP), and local waste strategy solutions. Complications arise because any demonstration of commercial viability is site-based and complex; pyrolysis and gasification processes are therefore perceived as a high long-term investment risk. These problems are exacerbated by the difficulties of identifying long-term feedstock supplies and ensuring that any plant that is built can easily be adapted to respond to changes in the legislative framework. Public resistance to the building of incineration plants is a further and important factor; the resulting delays are difficult to factor into the overall costs.

Some of the strands relating to the difficult commercial aspects of energy and waste were reinforced by **Kris Wadrop** (Solvert Ltd) in his talk on "Where's there's muck there's *n*-butanol (and a range of other high value chemicals)." He described his experience in establishing a commercial process for the production of *n*-butanol and acetone by advanced anaerobic digestion. This process of biological fermentation allows organic waste to be used to produce valuable commodity chemicals and fuels. Thermochemical pretreatment, enzymatic hydrolysis, nutrient addition and sterilisation occur before first-stage digestion to produce *n*-butanol. 17000 tonnes of *n*-butanol are used in the UK every year; currently all of this is imported. Kris emphasised the financial difficulties encountered by a small company trying to break into a market dominated by large companies with long-term contracts for waste supply with organisations such as Tesco.

Raffaella Villa (Cranfield University) spoke on "Organic waste disposal: emissions and risks." Her quote from Richard Buckminster Fuller is a wonderful expression of the lack of legal, political, financial and scientific imagination when it comes to the management of waste:

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

Raffaella described her studies of the anaerobic treatment of municipal organic waste in composting facilities. Heat can be obtained from biogas production (methane and carbon dioxide), but odour problems are ubiquitous and like all odour issues, they are famous for their difficulties. Studies of bioaerosol emissions have shown that for the most part they declined quickly from the source, although anomalous and unexplained maxima in atmospheric bioaerosol concentrations were observed some distance away from the plant. As with all EfW processes, feedstock content and consistency are problematic; there are seventy different types of waste which can be used in an anaerobic digester, and seventy-five hazards associated with them. Risks can be reduced by excluding certain types of waste and by applying Quality Assurance/Quality Control codes of practice to feedstock sources, but this possibility seems remote currently. Raffaella finished with a brief reference to the use of algal biomass as a feedstock for biogas production.

Paul Williams entitled his **Distinguished Guest Lecture** "Fuels, chemicals and materials from waste." He explained that a total of 288.5 million tonnes of waste per year are generated in the UK. This waste can be broken down into 86 million tonnes from mining and quarrying, 101 million tonnes from construction and demolition, 67.3 million tonnes from commerce and industry, and 31.5 million tonnes from households. The most important change in the disposal of this waste has been the move from landfall to recycling. Although there has been only a small growth in incineration, the development of new processes, changes in the availability of resources, and targets set by government policy have combined to bring renewed attention to the arguments in favour of EfW. Paul surveyed the basic thermal conversion technologies available – incineration, gasification and pyrolysis – and then dealt in more detail with pyrolysis

The primary products of pyrolysis (oil, char and syngas) can be subdivided in terms of the secondary products and their use, namely fuel and chemical feedstock from syngas, refinery feedstock and chemicals from liquid fuel, and solid fuel, activated charcoal and soil improver from char. The amounts and range of these products can be manipulated by changes in the burn. For example, slow pyrolysis (hours to days at 400 °C) produces mainly charcoal, whereas fast pyrolysis (1 second burn) results in the production of liquid at 400 to 650 °C, liquid and syngas at 650 to 900 °C, and syngas at 1000 to 3000 °C. The reactor type (fluidised bed, entrained flow, rotary kiln, etc.) is also relevant. For example, the Ensyn process produces bio-oil using an entrained flow reactor for fast pyrolysis; bio-oil is a potential substitute for fuel oil or as feedstock for the production of synthetic gasoline and diesel, although the high acidity of bio-oil and its poor stability are two of several problems which exist. Commercial-scale pyrolysis operations include Metso Mineral Industries, Japan; Toshiba Mixed Plastics Pyrolysis, Japan; Splainex Ltd, Netherlands; Empyro, Netherlands; and Dynamotive, Canada.

The characteristic feature of gasification is the provision of limited amounts of oxygen. The syngas produced has a tar content associated with fine particles and SO_x pollutants; line blockage and corrosion caused by the tar is problematic. This "dirty" gas is can be put straight into a boiler to produce steam. Such processes have a history of long acceptance in Japan. Although "dirty" syngas can be purified (e.g. by catalytic gasification), the commercial arguments for this are not robust.

Paul finally turned his attention to the "valorization" of waste. For example, 1000 million tyres are disposed of globally each year. The catalytic pyrolysis of tyres produces a highly aromatic oil (toluene, benzene, xylene). Plastics, composite plastics and carbon fibre materials can also be treated as specialised feedstock to produce products with specific and niche demand.

The range and detail of the presentations produced a picture of a vibrant area of development and opportunity; the urgent need for smarter methods of waste treatment and for the fiscal and legislative framework to be developed to support them was made abundantly clear. There seems to be no limit to the possibilities for fine-tuning the many and varied waste treatment processes available for local scale activity, but robust and proven technologies that can be built using conventional investment tools are few in the UK.

LEO SALTER

Vice-Chair, Environmental Chemistry Group

Syngas (synthetic gas) consists mainly of hydrogen and carbon monoxide plus some carbon dioxide.

An open access review of the historical development of syngas and the gasification technologies which are used to manufacture this commodity is available on the web: R. W. Breault, *Energies*, 2010, **3**, 216-240; doi:10.3390/en3020216.

Image Credit (p 3): Huguette Roe/Shutterstock.com.

Fuels, chemicals and materials from waste

In the UK, 288.5 million tonnes of waste are produced each year (**Figure 1**). For the European Union (EU-27), the waste generation figures are even more astonishing at 2.62 billion tonnes per year. Management of these wastes is often through landfill and incineration and low level mechanical recycling. However, such enormous tonnages of waste represent a significant potential for advanced recycling to recover fuels, chemicals and materials.

The advanced thermal treatment technologies of pyrolysis and gasification are generating increasing interest as viable alternative environmental and economic options for waste processing. These options have a number of advantages over conventional incineration or land filling of waste. Depending on the technology, the waste can be processed to produce syngas or oil products for use as fuels or petrochemical feedstocks or to recover valuable materials.

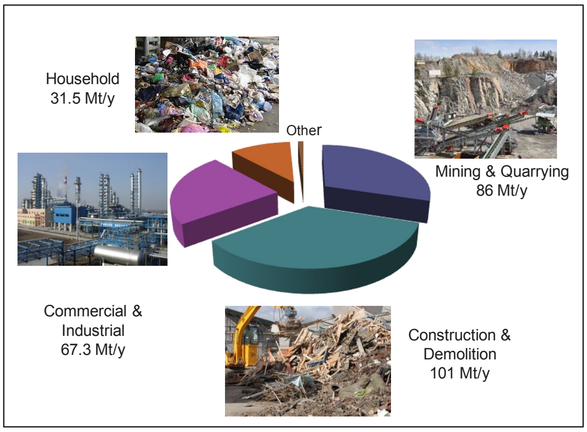

Figure 1: *Origins of waste in the UK (Defra 2008).*

Pyrolysis

Pyrolysis is the thermal degradation of organic waste in the absence of oxygen to produce a carbonaceous char, oil and combustible gases. Waste materials are composed of complex chemical polymers, and the process of thermal degradation or pyrolysis of such materials, in the absence of oxygen, breaks up the long polymer chains to produce chains and molecules with lower molecular weights. These shorter molecules result in the formation of the oils and gases characteristic of pyrolysis of waste.

The production of oils from the pyrolysis of waste has been investigated with the aim of using the oils either directly in fuel applications, or with upgrading to produce refined fuels. The pyrolysis oils derived from a variety of wastes are complex in composition and contain a wide variety of chemicals, which may be used as chemical feedstocks. The oil has a higher energy density, that is, a higher energy content per unit weight, than the raw waste. The solid char can be used as a solid fuel or as a char-oil, char-water slurry for fuel; alternatively, the char can be used as carbon black or upgraded to activated carbon. The gases generated have medium to high calorific values and may contain sufficient energy to supply the energy requirements of a pyrolysis plant.

Pyrolysis may be divided into three types according to the operating conditions: slow pyrolysis, conventional pyrolysis and flash pyrolysis. Slow pyrolysis is associated with the production of charcoal at low temperature with a long vapour residence time. Conventional pyrolysis involves moderate heating rates (20 °C/min) and pyrolysis temperatures typically between 400-600 °C. It produces a fairly even distribution of char, oil and gas, depending on the raw waste material. Fast pyrolysis involves high heating rates and short vapour residence time with rapid cooling of the pyrolysis gases, conditions which are optimum for the production of bio-oil.

Table 1 shows the fuel properties of oils derived from the pyrolysis of various wastes compared to gasoil. The plastics and tyre pyrolysis oils were produced by conventional pyrolysis and the bio-oil by fast pyrolysis. The oils produced from plastics and tyres have high calorific value, comparable to that of gas oil derived from petroleum. The bio-oil has a lower calorific value and contains oxygen at more than 40 wt%, because of the high oxygen content of the original cellulose, hemicelluloses and lignin of the feedstock biomass waste. The oxygen content is comprised of moisture, which can be more than 20 wt%, and also oxygenated compounds such as organic acids (5 to 10 wt%), aldehydes and hydroxyaldehydes (5 to 20 wt%), ketones and hydroxyketones (0- 10 wt%) and phenolic compounds (15 to 30 wt%). Because of the high oxygen and moisture content of bio-oil derived from biomass wastes, techniques for upgrading and refining pyrolysis bio-oils for liquid transport fuels or chemical feedstocks have been investigated. Upgrading methods for bio-oils mainly include catalytic cracking, catalytic esterification and catalytic hydroprocessing. Catalysts have also been used to upgrade the pyrolysis oils derived from waste. Zeolite catalysts have

Property	Polyethylene[1]	Nylon[1]	Polyester[2] Styrene copolymer	Tyre[3]	Bio-oil[4]	Gasoil[1]
Flash point (°C)	33.6	34.8	26.0	20	48.0	75
Pour point (°C)	2.7	-28	-	-	-30	-30
Ash (wt%)	0.013	0.018	0.53	0.002	0.003	0.01
Viscosity (cst 50/60 ° C)	2.19	1.8	3.9	2.38	9.726	1.3
Density (kg/m^3)	0.858	0.926	0.83	0.91	1.21	0.78
Carbon (wt%)	-	-	86.1	88.0	42.6	87.1
Hydrogen (wt%)	-	-	7.2	9.4	5.83	12.6
Sulphur (wt%)	0.01	0.01	0.0	1.45	0.01	0.2
Oxygen (wt%)	-	-	-	0.5	46-51	0.2
Initial B.Pt (°C)	-	-	75	100	-	180
50% B.Pt (°C)	-	-	189	264	-	300
CV (MJ/Kg)	52.3	44.4	33.6	42.1	17.6	46.0

Table 1: *Fuel properties of oils derived from the pyrolysis of various wastes (references p 8)*

been used on tyre pyrolysis oils and plastics pyrolysis oils with a view to produce a highly aromatic oil, which can be used as a chemical feedstock. For example, use of a two-stage pyrolysis-zeolite catalysis reactor transforms the tyre pyrolysis oil to a highly aromatic oil containing ~50 wt% of benzene, xylene and toluene.

