Institution: Lancaster University

Unit of Assessment: UoA7 – Earth Systems and Environmental Sciences

Title of case study:

Reducing the global impacts of persistent pollutants and wastes through world-leading environmental chemistry research

1. Summary of the impact (indicative maximum 100 words)

Global waste disposal strategies and chemical regulations have been transformed through LEC's world-leading research into the environmental sources, fate and behaviour of persistent organic pollutants (POPs). Firstly, our research has directly supported controlled high temperature incineration as a long-term option for the disposal of municipal waste, by showing that well regulated incineration is not an environmentally significant source of dioxin emissions. Secondly, our research has maintained the controlled utilisation of sewage sludge (biosolids) on agricultural land as an effective risk-based management solution that re-cycles valuable carbon and nutrients to soil. Our research has underpinned the development of the UK's Dioxin Strategy and supported international chemicals regulation for one of the most important global flame retardant chemicals in current use under the Stockholm Convention.

2. Underpinning research (indicative maximum 500 words)

Lancaster environmental scientists have developed world leading research into the environmental sources, fate, behaviour and effects of persistent organic pollutants (POPs) over the last two decades, led by Prof. Kevin Jones and colleagues (Dr. A Sweetman, Dr R. Alcock, Dr C. Halsall). The approach has been to combine

(i) state-of-the-art chemical analysis applied to determine the distribution of POPs at trace and ultra-trace levels in space and time in environmental media;

(ii) estimates/measurements of emissions and sources of POPs to the environment;

(iii) controlled laboratory and field experiments to quantify particular processes and fates; and

(iv) the development and application of chemical fate models to protect human and environmental health.

This 'chemical mass balance and inventory approach' has been used to develop a quantitative understanding of the contribution of particular sources, practices, pathways, policies or actions on environmental levels and the exposure to organisms, including people. This understanding has been used to underpin effective decision making by Government, agencies and industry in the UK and Europe, and by relevant international agencies (e.g. the Stockholm Convention on Persistent Organic Pollutants), and in the development of waste and chemical management actions. Examples of underpinning achievements and insights include:

(i) The first long-term ambient measurements and trends of dioxins (PCDD/Fs), polychlorinated biphenyls (PCBs), polychlorinated diphenyl ether (PBDEs) and polynuclear aromatic hydrocarbons (PAHs). This has been funded continuously by DEFRA for >20 years, to establish reliable baseline data, and to connect links between sources and exposure via 'chemical fingerprinting', together with the first national and global source inventories and environmental budgets to inform policy decisions. This work changed the perceptions and focus of policy makers across the world[1,2,3].

(ii) The first conclusive evidence that dioxins are not just emitted from industrial processes linked to the chlorine industry but have a natural baseline level from diffuse combustion sources, clarifying that 'zero emissions' can never be achieved and cannot form a basis for policy[3].

(iii) Our evidence-led risk-based approach to understanding the fate and behaviour of persistent chemicals across human food-chains has maintained the recycling of sewage sludge to agricultural land across Europe[4]. This whole systems approach pioneered by the Lancaster group is now enshrined in the risk assessment framework that underpins global policy approaches to new classes of chemicals (DEFRA, 2012).

(iv) The establishment of the first pan-European and global background air monitoring network, to provide scientifically-based context to concerns that polar regions and their biota would be significant global sinks for POPs[5]. Long-range transport of POPs was a key evidence measure informing the continuation or cessation of use of persistent organic pollutants under the Stockholm Convention.

(v) We pioneered approaches to quantify the relative importance of primary and secondary sources of POPs to the environment over time, which has informed decisions on which sources dominate and should be targeted, the effectiveness of source reduction measures, the movement of POP chemical distribution towards a state of global 'air-surface partitioning equilibrium' over time, and the relative importance of global source and sink areas for selected POPs[6].

Between 1993 and 2013, this area attracted research funding totalling ~£8M and supported >60 PhD projects in LEC. Recognised for providing strategic evidence-based advice, the group has attracted diverse funding streams including UK Government (Department for Environment, Food and Rural Affairs (Defra); Environment Agency; Health and Safety Executive), international Government (Ministry of Science and Technology and National Science Foundation in China), industry bodies (UKWIR, EuroChlor; Council of European Chemical Industries (CEFIC), Galvanisers Association and metals industry), multi-nationals (Du Pont; Unilever) and non-governmental organisations (Greenpeace; World Wide Fund for Nature), in addition to the usual Research Council and European Union sources.

