Institution: University of Southampton

Unit of Assessment: 15 General Engineering

Title of case study: 15-41 Sustainable resource management: reducing waste and protecting the environment

1. Summary of the impact

Research carried out by the University of Southampton has directly influenced the practice and behaviour of households, business, industry and government agencies. It has:

- Contributed to the 38% reduction of waste going to landfill and the 34% increase in recycling of municipal waste from 1995 to the present day.
- Underpinned the development of anaerobic digestion of food waste from the laboratory bench to the UK Government's preferred treatment option for this type of waste in only 10 years.
- Influenced landfill management and regulatory practices so as to improve resource recovery and reduce the long-term pollution potential.

2. Underpinning research

The modern waste industry is concerned with waste as a resource, following the principles espoused in the landmark paper *From waste to resource management* (Lisney, Banks and Riley, 2003). It is a dynamic and fast-changing business sector, with a turnover in the EU of €95 billion.

The University of Southampton Waste Management Research Group (WMRG) has for more than 15 years adopted a holistic approach to its work, covering the entire spectrum from waste avoidance through resource recovery to the responsible return of residuals to the environment. The WMRG has worked in partnership with users and industry to implement new ideas and technologies, and optimise existing technologies and operations. The research described in this study is focused on three key areas: biogas production from food waste, sustainable resource management and sustainable landfill. These projects were funded through the EPSRC's £1.6 million Sustainable Urban Environment (SUE) Waste Consortium [3.1] and Defra's Waste Implementation Plan (WIP) New Technologies Demonstrator Programme (NTDP) and Technologies Research and Innovation Fund (TRIF) [3.2].

Research into biogas production from food waste, led by Charles Banks, Professor (1995ff), Sonia Heaven, Reader (1994ff), and Yue Zhang, Lecturer (2006ff), was taken from the laboratory bench to pilot-scale in collaboration with industrial partner Greenfinch Ltd, and funded by Biffaward (2001-3). This research showed high energy yields from the substrate and provided the basis for obtaining Defra funding for the first UK full-scale food waste biogas plant [3.2] (Ludlow, 2007**)**. This NTDP project provided both a quantitative mass and energy balance for the process, and the evidence base for the feedstock and collection protocols needed for technically and economically viable operation. Further projects funded through TRIF [3.2] demonstrated successful energy production from a range of municipal waste fractions, including food waste combined with commercial and industrial wastes. Energy yields and the fertiliser value of the solid residue were improved, and solutions to bioreactor instability were developed to enable food waste biogas plants to run successfully at high ammonia concentrations [3.3]. The VALORGAS project (EU FP7, 2010-3), led by Southampton, raised awareness of food waste in Europe and helped establish it as a priority topic in the proposed Horizon 2020 research portfolio.

Research carried out under EPSRC's SUE Programme [3.1], led by Ian Williams, Professor (2002ff), Banks and William Powrie, Professor (1995ff), investigated the scientific, social and economic suitability of various waste management strategies and technologies in the urban setting. Williams led research on waste prevention, reuse and recycling, and how environmental legislation affects small and medium-sized companies. It revealed low levels of compliance with environmental regulations, and poor enforcement by the regulator and practical methods for overcoming these issues. Research over the period 2007-13 focused on the innovative reuse and recycling of small waste electrical and electronic equipment (WEEE), showing that the impact of the UK digital TV switchover on the disposal of WEEE had been underestimated. Research with environmental charity Wastewatch (2003-2007) showed how primary school-based educational

programmes increased household participation in recycling and reduced residual waste. Other studies led by Peter Shaw, Senior Lecturer (1994ff) and Williams addressed the optimisation of kerbside recycling facilities and showed that alternate weekly collection (AWC) schemes increase the amount of recyclable wastes collected and reduce residual waste, with improved operator productivity, reduced costs and no adverse impacts on the public [3.5].