The recovery of high-value materials from wastes using pyrolysis technology has, for example, included the recovery of carbon fibres from plastic composites. Carbon fibres are highly valuable materials that are used extensively in the aerospace and automotive sectors. Pyrolysis thermally decomposes the composite plastic to oil and gas, leaving the residual carbon fibre and some char. The char is amorphous and easily separated from the carbon fibre by mild oxidation, producing a recovered carbon fibre with strength properties approaching 95% of the properties of the original material.

Other studies have used steam gasification to upgrade the char product from pyrolysis of a range of waste materials, resulting in the production of activated carbons. Such wastes as tyres, municipal solid waste, agricultural wastes including palm shell, coconut and textile waste have all been investigated and have produced activated carbons with similar surface areas and porosities to those of commercial-grade activated carbons.

Commercial waste pyrolysis systems

The pyrolysis of plastics to produce oils for use as liquid fuel or chemical feedstock is common at the commercial scale in Japan. At the small scale, there are many companies manufacturing 1 tonne/day batch pyrolysis units, using plastics derived from household waste. For example, the MCC Yukaki Ltd company in Japan operates a plastics pyrolysis plant that typically processes one tonne per day of plastics, producing gases and medium and light oils. The oils are combusted to provide the energy requirements of the pyrolysis plant and exported for combustion to raise steam for power production (**Figure 2**). Larger-scale plastics pyrolysis is carried out at the Toshiba waste plastics plant (Sapporo, Japan), where ~14,000 tonnes of plastic are processed per year. The reactor consists of a rotary kiln, and the plant can process mixed plastic waste from municipal solid waste. The waste plastics contain polyvinyl chloride, and a pre-treatment step is therefore included, involving melting at lower temperature to drive off the chlorine as hydrogen chloride, which is later recovered. The de-chlorinated plastic enters the rotary kiln, where pyrolysis takes place. The condensed product is then further distilled to produce a heavy oil, a medium oil and a light oil, with the off-gases combusted to raise steam.

Other commercial plants use fast pyrolysis of biomass wastes such as forestry or agricultural wastes to produce bio-oil. For example, Ensyn (Canada) have developed an entrained flow, rapid heating fast pyrolysis system to produce an oil product for use as a chemical feedstock and fuel oil. The biomass interacts with hot sand at ~500 °C and is very rapidly heated to produce fast pyrolysis primary products, which are then rapidly quenched to produce a liquid bio-oil product. Dynamotive (Canada) uses biomass wastes such as sawdust or bagasse (the fibrous matter that remains after sugarcane processing). These wastes are fed into a fluidised bed reactor, where fast pyrolysis at 500 °C occurs. Conversion of the biomass produces bio-oil (60 to 75 wt%), char (15 to 20 wt%) and non-condensable gases (10 to 20 wt%).

Gasification

Gasification converts hydrocarbon materials into a syngas at high temperature in the presence of oxygen in the form of air, steam, CO_2 or pure oxygen. It has been extensively used for coal gasification, but has also been extended as an energy technology for processing biomass, sewage sludge, municipal solid waste etc.

Gasification in the presence of air reduces the calorific value of the produced gases. For example, air gasification of biomass normally produces a gas with a calorific value between 4 and 7 MJ/Nm^3, whereas gasification with oxygen/steam generates gases with higher calorific values (10 to 18 MJ/Nm^3). However, air gasification has the advantages of low energy input and low tar content in the gaseous stream. Oxygen gasification is not common due to the high cost of producing oxygen. Steam gasification is attracting increasing interest because it produces gases with a high H_2 content.

The tar produced from gasification results in downstream problems, including tar blockages, plugging and corrosion in downstream fuel lines, filters, engine nozzles and turbines. Specifications of the tar content in the product syngas is normally less than 100 mg/Nm^3 for internal combustion engines, and 5 mg/Nm^3 for gas turbines, whereas the tar content in the product gas is generally 10 g/Nm^3 for air-blown fluidised bed gasifiers and 0.5 to 100 g/Nm^3 for the other types of gasifiers. Tar reduction methods include in-process catalytic cracking of the tar or downstream processes such as high temperature cracking of the tar to gas, hot gas filtration, or wet gas cleaning with equipment including spray towers, scrubbers etc.

A range of technologies have been developed to gasify wastes. The fixed bed reaction system is one of the most common processes used for gasification. Two basic types of traditional fixed-bed gasifiers are up-draft (counter-current) and down-draft gasifiers (co-current). Both these fixed-bed reactor types are based on natural slowly descending fuel flow caused by gravity. In an updraft gasifer, the feed is fed to the top of the gasifier and flows down slowly through drying, pyrolysis, reduction and oxidation zones. In a downdraft gasifier, the feed and the gasification agent (air) move in the same direction. The volatiles from pyrolysis pass through the oxidation zone, where the tar is partly cracked. The gas products leave at the bottom with a low tar content. Other types of reactor include entrained flow gasifiers and fluidised bed gasifiers.

Commercial waste gasification systems

Japan has many waste gasification companies. The Nippon Steel company operates 30 plants in Japan for processing municipal solid waste. For example, the Nippon Steel plant in Ibraki, Japan uses a vertical fixed-bed, updraft gasifier to process 135,000 tonnes per annum of municipal solid waste. The product syngas is combusted directly for steam for power generation. The Ebara company operates 12 plants in Japan, 3 of which process mixed wastes and 9 of which process municipal solid waste; their capacities range from

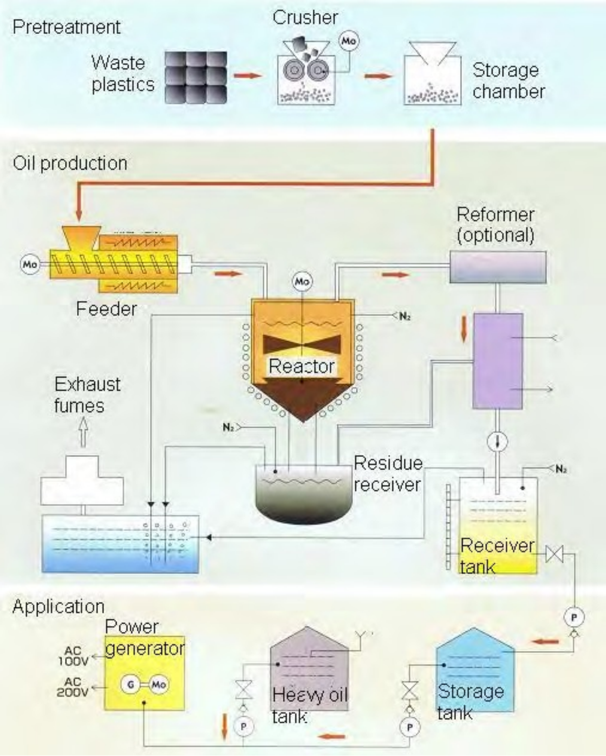

Figure 2: Schematic diagram of the MCC Yukaki Ltd, 1 tonne per day plastics pyrolysis system (Reproduced by permission of MCC Yukaki Ltd).

19,000 to 165,000 tonnes per annum. For example, the Ebara TwinRec gasifier (**Figure 3**) in Kawaguchi, Japan processes 125,000 tonnes per annum of municipal solid waste and has been operational since 2002. The technology is based on a fluidised-bed gasifier, which produces a syngas that is combusted at high temperature (1350 to 1450 °C) in a cyclonic combustion chamber to raise steam for electricity production or district heating.

Combined pyrolysis-gasification plants also exist, notably the Thermoselect system with 6 plants operating in Japan using industrial wastes and municipal solid waste. For the Thermoselect process (**Figure 4**), untreated waste is compacted to 10% of its original volume and then fed to the pyrolysis reactor, which is heated indirectly at 600 °C. The resultant organic pyrolysis gases, vapours and char are fed to a high-temperature gasification chamber operated at ~1200 °C, with oxygen as the gasifying agent. The product syngas is quenched and undergoes several cleaning steps to produce a clean gas suitable as a chemical feedstock or for energy recovery applications. At the base of the gasification reactor, temperatures of 2000 °C melt the metal and mineral components of the waste. The liquid melt flows to a homogenisation chamber at 1600 °C, where sufficient residence time allows the separation of two phases, a metal alloy and a mineral phase. Rapid quenching of the melt produces a granulate mineral material for use in road building, construction and aggregates, and a metal alloy for recovery of metals.