3. References to the research (indicative maximum of six references)

1. Coleman, P. J., Lee, R. G. M., Alcock, R. E. and Jones, K. C. (1997). Observations on PAH, PCB and PCDD/F trends in UK urban air: 1991-1995. *Environ. Sci. Technol*. **31**: 2120-2124. (113 cites)

2. Wild, S. R and Jones, K. C. (1995). Polynuclear aromatic hydrocarbons (PAHs) in the United Kingdom environment: a preliminary source inventory and budget. *Environ. Pollut*. **88**, 91-108. (354 cites)

3. Alcock, R. E., McLachlan, M. S., Johnston, A. E. and Jones, K. C. (1998). Evidence for the presence of PCDD/Fs in the environment prior to 1900 and further studies on their temporal trends. *Environ. Sci. Technol*. **32**: 1580-1587. (29 cites)

4. Breivik, K., Sweetman, A., Pacyna, J. M. and Jones, K. C. (2002). Towards a global historical emission inventory for selected PCB congeners – a mass balance approach. I. Global production and consumption. *Sci. Total Environ*. **290**: 181-198. (248 cites)

5. Jaward, F. M., Farrar, N. J., Harner, T. J et al. (2004) Passive air sampling of PCBs, PBDEs, and organochlorine pesticides across Europe. *Environ. Sci. Technol*. **38**, 34-41. (254 cites)

6. Meijer, S. N., Ockenden, W. A., Sweetman, A. J., Breivik, K., Grimalt, J. O. and Jones, K. C. (2003). Global distribution and budget of PCBs and HCB in background surface soils: implications for sources and environmental processes. *Environ. Sci. Technol*. **37**: 667-672. (235 cites)

4. Details of the impact (indicative maximum 750 words)

As the global chemical industry has grown rapidly over the past 5 decades (global chemical output was valued at US$ 171 billion in 1970; by 2010, it had grown to US$ 4.12 trillion) so has the need for evidence-based safety assessment and regulatory guidance to protect human health and the environment. We have pioneered the use of environmental inventories, mass balances and chemical fingerprinting to connect emission sources and their transfer through food chains. As such, our body of research has provided global leadership in the following three areas of impact.

Development of the UK position and strategy on dioxins that guided European risk assessment regulations

Over 330 million tonnes of waste are produced annually in the UK. With restricted landfill capacity, disposal of municipal solid waste (MSW) by controlled high temperature incineration with energy recovery (MSWI) is a critical option economically and environmentally. MSWI is a cornerstone of UK and European policy, currently accounting for 15% of the UK MSW disposal (Defra, 2013 Incineration of Municipal Solid Waste (https://www.gov.uk/government/publications/incineration-of-municipal-solid-waste). In 2010, MSWI provided 6.2% of the UK's total renewable electricity generation. However, in the early 1990s, MSWI was under threat as new emission standards on dioxins were proposed across Europe. There was a belief that MSWIs were responsible for enhanced human dioxin exposure. Our work on dioxin emissions (Section 2.i & ii), chemical fingerprinting (Section 2.i, 2iv & 2v) and food-chain models (Section 2.iii) provided a quantitative link between environmental concentrations and human exposure, and pioneered an approach that provided context from which to quantify the contributions of MSWIs. Our evidence provided the necessary context (Section 2ii) in which to place the incremental contributions which incinerators make to ambient levels and exposure and confirmed that correctly operated incinerators made a minor contribution to ambient levels and exposure,[A] ensuring that this disposal route continues to represent a vital part of energy generation mix since then. Research underpinned the 2012 UK National Implementation Plan[B] for the Stockholm Convention on POPs – the most important global treaty to protect human health and the environment from the adverse effects of POPs. According to DEFRA, LEC's work ".. *has underpinned the UK position and evidence base and consequently provided leadership in International Chemical's management*"[C].

Maintaining the controlled utilisation of sewage sludge (biosolids) on agricultural land as a safe and effective practice to re-cycle carbon and nutrients
In the UK, ~1.6 million tonnes (dry solids) of sewage sludge (the solid waste derived from waste-water treatment) is produced a year, of which 50% is currently recycled and applied to agricultural land[D]. Use of sewage sludge re-cycles valuable organic matter and nutrients (principally nitrogen and phosphorus) back to the soil. However, in the late-1990s, sludge-to-land disposal was under threat due to concerns about its potential contribution to environmental and human exposure to organic chemical contaminants[E]. In 2001, new legally enforceable limits for selected organic compounds in biosolids were suggested by the EU that – if enacted - would have effectively prohibited recycling to land.[F] The economic and environmental implications of this would have been huge. In the UK alone, annual costs for the water industry for disposal would have trebled (from £80M to £240M a year). The need to use alternative fertilizers would have cost UK farming approx. £2 billion a year and the opportunity to re-cycle ca. 24 million tonnes of carbon, 4 million tonnes of nitrogen and 2.4 million tonnes of phosphorus from sewage sludge would have been lost (Water UK 2004). Our research has played a key role in ensuring that land disposal of sludge remained possible. To quote a special advisor to the Waste and Resources Action Programme (WRAP) "*A large body of evidence to support safe land disposal was pioneered by Jones and his team at Lancaster, specifically in terms of persistent organic pollutant fate and behaviour. The evidence of processes and models of chemical fate played a large part in developing the UK and European risk-based approach to land disposal of sludge.*"[G]. This impact was achieved as follows.