Research led by Richard Beaven, Principal Research Fellow (1996ff), Powrie and David Richards, Professor (1995ff), into optimising resource recovery from and reducing the pollution potential of landfills has been funded by EPSRC, Defra, the Environment Agency and the waste industry since 1996 [3.5]. Main findings include better understandings of fluid flow in landfills [3.6], leading to the design and implementation of improved control systems including horizontal wells; and an understanding of mechanical/ physical properties of waste, giving better assessments of landfill stability and waste settlement.

3. References to the research

[3.1] EPSRC Sustainable Urban Environments Programme SUE Waste Consortium (*Strategies and technologies for sustainable urban waste management*), £1.6M, 2004-11, GR/S79626, 6 universities led by Southampton. Outputs include 2 special issues of *Proc ICE Waste and Resource Management*, **162**, WR1 (http://www.icevirtuallibrary.com/content/issue/warm/162/1) and WR3 (http://www.icevirtuallibrary.com/content/issue/warm/162/3)

[3.2] Defra's Waste Implementation Programme (WIP) New Technologies Demonstrator Programme (NTDP) and Technologies Research and Innovation Fund (TRIF); see D Brooks and W Powrie (2007). Defra's New Technologies Demonstrator programme. *Proc ICE Waste and Resource Management* doi:10.1680/warm.2007.160.1.5; W Powrie (2011). Evaluation of treatment technologies for biodegradable municipal solid waste. *ibid* doi:10.1680/warm.2011.164.3.127. Outputs include 2 special issues of *Proc ICE Waste and Resource Management* **160** (WR1), 2007 (http://www.icevirtuallibrary.com/content/issue/warm/160/1) and **164** (WR3), 2011 (http://www.icevirtuallibrary.com/content/issue/warm/164/3)

[3.3] CJ Banks, Y Zhang, Y Jiang, S Heaven (2012) Trace element requirements for stable food waste digestion at elevated ammonia concentrations. Bioresource Technology 104 127-135 DOI: 10.1016/j.biortech.2011.10.068

[3.4] T Curran and I D Williams (2012). A zero waste vision for industrial networks in Europe. *J Haz. Mat*., doi:10.1016/j.jhazmat.2011.07.122

[3.5] EPSRC project grant *Development of sustainable landfill practices and engineered landfill technology*, £283k plus £150k from Cleanaway, 1996-9, GR/L16149, Powrie, Banks, Tanton (retired) and Robinson (QMUL). EPSRC Platform Grants *Liquid and gas flow processes in wastes* , £437k from EPSRC plus £150k from Cleanaway, 2000-4, GR/R04232, Powrie and Beaven; and *Processes, mechanics and management of residual wastes*, £461k, 2004-9, GR/T25194, Powrie, Beaven, Richards and Banks.

[3.6] W Powrie and R P Beaven (1999). Hydraulic properties of household waste and implications for landfills. *Proc ICE Geotechnical Engineering* doi:10.1680/geng.1997.137.4.235

4. Details of the impact

Organic wastes produce greenhouse gases as they degrade. The UK produces around 16 Mt (Megatonnes) of domestic and commercial food waste each year: anaerobic digestion (AD) with biogas recovery could generate 16 GWh/year of renewable energy as methane, for injection into the gas grid, use as vehicle fuel or conversion into electricity and heat.

The joint University of Southampton and Greenfinch pilot study, and continued support for demonstration of this technology together with the effective dissemination of results through workshops funded by the Waste and Resources Action Programme (WRAP), has led to a rapid expansion in the number of source-segregated food waste collection schemes and biogas plants across the UK. Further supporting research formed the key evidence for the British Standard stability test for digestates in PAS 110 [5.1] and has informed current EU-wide discussions on end of waste criteria. Since 2006, 1.8 Mt of food waste digestion capacity has been established, with the largest plant processing 120,000 tonnes/year and generating 6 MW of electricity plus 5 MW of

heat. Currently ~75 MWe of power is supplied to the grid and planning approval has been granted for a further 200 biogas plants in the UK. Southampton's modelling of integrated waste management through AD has demonstrated how environmental benefits can be further increased through on-farm co-digestion with animal wastes, giving greater reductions in GHG emissions and enhanced opportunities for resource recovery. The necessary permitting for such a scheme is currently being drawn up by the Environment Agency and was the subject of an industry-led workshop at the Anaerobic Digestion and Biogas Association ADBA) conference (July, 2013).