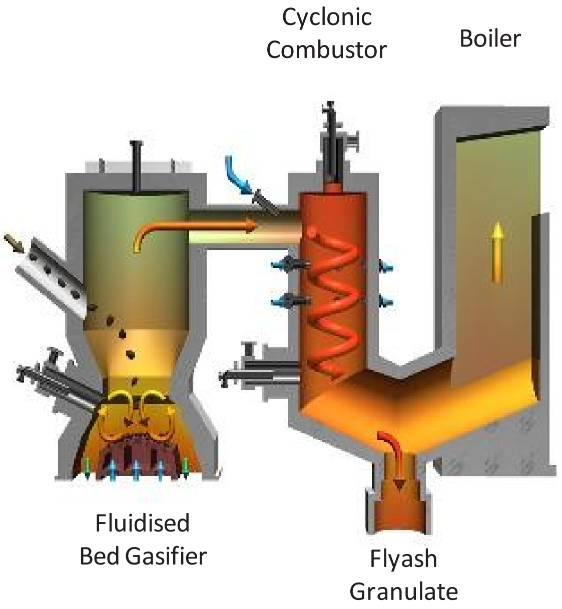

Figure 3: *Schematic diagram of the Ebara TwinRec fluidised bed waste gasification system (Reproduced by permission of Ebara Environmental Plant Co. Ltd).*

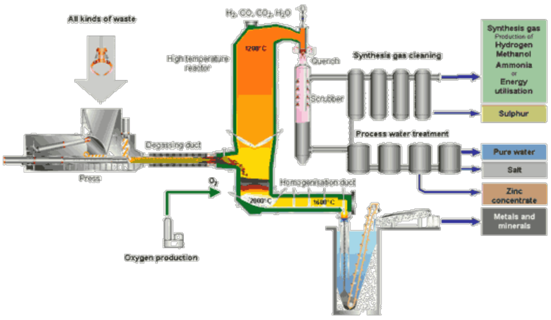

Figure 4: *Schematic diagram of the Thermoselect pyrolysis-gasification system (Reproduced by permission of Thermoselect).*

Conclusion

There is increasing awareness that wastes is a valuable resource. The alternative thermal treatment technologies of pyrolysis and gasification offer process routes to recover a range of useful and, in some cases, high-value products from waste. The technology is proven and well established in Japan, with many reference plants that have operated over several years. The technology is not, as yet, established in the UK, but the advantages of a novel and alternative approach to wastes management through pyrolysis and gasification is stimulating growing interest and development of the technology.

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This article is based on the ECG Distinguished Guest Lecture given by Professor Williams in the Chemistry Centre at Burlington House on Wednesday, March 14th 2012.

Organic waste management and its implications

Since the 2003 Waste Emissions Trading Act came into force, the UK government, in collaboration with the waste industry, has actively worked towards the diversion of organic waste from landfill and towards a “zero” landfill economy. Different types of waste classed as “organic” include agricultural waste, such as slurries and manure (~90 million tonnes/year), food and green waste (~20 million tonnes/year) and sewage sludge (~1.5 million tonnes/year).[1] The assessment and quantification of this organic fraction within mixed waste is pivotal for diversion targets and energy recovery.

Renewable energy from waste

Renewable energy from waste has an important role to play in tackling climate change by displacing the use of fossil fuels and by providing a more environmentally sustainable method of disposing of residual wastes, where recycling is not practical or economically feasible. Energy can be recovered from waste using a number of processes, including anaerobic digestion (AD), combustion, gasification and pyrolysis; each is capable of delivering sustainable methods of waste treatment and a clean source of energy. The recovery of energy from biomass-derived waste materials is supported by the Renewables Obligations (RO) as a mechanism to incentivise investment in suitable renewable energy production technologies. Where a heterogeneous fuel, such as mixed wastes, is used there is a requirement to understand what proportion of the total energy recovered is from a renewable resource, such as biomass. Work has been undertaken at Cranfield University, funded by TSB/SBRI with Defra and DECC, to develop appropriate methods of assessing the biogenic biomass content of mixed wastes, and the energy outputs from this fraction. This work involved the further development of an image analysis method previously devised at Cranfield University.[2]

The methods we developed demonstrate the capability to determine the biogenic proportion of mixed waste materials, and also to reliably estimate the net calorific value (NCV) of this fraction, which is indicative of the energy yield before process efficiency is taken into account. The net energy potential is calculated from measurements of the moisture content, which enhances the accuracy of the method. The moisture content is determined using a novel microwave technique developed by the National Physical Laboratory (NPL). The biogenic fraction of each waste component is determined by carbon-14 analysis, which is a highly accurate method of measuring the ratio of ‘new’ carbon (^{14}C) to ‘fossil’ carbon (^{12}C). The technique used requires an accelerated mass spectrometer (AMS). The sample is combusted to form CO_2, which is then converted into graphite by passing over a hot Fe catalyst with H_2. The graphite target is then bombarded with caesium (Cs) ions to release C ions. The rapid detection of $^{12}C^{4+}$, $^{13}C^{4+}$ and $^{14}C^{4+}$ ions allow for the calculation of the ratio of ^{14}C to $^{12}C/^{13}C$.

The developed system can be mounted above mixed waste prior to energy recovery and enables facility operators to determine the renewable energy potential of the input fuel. The imaging technique determines the physical composition of the waste (i.e. % paper, card, plastics etc) and matches the components to the chemical properties (NCV and ^{14}C); thereby allowing for the determination of renewable energy potential from the mixed waste. The relationship of waste composition, net CV and ^{14}C is illustrated in **Figure 1**.

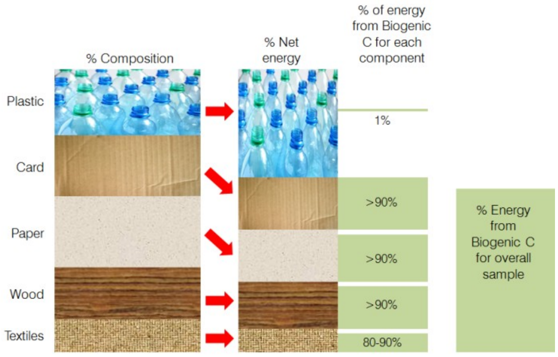

Figure 1: *Relationship of waste composition, net CV and ^{14}C.*

In a recent study this image analysis method was applied to two separate sets of waste samples with the aim of determining both the total energy potential, and the energy potential from the bio-based fraction of the mixed waste material. The waste mixtures were prepared using a known quantity of each component (paper, card, wood etc) and spread out to replicate a typical conveyor belt. The actual net calorific values from the biomass fraction (%bioNCV) of the mixed wastes were 74.7% and 80.1%, whereas the % bioNCV determined by the image analysis method were 70.7% and 79.5% respectively. The values calculated from the imaging method suggest that this technique has the potential to be used in facilities that generate energy through the combustion of mixed waste materials (**Figure 2**).

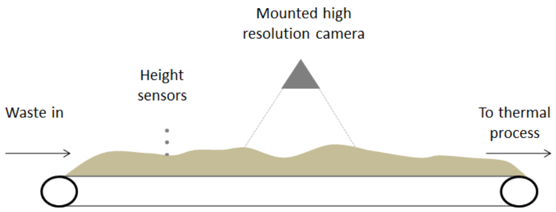

Figure 2: *Suggestion for how the image analysis method might be applied in a waste processing facility.*

The use of this technique in thermal waste processing companies would enable the operator to understand the proportion of energy produced from the biomass fraction of mixed wastes in real time, and to retain an electronic record for future accreditation. This reduces the requirement to undertake expensive off-site laboratory analysis and reduces the disruption of the operation of the facility. The system could also be of use at waste processing facilities that produce a refuse-derived fuel (RDF)/solid recovered fuel (SRF)[3,4], which would be a commodity sold to a third party for use elsewhere. The properties of the product – in this case the %bioNCV –could be determined prior to dispatch, thus potentially enabling a more dynamic market for the material, with the specific grade and value of the SRF known for each batch produced.

Further work is underway to improve the accuracy of the technique and reduce the time required to process the images (currently around 7 minutes). A prototype system, in combination with other work completed with a collaborating company, will soon be tested on a fully operational waste processing facility.

Anaerobic digestion exposure assessment

In 2009 about 6 million tonnes of organic waste were treated in the UK, 5.2 million tonnes of which were composted and only 2% were treated through AD. The UK target for 2017 is the diversion from landfill of 11 million tonnes of organic waste, with major investment in AD and its outputs (gas, electricity and biofertiliser).[5] Composting and AD are complementary, because AD is less suitable for the treatment of green waste, which contains high levels of lignin. However, unlike composting, AD can meet many environmental targets at once by diverting waste from landfill, collecting methane emissions and providing a nutrient-rich biofertiliser that can be re-used on land. Digestate, used as substitute or combined with fossil-based fertilisers, could potentially save 25 kg CO_2-eq per tonne of food digested.[1]

Depending of the waste input, composting and AD outputs will be of different qualities. AD and Composting Quality Protocols – PAS100 and PAS110 – were introduced to produce 'end of waste' criteria for the production and use of a waste-derived product without the need for waste management controls. The protocols state permitted input materials, treatment processes and output quality standards.

The digestate formed from AD will have different properties depending on the feedstock composition and origin (domestic, industrial, agricultural or mixed) and the process conditions. Different types of digestate possess different physical, chemical and biological characteristics. High quality digestate is rich in organic matter and inorganic nutrients and can be applied to soil as a conditioning fertiliser, in place of synthetic fertilisers. The organic fraction of the digestate is a mixture of fats, proteins, carbohydrates, lignin, amino acids, sugars, celluloses and fatty acids, along with live and dead micro-organisms. Depending on intended digestate uses, it is important to understand and manage any hazards and associated risks to the wellbeing of humans, livestock and the environment, in part as a contribution to securing stakeholder confidence. This includes minimising the introduction (and subsequent transfer to soil and food products) of potentially harmful components, such as toxic elements or pathogens. To do this, auditing processes need to be developed to adequately assess AD inputs and outputs. In addition, digestate use on land can have potentially harmful impacts on the environment (e.g. as a consequence of enhanced nitrate leaching or ammonia volatilisation). These can usually be minimised by following good agricultural practice.

The 2009 Anaerobic Digestate Quality Protocol (ADQP) aims to clarify end-of-waste management controls, provide confidence in the digestate quality standards and protect human health and the environment by setting out good practice for the use of quality digestate. The ADQP is a risk management tool that was developed by WRAP and the Environment Agency in conjunction with industry. Cranfield helped to develop this protocol, producing a technical report that defined input material and output quality. The work assessed the effect of the anaerobic treatment process on the hazards contained in the waste and how, through the use of the digestate in a specific end-use, those hazards can be transported to a receptor of concern (environment, human and animal). In practice, several barriers act to prevent exposure. By exploring the efficacy of these barriers we have been able to identify the most significant hazardous agents, wastes, exposure pathways and end uses. The combinations of these factors that pose the highest risk to human health, animals and the wider environment have been identified and highlighted as features that can then be addressed by the AD quality protocol.