Between 1994 and 2008, we secured support (£2.6m) from the then Ministry of Agriculture, Fisheries and Food, then Department of the Environment, and the Water Industry, to provide a complete scientific assessment of the significance of organic contaminants in biosolids, their inputs to the UK agricultural system relative to other sources, and the potential to transfer to ground-waters, crop plants, grazing animals and the human food-chain (Section 2ii, 2iii). Through more than 50 peer-reviewed publications, and workshops held to inform interested parties in the UK, Europe and elsewhere, we challenged the need for routine standards, the selection of compounds for standard-setting and provided scientifically defensible evidence that existing limits to applications based on the heavy metal content would safeguard environmental concerns. Our evidence on organic contaminants represented key cited data for European decision-making[F] and so continues to underpin recycling of biosolids to land across Europe where agricultural reuse accounts for about 40% of overall sludge production. Further, our findings highlighted that biosolids would make only a minor contribution to human exposure via crop plants, but that the surface application/spraying of sludge onto grassland could lead to transfers of persistent and bioaccumulatory compounds to meat and milk. Since 2001, our research and its policy uptake across Europe has ensured a sustainable risk-based approach has been adopted that encouraged routine application of biosolids to land via evidence-based codes of practice (Water UK 2004 and via later guidance documentation Water UK 2010)[D&H]. Thus, the impact of our research continues, helping to enhance yields, save on landfill and incineration, whilst recycling a growing waste product into a valued resource.

Defining and guiding the regulation of flame retardant chemicals under the Stockholm Convention.
Polybrominated diphenyl ethers (PBDEs) are a key group of flame retardant chemicals. Our research into the atmospheric transport and bioavailability of deca-bromodiphenyl ether or Deca-BDE (see Section 2i, 2iii, 2iv & 2v) supported maintaining its use while banning other PBDEs whose detrimental effects on human health and the environment exceeded their socio-economic benefit. Deca-BDE is widely used in electrical and electronic goods found in households and offices (especially in high impact polystyrene (HIPS) casings), in vehicles and in certain textiles and fabrics. In 1994, the European Commission Regulation 1179/94 listed Deca-BDE in the Priority List 1 as a compound to potentially ban and designated the UK government as the Member State

rapporteur for the environmental assessment. In May 2009, the UK EA released the Environmental Evaluation Report of Deca-BDE[I] The final risk assessment document (EA, 2009) cited Lancaster research as evidence for the global distribution of these chemicals. The European Commission's Communication on the risk assessment of Deca-BDE confirmed that the Member States scientists '*have completed the risk evaluation activities with regard to man and the environment*" for Deca-BDE and that there are no significant risks to the environment or human health which would justify risk reduction measures'. Maintaining the use of flame retardants has positive net benefits reducing the number and impact of fires. In Europe alone, the European Commission has estimated a 20% reduction of fire deaths as a result of the use of flame retardants in the past 10 years. An EC report demonstrated that 2,926 Europeans lost their lives in 2005 in domestic fires, which in economic terms, this is equivalent to about €12.6 billion or 0.17% of GDP. http://ec.europa.eu/consumers/safety/news/flame_retardant_substances_study_en.htm. On that basis, a 20% reduction in deaths due to the continued use of Deca-BDE flame retardants would represent an annual saving of almost 600 lives and €2.5 billion.

In addition to these three specific examples, the global impacts of our world-leading research has been facilitated through Sweetman's leading role in defining and developing the UK National Implementation Plan since 2007[B] and his participation in annual meetings of the UN/ECE Task Force on POPs on-behalf of Defra. In this way our long-term monitoring data, modelling approaches and fundamental process-based research, continue to provide evidence and policy advice directly to the Parties of the Stockholm Convention. Sweetman's promotion to Senior Lecturer during the REF period is both recognition of his contribution to delivering high-level impact from LEC's research and an investment to ensure that our research will continue to deliver impact in the future. Our investment in new analytical facilities will also ensure that our research continues to provide the evidence needed to balance the restriction of some persistent chemicals with the need to ensure chemicals whose benefits outweigh their risks remain in use, contributing valuable economic and society benefits.

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. Defra 2007. UK National Implementation Plan on POPs http://archive.defra.gov.uk/environment/quality/chemicals/documents/pop-nationalplan.pdf
B. Defra 2012, National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82680/consult-nip-pop-doc-20121121.pdf
C. Letter from Science and Evidence Team, Defra
D. Water UK 2010. Recycling of Biosolids to Agricultural Land. Jan 2010. http://www.water.org.uk/home/policy/publications/archive/recycling/biosolids/recycling-biosolids-to-agricultural-land--january-2010-final.pdf
E. EC 2002 Disposal and recycling routes for sewage sludge - Part 4: Economic Report. http://ec.europa.eu/environment/waste/sludge/pdf/sludge_disposal4.pdf
F. JRC 2001, Organic Contaminants in Sewage Sledge for Agricultural Use 2001 http://ec.europa.eu/environment/waste/sludge/pdf/organics_in_sludge.pdf
G. Letter of Support from Special Adviser at WRAP
H. Water UK 2004. The Application of HACCP procedures in the Water Industry: Biosolids treatment and use on agricultural land. WRc REF: UC6332/3. March 2004. http://www.water.org.uk/static/files_archive/0WUK_Haccp_guide_FINAL_19_Mar_04.pdf
I. Environment Agency 2009. Science Report – Environmental evaluation: Decabromodiphenyl ether. ISBN: 978-1-84911-112-6 http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/scho0909bqyz-e-e.pdf