The rapid expansion of food waste digestion in the UK following the start-up and operation of the Defra demonstration plant [5.3] led to further research [5.2] that has improved digestion efficiency and allowed loadings on full-scale plant to be more than doubled without risk of failure. This has major commercial significance as the throughput of already-constructed plant can be increased, giving additional revenue from both gate fees for acceptance of waste material and sales of renewable energy, and a reduction in capital payback periods. In the case of new plants, the capital costs of installation for a given waste stream can be significantly reduced [5.4].

Research in collaboration with local authorities led to a number of improvements in public recycling behaviour, infrastructure and professional services between 2008-13, including an increase in diversion rates away from landfill by over 20% in Lancashire and "significant and sustained improvements" in the performance of a civic amenity site in Plymouth as a result of the implementation of WMRG advice [5.5]. The Development Director at leading waste management company Biffa said: "(The economic) performance of the sector has been improved as a consequence of the change in operational practices stimulated by this evidence." [5.6] Output from SUE Waste Consortium studies with third sector organisations on reuse was incorporated into WRAP guidance in 2012-3 [5.1], informed the development of Defra's National Waste Management Programme for England (2010-1) and led to major changes in the GLA's policy on waste collection from businesses [5.6]. Work on WEEE was used extensively in a high profile but confidential waste-related legal case involving large multi-national organisations at the High Court, with Williams giving evidence as the environmental expert (Claim No. HC09CO4852).

The €8.3 million ZeroWIN project (2009-14) involving SMEs and large multi-nationals (including Hewlett Packard and Continental Tyres) from 11 countries [5.8] is creating innovative technologies, waste-prevention methodologies, strategies and system tools based on the vision developed by Curran and Williams [3.4]. This system uses a distinctive combination of methods, tools, technology, design innovations and policy measures. Companies have demonstrated via 10 case studies that the system works successfully in practice and is commercially viable. The vision has facilitated the world's first eco labelled D4R laptop; was used as a template for the refurbishment of the Deutsche Bank Twin Towers in Frankfurt, which was awarded the highest possible (LEED Platinum and DGNB Gold) certifications for their resource and energy efficiency in 2011 [5.7]; and stimulated the AU Optronics Corporation (Taiwan) in 2012 to introduce new ISO environmental standards [5.8]. Involvement in the CLEAR Info project with the Environment Agency (2011-4, LIFE 10 ENV UK 175), which aims to obtain evidence for regulating companies, will allow European regulators to share data across regulatory boundaries and influence business decisions in the boardroom, enhancing the importance of environmental risk in financial markets.

Other impact highlights in industry and business include Southampton leading the development of European industrial networks in the automotive, construction, electronics and photovoltaic sectors targeting 3 million companies (>20 million employees) with €2.8 trillion turnover and value creation of €800 billion. As an example, an industrial network between Wiesauplast and Continental Tyres in Germany resulted in the design and installation of a technologically advanced plastics mill in 2012 using re-granulated recyclate to manufacture the control housing of Continental's brake systems. Continental manufactured 18 million control housings in 2012, or 25% of the world total.

Williams and Shaw have contributed to raising awareness and understanding of these waste management issues among the wider public through a number of media appearances, including an article in the New Scientist (April 2008) and two in Materials Recycling World (2008 and 2013). Williams also appeared on BBC Radio 4's programme, "Costing the Earth: Greening the Teens" in May 2011, and BBC World Service Global News in January 2012, a service that enjoys a weekly international audience of around 40 million [5.7].