The work assessed exposure associated with digestates derived from 70 waste input materials processed through 6 types of AD settings and for 7 different end-uses. The methodology adopted the general principles of Defra's Guidelines on Environmental Risk Assessment and Management.[6,7] The management of exposure pathways is central to effective risk management throughout the process chain from waste input to end use of the AD residue. In practice, critical control points at each stage of the process chain provide opportunities to actively reduce risk. Under normal operating conditions, with the application of good practice, barriers (management measures) can be applied that will effectively guard against exposure to hazards.

Rational and, where possible, evidenced judgements about the likelihood and significance of receptor exposure to physical, chemical and biological hazards are coded. Most concern should be given to situations where significant hazards are readily available to receptors (e.g. direct ingestion), i.e. where potent, hazardous constituents in input streams remain unaffected by AD treatment and can migrate through the environment in sufficient quantities to cause harm. Hazard profiles containing a high concentration of animal and human pathogens appear near the top of the table, together with wastes derived from the leather industry containing high concentrations of chemicals. Pathways of high availability have no significant exposure barriers to certain hazards (direct ingestion). The end-uses that received the highest exposure ranking were ready to eat crops and grazing and animal feed as they offer the highest number of available pathways. The matrices highlighted that greater opportunities for exposure to hazardous agents occur with higher contaminated wastes for certain end-uses. These conclusions offer insights into where controls might be most effective; through (1) the exclusion of certain waste types; (2) the application of codes of practice backed up by the quality protocol for specific exposure routes and (3) specific attention being given to certain end uses. The approach explicitly linked expert understanding on waste categories, AD processes and the environmental fate of contaminants in the context of AD product end use and has highlighted the key drivers of potential exposure, providing a basis for control through the ADQP.

Bioaerosols and composting

The composting process relies on the proliferation of micro-organisms to decompose solid organic waste feedstock in order to produce a stable, organic material (compost). However, this process releases these micro-organisms into the lower atmosphere, where they are known as bioaerosols. Bioaerosols can be micro-organisms, including bacteria and fungi or their constituent parts.[8] Bioaerosols are sufficiently small (**Figure 3**) to penetrate into human lungs. Some bioaerosols therefore have the potential to cause health effects, particularly with people who have suppressed immune systems or pre-existing conditions, such as tuberculosis. Waste composting facilities are therefore regulated by the Environment Agency (EA), which requires the site operators to demonstrate that bioaerosols can be maintained below the recommended levels at 250m from the site boundary through a site specific bioaerosol risk assessment.[9]

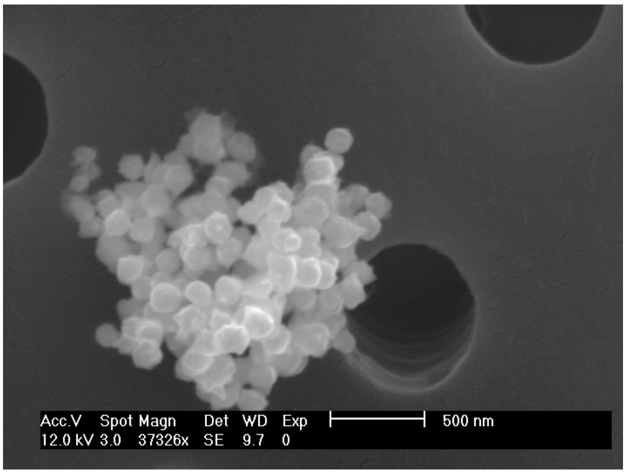

Figure 3: *The nanometer size of bioaerosol particles.*

Research is underway to improve the air dispersion modelling techniques for predicting downwind dispersal of bioaerosols from composting facilities. These techniques have been tested previously, but have typically been found to underestimate the downwind concentrations of bioaerosols,[10] probably because monitoring techniques are inadequate. To model bioaerosol concentrations, it is necessary to understand the concentration of bioaerosols released at source (the source term). However, composting facilities, where numerous large vehicles operate, create a health and safety risk for sampling. In addition, research has shown that the highest concentrations are released from compost processing activities (turning, shredding and screening of the material) and not from stationery sources.[11] Most bioaerosol concentration data are therefore taken at least 10 metres downwind of the actual source. Current research is taking samples directly from the composting activities under controlled conditions. It is hoped that this will improve our understanding of the source term.

In addition, the data used previously to validate model output[10] have contained only a limited number of sampling points, due to the labour intensive nature of bioaerosol sampling techniques. As a result of an extensive sampling project,[12, 13] a database containing over 300 measurements is now available to validate model output. These data are currently used to calibrate modelling techniques, in order to develop a best-practice modelling protocol for bioaerosols from composting facilities.

Remaining knowledge gaps associated with bioaerosols include the lack of a defined dose-response relationship that explains the link between exposure to a certain concentration of bioaerosols and particular health impacts. This is due to the numerous different bioaerosols emitted by composting facilities, but also due to the complex nature of human responses to different bioaerosols. It is hoped that by improving the confidence associated with modelling downwind dispersal of bioaerosols, we can begin to improve our understanding of the dose or amount of bioaerosols that people are exposed to, as a first step to closing this knowledge gap.

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A biogas plant. The four stages of anaerobic digestion – hydrolysis, acidogenesis, acetogenesis, and methanogenesis – convert organic waste into the biogases methane and carbon dioxide. Reference (for example): Appels, L. *et al.*, *Progress in Energy and Combustion Science*, 2008, **34**, 755-781.

Image Credit: Muzsy/Shutterstock.com.

The role of ‘Big Society’ in monitoring the state of the natural environment

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Abstract

Environmental monitoring is essential for assessing the current state of the environment, measuring impacts of environmental pressures and providing evidence to government. Recent UK government announcements have indicated an increased role for ‘Big Society’ in monitoring. In this paper, we review available literature concerning the use of citizen science for monitoring, present examples of successful volunteer monitoring work and highlight important issues surrounding the use of volunteers. We argue that in order to ensure that environmental monitoring continues to be effective it is important to learn from examples where volunteers are currently used, acknowledging constraints and identifying potential approaches which will help to maximise both their engagement and data quality. Effective partnerships between environmental monitoring organisations and volunteers may thus aid the UK in developing robust coordinated monitoring systems that will be less vulnerable to funding variances.

Environmental impact

The recent austerity measures announced by various governments e.g. Greece, Ireland and UK will have a significant effect on public spending, and potentially on government funded environmental monitoring. The paper aims to review current volunteer monitoring (particularly in conservation) and identify the common aspects for big society environmental monitoring. Scientists and stakeholders across all types of monitoring (some of whom may be less familiar with volunteer monitoring) will have improved knowledge of the process and can design monitoring schemes to maximise the use of volunteers and minimise the effect of government austerity measures. The intended outcome is to ensure that high quality, scientifically robust environmental monitoring can be maintained despite decreasing government funding.

Introduction

The world faces fundamental environmental issues and challenges. Human activities have led to substantial and potentially irreversible loss in the diversity of life, brought about through changes to ecosystems to meet rapidly growing demands for natural resources such as food, fresh water, energy and materials.[1] Monitoring the state of the natural environment is essential to identifying environmental problems, helping to understand drivers of change and testing the effectiveness of national and international policies to reverse declines. In addition, governments have a multitude of legislative and statutory obligations and commitments to meet. Measuring and monitoring the natural environment provides evidence for such reporting obligations[2] and underpins the development of environmental policies.

The ongoing economic crisis has left many governments with large budget deficits. One solution is the reduction of government expenditure. For example the Republic of Ire-

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land's National Recovery Plan[3] aims to reduce expenditure by €15billion by 2014. In the UK, the latest government spending review aims to reduce spending by £81billion (~€90billion) by 2014.[4] Such reductions in government expenditure could mean a reduction of funds for environmental monitoring. Continuing to use the UK as an example, recent UK Government policy speeches[5,6] have described the use of Big Society as a way to compensate for reduced funding. In particular, the Secretary of State for the UK's Department for the Environment and Rural Affairs (Defra) when launching the consultation on the Natural Environment White Paper, described the 'new opportunity to hand over control to local people'.[7] In the field of environmental monitoring, this policy potentially results in changes to the interaction between environmental science and local communities. Thus, to reduce costs, the implication is that government intervention will be reduced and the current mixed environmental monitoring market will move to become closer to a free market. At the same time it remains essential that the evidence from environmental monitoring continues to be reliable because it underpins policy decisions and wider public benefits e.g. the annual £88m spent on environmental monitoring underpins up to £6,000m of benefits to the UK.[8] The use of 'Big Society' within science is a long established tradition, although it is more normally referred to as citizen or volunteer science.[9] Within biodiversity monitoring, and for particular taxa the voluntary sector has been central to the delivery of monitoring over several decades[10,11] with around 22% of UK environmental monitoring activities receiving no government funding.[8] However, a reliance on volunteers to fulfil all environmental monitoring requirements could potentially lead to a failure in those areas where citizen science is not likely to be effective.

The purpose of this paper is to:

1. Highlight the need for and stimulate the debate within and between environmental monitoring organisations about how they respond to this new policy.

2. Highlight best practice examples where citizen science engagement is already integral to monitoring important elements of the environment.

3. Identify advantages and disadvantages of a citizen science approach and develop an understanding of limitations.

4. Identify the factors that need to be considered in adapting monitoring schemes to enable significant citizen science involvement which will result in a robust, validated evidence base.

Using the UK situation as a case study, two examples of monitoring schemes which involve volunteers are presented – one using pre-existing individual interest monitoring (e.g. bird watching), and a second where there is little pre-existing volunteer activity. These monitoring schemes are explored, alongside, further examples, to indicate how Big Society involvement may or may not contribute successfully to environmental monitoring. Although the case study is the UK, the conclusions are applicable across monitoring schemes elsewhere.

Biodiversity monitoring by volunteers

Terrestrial biodiversity surveillance in the UK involves at least 30 organisations, including the regional administrations and their agencies, Non-Governmental Organisations, societies and research bodies, often in partnership.[12] Many schemes rely on volunteer observers to some extent; with an estimated value of over £20 million during 2007–08, supported by approximately £7 million of government funding.[12] Species recording has a long tradition in Britain and Ireland with the earliest records dating from the early part of the 17th Century. This activity spans a wide range of species groups and volunteer involvement is extensive. Over 80 national schemes and societies, operating as charities (not for profit organisations providing public benefit), co-ordinate the activity of several thousand individual volunteers. For example, over 20,000 people are currently contributing records of bird sightings towards an Atlas of British Birds.[13] Although birds are the most systematically recorded species group, national recording schemes span many other groups including mammals, plants and a wide range of invertebrate groups. Governmental organisations support this extensive activity, mostly as partners within the National Biodiversity Network (NBN) which acts as an umbrella body for organisations collecting or interpreting biodiversity data in the UK. The NBN, through its internet portal the NBN Gateway has collated, integrated and disseminated over 56 million individual records or species across Britain and Ireland;[14] online databases operated by the BTO for birds provide access to even greater numbers of records, currently more than 150 million. This data has been used to provide evidence of the impact of environmental change on biodiversity such as the impacts of recent climate change,[15] nitrogen enrichment through industrial and agricultural pollution[16] and habitat degradation.[17]

Large collations of volunteer-collected data demonstrate the potential of Big Society monitoring as a barometer of the health of the environment. However, provision of evidence from such monitoring programmes is not cost-free, but rather relies on long-term support in terms of volunteer liaison, data handling, quality assurance, publication and statistical support for measuring trends. For example while specific projects to map the distribution of a whole taxonomic group through an atlas often provides a focus for ongoing species recording; atlas projects often run for a decade or more, beyond the time frame and funding of most research projects. Sustained support for such projects in the United Kingdom has been provided by the British Trust for Ornithology (for birds) and the Biological Records Centre (helping to co-ordinate the activity of national schemes for most other species groups) with co-support from the Joint

Nature Conservation Committee (both BTO and the BRC) and the Natural Environmental Research Council (supporting the BRC).

Monitoring atmospheric pollutants

The National Ammonia Monitoring Network (NAMN)[18] is part of the UK Eutrophying and Acidifying atmospheric Pollutants (UKEAP) network which has measured air pollutants at rural sites across the UK over the past two decades on behalf of Department of Environment Food and Rural Affairs. UKEAP sits within the framework of UK pollutant monitoring and contributes to the research effort investigating the flow of chemicals in the environment. With ammonia as a measurand, the network cannot tap into pre-existing individual monitoring organisations. However NAMN has organised and recruited volunteers (Local Site Operators – LSOs) who are an essential part of the network: they collect, replace and return the sampling devices for analysis. The NAMN coordinating bodies employed a number of strategies to create and operate the network successfully with LSOs: the sampling device was designed for easy handling,[19] they run at least one site themselves to provide quality assurance, training and instructions are provided and periodic operator and stakeholder meetings – often through socially oriented events such as a dinner - are arranged to provide knowledge exchange. However, the NAMN requires samples from across the UK and unpaid volunteers do not provide this coverage. To ensure there is adequate coverage, NAMN pays some site operators travelling expenses or an honorarium. Even including this, the use of the LSOs saves Defra an estimated £70,000 pa.

Key requirements for volunteer monitoring

Quality assurance and standardisation of method

Use of the standardised sampling device for the NAMN illustrates part of a key requirement for environmental monitoring: the measurement process must be calibrated, verifiable, repeatable, and use documented procedures i.e it is quality assured. In some cases these processes may be required to conform to an accepted accreditation status. Use of QA and accreditation to agreed standards means that measurements from differing temporal periods or geographic regions made by different individuals can be compared with confidence; it allows for the back correction of previous analysed samples, the use of the data for modelling and it allows for a change in volunteers without loss of knowledge. There is evidence[20] from wildlife conservation that effective monitoring can be done using a Quality Assurance process. Quality Control to ensure that the documented protocols are being interpreted correctly by those carrying them out is also essential. Without QA and QC, although the quantity of data increases, only a proportion of that is useable.[21] Use of unvalidated data may lead to erroneous results and interpretations. Currently for most environmental monitoring quality assurance is specific to particular tasks, it may be that there is a requirement for an UK wide Environmental Monitoring accreditation (similar to UKAS or ISO laboratory accreditation) that allows end users to be confident that data has come from a monitoring organisation with an accredited process. An example of the use of documented protocols, staff training, quality control and quality assurance is the UK Countryside Survey,[31] carried out by professional surveyors. In 2007 the survey involved interviews and botanical testing for applicants, a 4 week training course, visits from experienced surveyors and data checking early on in the survey (QC) and QA exercises on all aspects of the survey. This survey used paid staff in part due to the importance of high quality data collected according to rigorous field protocols.

Expert and technological limitations

As in any other professional field, there are aspects of environmental monitoring which are beyond the capability of untrained volunteers e.g. highly technical processes such as DNA analysis, or identification skills for particular species/habitats. Big Society can still play its part e.g. through the collection of samples, or providing access to sites and through very simple protocols across many sites[22] or the use of volunteer experts. A well known example of this is the Open Air Laboratories Network (OPAL) which aims to get over one million people more aware of their open spaces and to participate in monitoring the state of the environment.[23] The Predatory Bird Monitoring Scheme (PBMS) is another example which relies on volunteers to send in dead birds. It receives around 450 samples per annum on which autopsies are carried out to provide a measure of chemical contamination in the natural environment and the impacts of a range of non-chemical threats. The PBMS is a good example of a designed monitoring scheme that takes account of expertise to create the optimum mix of professionals and volunteers to produce cost effective monitoring. However for some monitoring schemes the expertise cannot be separated so easily from the collection and a high degree of biological skills are required. Some species groups e.g. birds and butterflies have skilled amateurs who are able to identify species and interested in the whole taxa. Hence the success of schemes like the BTO ones and the Butterfly Monitoring Scheme. Other species groups including plants are more difficult both because of the range and number of types as well as the extent to which they attract interest e.g. there is little public interest in bryophytes, lichens, sedges, grasses. Plant recorders tend to prefer rare or attractive species confined to high quality habitats. Monitoring schemes like Countryside Survey which require quantitative recording of all plant species in large numbers of plots within specific 1km squares in areas which are generally of low botanical interest are likely to be of limited appeal to amateur botanists.

In order to ensure high quality data collection, where it is required, the professional environmental community must identify areas where expertise or technological limitations are likely to be a barrier to involvement of volunteers. The process of doing this will enable recognition of areas where improvement of protocols or technical kit may enable greater use of volunteers, as in the NAMN example.

Incomplete monitoring

For some monitoring activities it is of key importance that monitoring is both spatially and temporally representative. For example, Countryside Survey (CS) provides information at a national level, for specific time intervals. CS is a labour intensive survey where multiple measurements are taken across GB 1km squares, some of which are remote and not easily accessible. Failure to collect data of a consistent quality from all sites during the specific survey years would have significant impacts on the statistical validity and representativeness of the data collected. The use of paid trained scientific staff ensures that all data are collected at all squares at the appropriate time. For monitoring schemes exclusively carried out by volunteers incomplete monitoring can take a number of forms:

Geographic – remote and unpopulated areas as well as areas perceived as 'less interesting' will be less well represented in the sample. This can be countered e.g. the NAMN pays an honorarium for collection from remote sites.

Temporal – datasets become more valuable with time but discontinuities in data collection can be problematic. Consistent regular monitoring can be particularly useful in situations where evidence is needed fast, e.g. In 2010 the Environmental Change Network[24] provided evidence from monitored vegetation plots to the UK Government to determine that chemical deposition from the Icelandic volcanic eruption would not cause health problems for cattle.

Species/Science area – some areas of science attract more volunteers than others. For example bird monitoring is popular and can be coordinated and quality assured[25] largely because there are a large number of expert volunteer bird watchers in the UK (and a comparatively small number of bird species), but the data quality remains subject to geographic and temporal limitations. Conversely, although some plant monitoring is carried out by expert volunteers,[26] in general vegetation or soil monitoring attracts smaller numbers of experts and therefore often needs to be carried out by paid experts ensuring high data quality. An example of monitoring which demonstrates the impacts of the use of non-paid versus paid experts is a survey of biodiversity on farmland carried out between 2000 and 2003 which included among other taxa, birds and vegetation.[27] Considerable effort was put into recruiting volunteers, providing materials and instructing them in bird survey techniques to cover the sample of 89 farms pairs selected for the study, by a paid staff member at the BTO. Ultimately given the distribution of sites and the need for work to be temporally aligned with other survey work on the farms, staff on short-term contracts with the BTO were used to fill gaps where no volunteers could be recruited. In contrast the vegetation aspects of the survey, which required intensive sampling in and around a cereal field on 89 pairs of farms, were covered by four professional staff trained in botany. Whilst staff costs were certainly higher overall for the vegetation aspects of the survey there were staff costs in terms of training and recruitment as well as managing logistics and employing survey staff for the bird surveys. Additionally, datasets were complete for all aspects of the vegetation survey, with all 89 pairs of farms surveyed compared to 61 farm pairs for birds with some missing associated habitat data which bird surveyors had been asked to collect.

Knowledge exchange

A key element of any volunteer monitoring is knowledge exchange. Individuals will be involved in monitoring for a number of reasons that can be summed up through Maslow's hierarchy of needs:[28] Belonging (social interaction)[29] leading to self-esteem (group status) and finally self-actualisation (realising one's own potential). In the examples described above, explicit activities are carried out that allow realisation of these needs e.g. the creation of a species atlas or the NAMN dinners. To design appropriate volunteer monitoring schemes this must be accounted for to make the relationship, and the monitoring scheme, work. There must be a two way exchange of information and respect[30] that allows a volunteer to understand that their individual contribution has been recognised and has contributed to the whole. For example with the PBMS an individual who submits a bird to the scheme receives a copy of the autopsy report (acknowledging the contribution) and can see the species analysis on the PBMS website. Without this type of interaction, the volunteers will soon stop providing the raw data. For ecologists working with landowners, whether that is monitoring on their land or actually using them as data providers e.g. on management, the importance of feedback cannot be overemphasised and should be incorporated into the design/costs of monitoring.