In the areas of landfill engineering and pollution control, WMRG's research findings have been used by industry (with authorisation from the Environment Agency) to replace at least 300,000 tonnes of virgin aggregate with tyre-derived products in landfill drainage systems since 2005 [5.9]; and consultants and landfill designers in hydrogeological risk assessments, leachate balances and landfill stability/ settlement assessments since 1999 [5.10]. In 2011-2 Powrie and Beaven acted as expert witnesses in litigation associated with the notorious Cranbourne landfill, near Melbourne, Australia (Supreme Court of Victoria Proceeding No. 9776 of 2008). Beaven featured on BBC Radio 4's Costing the Earth on 8 October 2013, investigating landfill mining.

Powrie brought the whole experience of the WMRG to bear in his chairship of the Technologies Advisory Committee for Defra's NTDP [3.2] between 2004 and 2010. For example, studies led by Stringfellow, Senior Research Fellow, with Powrie and involving Orchid Environmental Ltd on a full-scale mechanical heat treatment system led to substantial improvements in plant operation in Huyton, Liverpool in 2009 and a reduction in residual waste material [3.2].

5. Sources to corroborate the impact

[5.1] Statement from Sector Specialist for Organics and Energy from Waste, WRAP BSI PAS 110: http://www.wrap.org.uk/content/bsi-pas-110-producing-quality-anaerobic-digestate

[5.2] C J Banks and Y Zhang (2010). *Optimising inputs and outputs from anaerobic digestion processes*. Technical report: Defra project code WR0212. Available at http://www.organics-recycling.org.uk

[5.3] R Arnold, C J Banks, M Chesshire, M Foxall and A Stoker (2010). *Defra Demonstration Project: Biocycle South Shropshire Biowaste Digester* http://archive.defra.giv.uk/environment/waste/residual/newtech/demo/documents/Biocycle-final.pdf

[5.4] C J Banks, Y Zhang and M Walker (2011). *Optimising processes for the stable operation of food waste digestion*. Technical Report, Defra project code WR1208. Available at http://www.organics-recycling.org.uk. WRAP-funded workshops in Bristol, Birmingham and Glasgow in 2011: http://www.bioenergy.soton.ac.uk/publications.htm; VALORGAS (2013) D4.6 Technical solutions to allow digesters operating on high nitrogen food waste to achieve the maximum energy yield, http://www.valorgas.soton.ac.uk/deliverables.htm

[5.5] Statement from Waste and Recycling Coordinator, Borough of Pendle

[5.6] Statement from Development Director, Biffa http://legacy.london.gov.uk/gla/publications/environment/reuse-fullreport.pdf

[5.7] EC Framework 7 funded grant *Towards Zerowaste in Industrial Networks* (*ZeroWIN*) (FP7-ENV-2008-1, Grant 226752, 2009-2014; Kopacek, Williams et al, €8.3 million). Vision reported in: I D Williams et al (2011) *ZeroWIN Commonly Agreed Vision Paper*; Deliverable 1.3b, v 1.0 (FP7 ENV 2008 1; 226752-Zerowin; www.zerowin.eu). Year 10 Challenge to secondary schools in 2013 (feedback from schools). Williams on BBC World Service Global News, 2 January 2012 (http://www.bbc.co.uk/podcasts/series/globalnews/all). Williams on BBC Radio 4; interview on Costing the Earth: "Green Teens", 4 May 2011, (http://www.bbc.co.uk/iplayer/episode/b010t7tz/Costing_the_Earth_Greening_the_Teens). Den Boer, E.; Williams, I.D. and Curran, A. (Eds) (2013). *ZeroWIN Final Case Study Reports for all Networks / Pilot Applications*; Deliverable 6A.3, version 1.0 (July) (FP7 ENV 2008 1; 226752-Zerowin). Austrian Society for Systems Engineering and Automation, Vienna, Austria.

[5.8] Statement from Senior Engineer, AUO

[5.9] http://www.angloenvironmental.com/reports/TyreGuidance.pdf http://www.intowaste.co.uk/consultancy.html

[5.10] Statement from RUKHYDRO Limited. Beaven on BBC Radio 4, Costing the Earth, "CSI Landfill" 8 October 2013 http://www.bbc.co.uk/programmes/b03c3cnb