Coordination

For monitoring exclusively carried out by volunteers an area of key importance is co-ordination. Effective co-ordination representing the interests of the volunteers, the professionals and the end users e.g. policymakers, is essential in order to ensure successful monitoring. It is through this approach that a clear vision, strategy and framework can be determined. It overcomes the drawbacks outlined above, and enables useful data to be analysed, modelled and combined as shown by the activities of the BRC.

Figure 1 illustrates the interactions required to convert raw data to evidence. Coordination sits in the middle and is essential to providing useful data for the analysis and modelling required in order to develop understanding. It is this understanding that provides the evidence to formulate or validate policies. The lower part of the illustration shows the continuum between professional and volunteer monitoring. Research is needed, drawing on social science expertise on successful engagement with volunteers and environmental monitoring expertise to help achieve the optimal balance between professional and volunteer for a particular monitoring scheme.

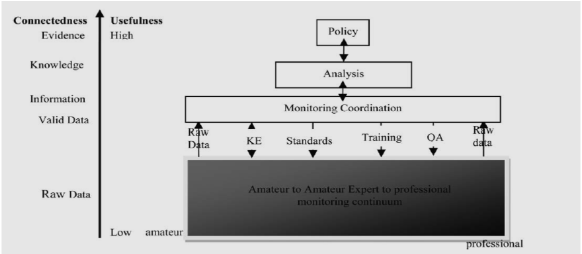

Figure 1: *The interactions required to convert raw data to evidence; illustrating the monitoring as a continuum between expert and amateur monitoring; the need for a coordination group and the interactions.*

Conclusion

Environmental monitoring in the UK has to adapt to the current era of austerity and the political driver of 'Big Society'. The current engagement of volunteers in UK monitoring provides valuable data. Any increase in the use of volunteer monitoring needs to build on its successes whilst recognising its constraints. Bodies carrying out environmental monitoring and users of their outputs need to safeguard valuable monitoring time series and highlight where volunteer data collection may be inappropriate. Where decisions are taken to widen the potential for public engagement in environmental monitoring at local levels, careful management needs to be implemented to ensure successful monitoring. Co-ordinating bodies which are inclusive are required to provide an overview of the monitoring and feed validated data into the professional analysts to provide evidence for policymakers. These bodies should encourage systematic, high quality, objective data collection which is consistent within and between areas/countries but aimed at providing information needed for locally relevant concerns.

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Forthcoming symposium

Soft Ionisation Mass Spectrometric Techniques and the Environmental Sciences

University of Birmingham **7th November 2012, afternoon**

The need for quantitative and rapid detection of chemical compounds in complex media and at ultra low concentrations provides significant challenges to modern analytical chemistry for applications in the environmental science area. Soft chemical ionisation mass spectrometric techniques can be used to address some of these challenges. The aim of this half-day meeting is to provide a forum for the discussion of recent applications and developments of soft chemical ionisation techniques for use in environmental science research. The meeting is organised jointly between the Molecular Physics Group (MPG) of the Institute of Physics and the Environmental Chemistry Group (ECG) of the Royal Society of Chemistry.

Confirmed Speakers: Professor C. J. Percival, University of Manchester
Professor P. S. Monks, University of Leicester
Dr. M. A. Blitz, University of Leeds

Free of charge for MPG/ECG members, but please register in advance. For further details, please contact Dr. Chris Mayhew (c.mayhew@bham.ac.uk) or Dr. William Bloss (w.j.bloss@bham.ac.uk), or go to www.rsg.org/ecg and select "forthcoming events".

The ESED Awards Symposium

A brief report of the 2011 Environment, Sustainability and Energy Division Awards Symposium held in the Joseph Black Building at the School of Chemistry, University of Edinburgh on February 8th 2012.

The **Environment Prize** was awarded to **James Clark** (University of York) for fundamental and applied research contributions to the areas of green chemistry, clean technology and sustainability and for educational, publishing and public awareness contributions in the green chemistry area (see http://www.rsc.org/ScienceAndTechnology/Awards/EnvironmentPrize/2011winner.as). His lecture *From Waste to Wealth using Green Chemistry* showed how the key issue of Green Chemistry in the 1990s—the reduction of waste to reduce waste disposal costs—has now broadened to include an examination of resource usage, product legislation and, most importantly, the need for chemists to be aware of life cycle analysis methodologies.

The **ESED Early Career Prize** was awarded to **Mercedes Maroto-Valer** (University of Nottingham) for her internationally recognised research at the interface between energy and the environment and in particular for her outstanding contributions to carbon capture and storage (see http://www.rsc.org/ScienceAndTechnology/Awards/ESEFEarlyCareerAward/2011winner.as). Her lecture *Carbon Capture and Storage: Opportunities for the Chemical Sciences to Impact Climate Change* examined the emerging technologies for increasing the efficiency of carbon capture technologies, such as the development of highly microporous carbon dioxide absorbents for post-combustion capture, and the methods for carbon dioxide reduction to methane, such as the use of titania nanorod films.

The Sustainable Energy Prize was awarded to **Ed Constable** (University of Basel) for his work on supramolecular coordination chemistry for the design and fabrication of next generation energy-devices, and especially for his work on energy generation from photovoltaics and efficient lighting devices based on light-emitting electrochemical cells (LECs) and organic light-emitting diodes (OLEDs) (see http://www.rsc.org/ScienceAndTechnology/Awards/SustainableEnergyAward/2011winner.as). His lecture *Light-in, Light-out—The Yin and Yang of Sustainable Materials Chemistry* discussed dye-sensitized solar cells, based on variants of the Grätzel Cell that use copper and zinc, in which the insertion of different interfaces increases the efficiency of current generation.

LEO SALTER, Vice-Chair, Environmental Chemistry Group

Image: Polly L. Arnold / University of Edinburgh

Current issues in contaminated land risk assessment

A report of the Joint Meeting of the Society of Brownfield Risk Assessment (SoBRA)/RSC Toxicology Group held at the RSC's Chemistry Centre, Burlington House, London on December 21st 2011.

I am happy to report another successful meeting, jointly hosted by SoBRA and the RSC Toxicology group. The December meeting has become established as a forum for updating delegates and exchanging views on the current issues within contaminated land risk assessment.

The day opened with the out-going Chair of SoBRA, **Mary Harris**, welcoming delegates to the meeting. **Dr Chris Johnson** (British Geological Survey) was the first speaker, outlining a project to map the background levels of soil contamination across England. This will allow interpretation of what soil contamination is considered 'above background', and may thus need further investigation. Of course, there is no universal 'background' across the country as industrial activity (past and present) and geological factors can result in local hotspots.

Mike Quint (Environmental Health Sciences Ltd) then gave a presentation on the thorny issue of defining 'significant possibility of significant harm'. The new proposals in the consultation draft discussed by Mike have introduced categories of contaminated land. Models have been developed to help determine categories, such as LQM/CIEH dose response roadmaps and the ATSDR approach. The models are in development and caution needs to be taken, as was memorably stated by Mike – all 'blobs' (data points) aren't equal!

After refreshments, there were two presentations from the nuclear sector. **Candida Lean** gave an overview of the ReCLAIM dose assessment tool, which calculates radiation exposure doses from multiple pathways for >50 radionuclides and accounts for different depths of contamination. It can be used to generate radiation exposure scenarios with user-specified inputs to customise the model. The tool is Excel-based and free to download. The second presentation was a group effort describing the nuclear industry guidance on qualitative risk assessment. The guidance is based on existing guidelines and was developed through industry workshops and peer-review. The tool is mainly for assessing risks from land in its current state. The guidance was issued in December 2011 and is open for comment until November 2012; a revision is planned for 2013.

Next, **Sue Goodman** from the Environment Agency outlined the role of the Water Framework Directive, which requires all waters to achieve 'good status' by 2015. In the North East region, a significant number of watercourses are currently graded below 'good'. The reasons for this are diverse but some are thought to be due to contaminated land and the Environment Agency is looking to implement an evidence-based project to identify such sites. **Tristan Ibrahim** then spoke about the interactions between groundwater and surface water that need to be considered in order to understand pollution movement, particularly the concept of Hyporheic Exchange Flow.

Dave Megson (University of Plymouth) and **Sarah Dack** (Mouchel) then reported a case study on dioxin/furan contamination at an allotment site. Using the CLEA model there was no SPOSH (Significant Possibility of Significant Harm) from the dioxin/furan contamination but many of the allotments were used to keep chickens/ducks. All eggs tested exceeded the EU guideline of 3 ng/kg fat. An example of a child living next to the site and eating eggs from the site was estimated to exceed the TDI for dioxins/furans by up to 9 times. As a result the site was deemed contaminated and remediation will be undertaken.

Finally, **Tracy Braithwaite** (AWE) outlined the Soil and Groundwater Technology Association's (SAGTA) proposed actions in light of the new developments on risk assessment, particularly understanding sustainable risk assessments, the absence of supporting guidance for the national planning policy framework, the definition of land use categories and groundwater risk assessment compliance points. Anyone interested in contributing to SAGTA's responses should get in touch. The meeting closed with a lively discussion of unresolved issues and a drinks reception that enabled the discussion to continue a little longer. Many issues remain, however, and some, at least, will be addressed at this year's meeting (December 2012) - be sure to book your place!

KATE JONES
Principal Scientist, Health & Safety Laboratory, UK

Most presentations from this meeting are available at http://www.rsc.org/Membership/Networking/InterestGroups/Toxicology/Meetings.as. This report is reproduced in abridged form with permission from the ***Toxicology Group Newsletter*** – Spring/Summer 2012.

First UK solar to fuels symposium

A report of the meeting held at the RSC's Chemistry Centre in London on January 18th 2012.

The First UK Solar to Fuels Symposium (see http://www.rsc.org/ConferencesAndEvents/RSCConferences/Solar/index.as) was organised by the Environment, Sustainability and Energy Division (ESED) with the support of the Dalton Division, the Faraday Division and the Materials Chemistry Division; it was also sponsored by RSC Publishing under the auspices of the journal *Energy and Environmental Science*. The aim of the one-day symposium was to provide an opportunity for the growing interdisciplinary UK solar-to-fuels research community to address the challenges of using sunlight to drive the synthesis of molecular fuels. An RSC report of the research area, "Solar Fuels and Artificial Photosynthesis: Science and Innovation to Change our Future Energy Options", is available at www.rsc.org/solarfuel.

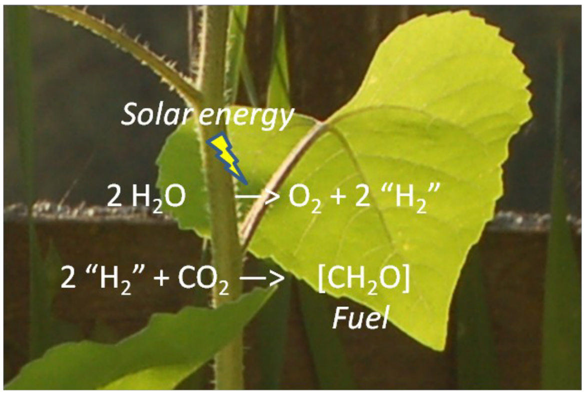
The importance of this topic was underlined by a brief presentation ("US Perspective on Solar to Fuels: How We Got to Where We Are") given by **Raymond Orbach** (Director of the Energy Institute, University of Texas at Austin). He described a recent competition, set up by the US Department of Energy, in which institutes competed for $122 million to set up a "Sunlight Energy Innovation Hub". The Hub was to focus on creating a prototype device to produce fuel from the sun ten times more efficiently than plants. The competition was won by the Joint Centre for Artificial Photosynthesis at Caltech (which led a consortium of Californian university and research institutions). The bidding process energised and developed the research community involved in solar to fuel.

In opening the proceedings, **James Durrant** (Imperial College, London) described a resurgent and expanding UK community that needed more coherence and a clear vision for sunlight to fuels technology and explained that the meeting was an attempt to establish and support such a community. **Bill Rutherford** (Imperial College, London) then spoke on "Artificial Photosynthesis – What Can We Learn From the Natural Kind?" He deconstructed the problem into three components—the conversion of light into chemical energy, the storage of the chemical energy so produced, and the processes of light collection—and then linked these to the natural processes involving Photosystems I and II. He did, however, point out that the use of semiconductor systems for artificial photosynthesis meant that the properties of natural reaction centres such as Photosystems I and II had limited relevance. For more details on the chemical challenges in solar energy utilization see http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1635072/pdf/zpq15729.pd.

Christopher Pickett (University of East Anglia) talked about "Photoelectrocatalysis at p-type silicon: CO and H_2 generation with dithiolene, porphyrin and phosphine complexes", explaining that "visible light-driven photoelectrochemical conversion of carbon dioxide to carbon monoxide, or of protons to dihydrogen, are half-cell reactions of relevance to the use of carbon dioxide as a C1 feedstock and to the generation of hydrogen as a solar fuel." Fundamentally the challenges are to design catalysts that can approach (or even exceed) the efficiencies of natural systems in driving energetically uphill redox catalysis, and to then anchor such catalysts to the electrode surface to overcome problems caused by localised substrate depletion. Pickett described the reduction of organometallic Mo or W complexes on p-type silicon under illumination. [This work is analogous to that of Chorkendorff and coworkers, reported in *Nature Materials* (2011), **10**, 434, who showed that surface bound Mo_3S_4 centres efficiently catalyse the evolution of hydrogen when coupled to a p-type silicon semiconductor that harvested red photons from the solar spectrum]. The speaker also discussed the use of electrochemical catalysis of carbon dioxide reduction to carbon monoxide in the presence of iron porphyrins. As with much of the work described in the meeting, the issue is one of overcoming the thermodynamic stability of carbon dioxide to convert it into an energy usable form in a way that produces more energy than is used–and preferably only uses energy generated by renewable non-fossil fuel processes.

Lee Cronin (University of Glasgow) spoke on "New Paradigms in Water Splitting", where the issue is one of storing energy by electrochemically or photochemically splitting water to produce oxygen and hydrogen, using, for instance, water splitting systems embedded into photoelectrodes. Candidates for such splitting systems include model Photosystem II systems. For example, a redox-active polyoxometalate (POM) catalyses the rapid oxidation of water to oxygen. However, the associated protons must also be converted to hydrogen.

For further details see www.glasgowsolarfuels.com.



After lunch **Robin Perutz** (University of York) spoke on "A Porphyrin – Rhenium Dyad versus Two Monomers: Reduction of CO_2". Starting from the known properties of rhenium bipyridine tri-carbonyl species as photocatalysts for carbon dioxide reduction in the UV, he went on to describe the synthesis, characterisation and examination of similar species as photocatalysts at visible and longer wavelengths. A dyad in which rhenium tricarbonylbipyridine was linked through an amide bond to a zinc tetraphenylporphyrin was investigated in relation to its ability to reduce carbon dioxide to carbon monoxide. Detailed analysis showed that two separate photochemical steps were occurring, that the separate components were more efficient than the dyad, that yields (turnover) were probably limited by fast electron transfer, and that the porphyrin was reduced to chlorine (which was shown to have been produced concomitantly).

Erwin Reisner (University of Cambridge) then gave a paper entitled "Solar water splitting with catalysts integrated in nanostructured metal oxide materials". He described the assembly of functional hybrid materials, in which molecular catalysts are integrated in nanostructured metal oxide materials to enhance the rate and selectivity of fuel-forming reactions. For example, attachment of hydrogenase or a synthetic cobalt complex on ruthenium dye-sensitised TiO_2 nanoparticles enhances the rate of proton production by two orders of magnitude during visible light irradiation in the presence of a sacrificial electron donor.

Ivan Parker (University College London) also spoke on "Solar water splitting" and looked at the possibilities of using a photodiode to form hydrogen directly from water with subsequent hydrogen and oxygen separation. In this way, "all the energy needs of a typical household would be addressed by photosplitting 5 litres of water a day." The results indicated that platinum-coated titanium dioxide worked best.

In the concluding talk of the meeting, **Peter Edwards** (University of Oxford) spoke on "Energy Storage and the Chemical Bond". He described the chemist's dream of "the efficient, catalytically-enhanced transformation of carbon dioxide", in which, using energy taken from renewable sources, carbon dioxide taken from the atmosphere would be used for the closed loop production of carbon-neutral synthetic fuels. Trapping carbon dioxide at source on site with methane to produce syngas or the air capture of carbon dioxide using polyamine supports are possible approaches.

Over a hundred people attended this meeting and it is hoped that it will be the first of a series. Although considerable time was set aside for discussion it was never enough; much thought-provoking commentary occurred throughout the meeting and various emergent technologies were mentioned as being involved in this area and which may become commercially viable in the future (see for instance http://airfuelsynthesis.com). I hope that this report accurately conveys the fascinating multidisciplinary efforts covered in the meeting.

LEO SALTER
Chair, Environment, Sustainability and Energy Division and Vice-Chair, Environmental Chemistry Group

Forthcoming symposium: advance notice

Recent Advances in the Analysis of Complex Environmental Matrices

Thursday 28 February 2013 **Burlington House, Piccadilly, London**

This joint meeting of the Environmental Chemistry and Separation Science Groups aims to cover recent developments in analytical instrumentation that make it possible to simultaneously analyse numerous pollutants in complex environmental matrices with minimal sample clean-up.

For further details please contact Professor Graham Mills, University of Portsmouth
Email: graham.mills@port.ac.uk Tel: 023 9284 2115

Also look out for information appearing on www.rsg.org/ecg under "forthcoming events".

The World Meteorological Organization's Annual Statement on the Status of the Global Climate

The World Meteorological Organization's Annual Statement on the Status of the Global Climate said that 2011 was the 11th warmest since records began in 1850. It confirmed preliminary findings that 2011 was the warmest year on record with a La Niña, which has a cooling influence. Globally-averaged temperatures in 2011 were estimated to be 0.40° Centigrade above the 1961-1990 annual average of 14° C.

Precipitation extremes, many of them associated with one of the strongest La Niña events of the last 60 years, had major impacts on the world. Significant flooding occurred on all continents, whilst major droughts affected parts of east Africa and North America. Arctic sea ice extent fell to near record-low levels. Global tropical cyclone activity was below average, but the United States had one of its most destructive tornado seasons on record.

The annual statement for 2011 was released for World Meteorological Day 23 March. In addition, WMO also announced preliminary findings of the soon to be released Decadal Global Climate Summary, showing that climate change accelerated in 2001-2010, which was the warmest decade ever recorded in all continents of the globe.

The rate of increase since 1971 has been "remarkable" according to the preliminary assessment. Atmospheric and oceanic phenomena such as La Niña events had a temporary cooling influence in some years but did not halt the overriding warming trend.

The "dramatic and continuing sea ice decline in the Arctic" was one of the most prominent features of the changing state of the climate during the decade, according to the preliminary findings. Global average precipitation was the second highest since 1901 and flooding was reported as the most frequent extreme event, it said.

The full report will be released later in the year following further analysis of data received from National Meteorological and Hydrological Services and collaborating monitoring agencies. The decadal summary aims to increase understanding of our varying and changing climate from a longer-term perspective and complements WMO's annual reports.

"This 2011 annual assessment confirms the findings of the previous WMO annual statements that climate change is happening now and is not some distant future threat. The world is warming because of human activities and this is resulting in far-reaching and potentially irreversible impacts on our Earth, atmosphere and oceans," said WMO Secretary-General Michel Jarraud.

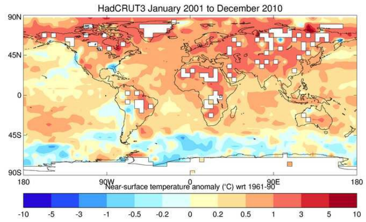


Figure 1 *from the press release: Global decadal temperature changes with respect to long-term average 1961-1990.*

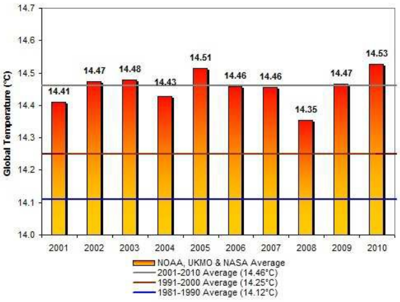


Figure 2 *from the press release: Average global annual combined land and sea surface temperature during 2001-2010. The horizontal lines indicate the average over the last three decades.*

The full press release, including seven figures and highlights on temperature, precipitation, extreme events and sea ice, is available at:

http://www.wmo.int/pages/mediacentre/press_releases/pr_943_en.htm

The WMO Statement on the Status of the Global Climate 2011 is available at:

http://www.wmo.int/pages/prog/wcp/wcdmp/documents/1085_en.pd

Forthcoming symposium

RSC Environmental Chemistry Group, RSC Toxicology Group and IES

Silent Spring 50th Anniversary – the lasting legacy of Rachel Carson

A one-day symposium organised by the RSC Environmental Chemistry Group, the RSC Toxicology Group and the Institution of Environmental Sciences (IES)

Where: **Chemistry Centre, Burlington House, Piccadilly, London**

When: **2nd October 2012 from 10:00 to 17:00**

Programme

- Introduction – Rachael Carson's work
- Rachel Carson's influence on US legislation
- Toxicology case studies of environmental exposure
- The changing profile of persistent organic pollutants
- Bioavailability and/or environmental fate modelling
- Current pesticide practice
- Consequences of hazard-based regulation such as REACH
- Have we forgotten again? Future problems

The Royal Society of Chemistry and the Institution of Environmental Sciences are pleased to announce a scientific meeting to discuss the legacy of Rachel Carson in the 50th year since publication of her hugely influential book, *Silent Spring*. The publication of *Silent Spring* triggered a debate that led to a ban on the insecticide DDT and started the modern environmental movement. The meeting will explore Rachel Carson's influence on legislation, pesticide usage and design, and the "environmental movement". It will also cover current regulation, toxicology and environmental assessment and look at what the future issues might be.

Details for registration can be found at: ies-uk.org.uk/events/rachelcarson

Forthcoming symposium

Health and Hydrogeology: *understanding the impact of groundwater on people*

Wednesday, 7th November 2012: The Geological Society, Burlington House, Piccadilly, London

A one-day conference organised by the Hydrogeological Group of the Geological Society in association with the Royal Society of Chemistry Environmental Chemistry Group.

Groundwater is a vital resource, providing drinking water for over a billion people worldwide. It can also provide a pathway for contaminants to migrate which harm human health. This conference brings together leading academics, regulators and consultants to discuss known and emerging groundwater pollutants and the potential implication for human health in the UK and beyond. Topics include:

- Emerging groundwater pollutants
- Radon in drilled bedrock wells in Norway
- Hydrogeology and health: a study of private wells in Ireland
- Assessing the impact of chlorinated solvents on human health
- Health impacts from rising groundwater levels in Riyadh
- Geothermal arsenic in Nicaragua: an integrated hydrogeological and epidemiological analysis of a public
- health crisis
- Potential risk of public water supplies from increasing trends of metaldehyde
- Groundwater safeguard zones
- Transport of viruses in partially saturated soil and groundwater

Booking information

Entry is **£65** for Fellows of the Geological Society and Royal Society of Chemistry
£95 for non-Fellows. Reduced rate of **£45** for students.

Price includes buffet lunch and morning and afternoon refreshments. To book your place please visit www.geolsoc.org.uk/darcy12

Who will benefit from this event?

- Environmental Regulators
- Environmental Consultants
- Water companies
- Remediation contractors
- Research and academic institutions
- Local and Central Government

Recent papers in the *Journal of Environmental Monitoring*

Many of the themes that have been explored in the ECG *Bulletin* are also reflected and elaborated upon in papers published in the RSC's *Journal of Environmental Monitoring*. Here is a selection of some recent highlights from that journal:

Arsenic in groundwater

Metal concentrations in the soils and native plants surrounding the old flotation tailings pond of the Copper Mining and Smelting Complex Bor (Serbia)
M. M. Antonijević *et al.*
J. Environ. Monit., 2012, **14**, 866-877

Arsenic contamination and speciation in surrounding waters of three old cinnabar mines
Raquel Larios *et al.*
J. Environ. Monit., 2012, **14**, 531-542

Migration of As, Hg, Pb, and Zn in arroyo sediments from a semiarid coastal system influenced by the abandoned gold mining district at El Triunfo, Baja California Sur, Mexico
Ana Judith Marmolejo-Rodríguez *et al.*
J. Environ. Monit., 2011, **13**, 2182-2189

Community exposure to arsenic in the Mekong river delta, Southern Vietnam
Hoang Thi Hanh *et al.*
J. Environ. Monit., 2011, **13**, 2025-2032

Arsenic transformations in terrestrial small mammal food chains from contaminated sites in Canada
Jared R. Saunders *et al.*
J. Environ. Monit., 2011, **13**, 1784-1792

Study of leachability and fractional alteration of arsenic and co-existing elements in stabilized contaminated sludge using a flow-through extraction system
Janya Buanuam *et al.*
J. Environ. Monit., 2011, **13**, 1672-1677

The biogeochemistry of arsenic in a remote UK upland site: trends in rainfall and runoff, and comparisons with urban rivers
A. P. Rowland *et al.*
J. Environ. Monit., 2011, **13**, 1255-1263

Climate change

Effective monitoring of agriculture: a response
Jeffrey D. Sachs *et al.*
J. Environ. Monit., 2012, **14**, 738-742

Effective monitoring of agriculture
David B. Lindenmayer *et al.*
J. Environ. Monit., 2011, **13**, 1559-1563

A 100-year sedimentary record of natural and anthropogenic impacts on a shallow eutrophic lake, Lake Chaohu, China
Fengyu Zan *et al.*
J. Environ. Monit., 2012, **14**, 804-816

Analysis of the air pollution climate at a background site in the Po valley
Alessandro Bigi *et al.*
J. Environ. Monit., 2012, **14**, 552-563

Climate change drives warming in the Hudson River Estuary, New York (USA)
David A. Seekell *et al.*
J. Environ. Monit., 2011, **13**, 2321-2327

Spatial and temporal trends of selected trace elements in liver tissue from polar bears (*Ursus maritimus*) from Alaska, Canada and Greenland
Heli Routti *et al.*
J. Environ. Monit., 2011, **13**, 2260-2267

Global climate change and contaminants – an overview of opportunities and priorities for modelling the potential implications for long-term human exposure to organic compounds in the Arctic
James M. Armitage *et al.*
J. Environ. Monit., 2011, **13**, 1532-1546

Molecular-level methods for monitoring soil organic matter responses to global climate change
Xiaojuan Feng *et al.*
J. Environ. Monit., 2011, **13**, 1246-1254

The legacy of chlorinated solvents and pesticides

Sources of organochlorine pesticides in air in an urban Mediterranean environment: volatilisation from soil
Gerhard Lammel *et al.*
J. Environ. Monit., 2011, **13**, 3358-3364

Presence and partitioning properties of the flame retardants pentabromotoluene, pentabromoethylbenzene and hexabromobenzene near suspected source zones in Norway
Hans Peter H. Arp *et al.*
J. Environ. Monit., 2011, **13**, 505-513

Evaluation of old landfills – a thermoanalytical and spectroscopic approach
Ena Smidt *et al.*
J. Environ. Monit., 2011, **13**, 362-369

Occurrence of pesticides in surface water bodies: a critical analysis of the Italian national pesticide survey programs
Antonio Finizio *et al.*
J. Environ. Monit., 2011, **13**, 49-57

Mercury pollution

Science and strategies to reduce mercury risks: a critical review
Noelle E. Selin
J. Environ. Monit., 2011, **13**, 2389-2399

The nitrogen cycle

Nitrate leaching to shallow groundwater systems from agricultural fields with different management practices
P. Nila Rekha *et al.*
J. Environ. Monit., 2011, **13**, 2550-2558

Impact of elevated O_3 on visible foliar symptom, growth and biomass of *Cinnamomum camphora* seedlings under different nitrogen loads
Junfeng Niu *et al.*
J. Environ. Monit., 2011, **13**, 2873-2879

How does exposure to nitrogen dioxide compare between on-road and off-road cycle routes?
T. Bean *et al.*
J. Environ. Monit., 2011, **13**, 1039-1045

A suite of microplate reader-based colorimetric methods to quantify ammonium, nitrate, orthophosphate and silicate concentrations for aquatic nutrient monitoring
Stephanie Ringuet *et al.*
J. Environ. Monit., 2011, **13**, 370-376

Nitrate leaching to shallow groundwater systems from agricultural fields with different management practices
P. Nila Rekha *et al.*
J. Environ. Monit., 2011, **13**, 2550-2558

Longitudinal variability in streamwater chemistry and carbon and nitrogen fluxes in restored and degraded urban stream networks
Gwendolyn M. Sivirichi *et al.*
J. Environ. Monit., 2011, **13**, 288-303

A distributed modelling system for simulation of monthly runoff and nitrogen sources, loads and sinks for ungauged catchments in Denmark
Jørgen Windolf *et al.*
J. Environ. Monit., 2011, **13**, 2645-2658

Urban air quality

Particle-bound polycyclic aromatic hydrocarbons in an urban, industrial and rural area in the western Mediterranean
Montse Varea *et al.*
J. Environ. Monit., 2011, **13**, 2471-2476

Environmental exposure to POPs and heavy metals in urban children from Dhaka, Bangladesh
Linda Linderholm *et al.*
J. Environ. Monit., 2011, **13**, 2728-2734

Aerosol size distribution and mass concentration measurements in various cities of Pakistan
Khan Alam *et al.*
J. Environ. Monit., 2011, **13**, 1944-1952

Seasonal trends and potential sources of ambient air OCPs in urban and suburban areas in Dalian, China
Qingbo Li *et al.*
J. Environ. Monit., 2011, **13**, 1816-1822

Seasonal evaluation of outdoor/indoor air quality in primary schools in Lisbon
P. N. Pegas *et al.*
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