Institution:	**Loughborough University**
Unit of Assessment:	**B14 Civil and Construction Engineering**
Title of case study:	**Radical energy, cost and water savings from recycling food waste**

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

Research into a new waste treatment process model at Loughborough University (1993 to date) has resulted in the following benefits for Unilever:

- Savings of £2m for wastewater treatment over the last 4 years
- In 2012 additional savings of £0.2m from biogas and £0.1m in water supply and landfill costs
- A reduction in carbon dioxide emissions of 10 million tonnes (2012) from the substitution of fossil fuels
- Significant reductions in the risks of spills, sewer overloads and the recycling of scarce resources, namely water and fertilizer
- Newly developed underpinning generic principles to be incorporated in updated designs and guides for users (to be published by Foundation for Water Research/ICE/CIWEM)
- Researchers (five) being employed as a direct result of the specialised expertise gained and their ability to provide similar benefits to other sectors of industry

2. Underpinning research (indicative maximum 500 words)

Research at Loughborough University (LU) from 1993 to date had established that combining biogas recovery with waste treatment would improve the viability of recycling food-processing wastes, if the stability of the process could be improved **[R1** for example**]**. Surveys of biogas production from the traditional areas of application of anaerobic digestion, namely sewage and animal slurry treatment **[R2]**, suggested half these plants suffered from breakdowns due to unforeseen shock loads.

This research carried out by Andrew Wheatley (LU, 1991 to date), Kenneth Johnson (RA 1993-1995) and Christopher Fell (RA 1997-2000) devised a highly effective way of characterising food-processing effluent **[G1] [R3]** to predict the changes likely to cause excesses of metabolic intermediates. These were the most commonly reported cause of the problems with the traditional applications of anaerobic digestion to treat domestic sewage and agricultural wastes. The result was a technique that was mathematically simple and easy to validate without the need for exotic equipment, but was responsive to the potentially sudden diurnal and seasonal variations in waste characteristics. It overcomes the inability of the previously used mechanistic models, founded on classical kinetic equations, to adequately represent rapidly changing and complex organic food wastes **[R4]**.

The resulting model was based on dividing the load into three proportions according to particle size analysis (filtration and settlement R1) as a surrogate for the kinetic microbial growth rate constants **[G2]**. This basic model was then used to guide new research necessary to optimise pre-treatments to reduce particle size in difficult waste streams such as those containing large amounts of solids, for example intact yeast cell walls (Shelton Smith PhD 2008).

Wheatley, with the financial support of Unilever **[G3]**, led research by John Shelton-Smith (2003-2008) and Helen Theaker (2008-2009) to apply and improve the knowledge on the effectiveness of novel particle disruption techniques (ultrasound, microwaves, pressure swing, cavitation and electropulses) to wastes from brewing and yeast processing. The researchers were able to use the phase-analysis method of characterising waste from their earlier work to predict risk and yields of biogas from the proposed anaerobic treatment. The research was used to model the most efficient sequence for the treatment train - and which waste streams to include - to achieve both the best stability and biogas yields. Alternatives were compared firstly in laboratory tests and then the preferred design validated with a 25m^3 pilot plant built with Unilever and contractors to provide real time scale up data on the resilience to shocks **[R5]**.

A virtual full scale design was also produced to calculate the capital and running costs for the Marmite site using the data from the pilot trial **[R5]**.

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

R1 Monroy, O., Johnson, K.A., Wheatley, A.D., Hawkes, F. and Caine, M. (1994) "The Anaerobic Filtration of Dairy Waste: Results of a Pilot Trial", *Bioresource Technology*, 50 (3), 243-251, ISBN 0950 9623, doi: 10.1016/0960-8524(94)90097-3

R2 Johnson, KA, Wheatley, AD, Monroy, O (1994) "Mixing and Solids Accumulation in Anaerobic Filters. Two Case Studies", *Environmental Technology*, 15, 263-270, ISSN: 0959-3330, doi: 10.1080/09593339409385427

R3 Johnson, K.A., Wheatley, A.D. and Fell, C.F. (1995) "An Application of an Adaptive Control Algorithm for the Anaerobic Treatment of Industrial Effluent", *Transactions of Inst. Chem Engineers*, 73, 203-211, ISSN: 0957-5820

R4 Wheatley, A.D., Fisher, M.B. and Grobicki, A.M.W. (1997) "Applications of Anaerobic Digestion for the treatment of Industrial Wastewaters in Europe", *Water and Environment Journal*, 11, 1, 39-46, doi: 10.1111/j.1747-6593.1997.tb00086.x

R5 Shelton-Smith, J. and Wheatley, A.D. (2006) "Opportunities for Centralised Anaerobic Digestion Facilities to meet the Food Waste Regulations – A Business Plan", *11th European Biosolids and Organic Resources Conference*, Wakefield AquaEnviro, ISBN-13: 978-1903958209

R6 Bryns, G., Smedley, V. and Wheatley, A.D. (2012) "Carbon dioxide releases from wastewater treatment", *Engineering sustainability – The Proceedings of the Institution of Civil Engineers*, 166, 111-121, DOI: 10.1680/ensu.11.00037

Grants awarded:

G1 Wheatley *et al.*, *The anaerobic Digestion of industrial Effluent*, EPSRC GR/H/18494, 1992-1995, £300k

G2 Wheatley *et al.*, *Non-invasive wastewater analysis*, EPSRC GR/G/18858, 1991-1994, £150k

G3 Wheatley, *Codigestion of domestic and industrial waste materials*, Muntons, Severn Trent and Biffa, 1995-2008, £100K

G4 Wheatley, *Application of anaerobic digestion to a case study food processing effluent*, Unilever, 2000-2003, £150k

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

Food waste is a highly publicised priority problem since land and water used in its production are the largest demands on global resources. According to the DECC/DEFRA Anaerobic Digestion Strategy and Action Plan (http://bit.ly/1995KKQ) 16 million tonnes (dry weight) of food and drink waste is generated annually in the UK, furthermore producing at least 10 times this in wastewater. It was calculated **[R6]** that treating effluent using conventional wastewater treatment requires about 800 KWh per wet tonne, up from 500KWh in 2005.

The immediate impact from this research has been to demonstrate new technology that provides renewable energy whilst reducing wastewater and greenhouse-gas emissions. Dissemination throughout the food and processing industry will have significant economic and sustainability benefits. Our partners, Unilever, have pioneered this application (R1) led by its commitment to innovation and sustainability. Reducing waste at food processing sites is a priority during any major investment or refurbishment. The Marmite plant generates 15 tonnes of high-strength food-processing effluent an hour round the clock and if the company were to discharge this into the sewer it would cost more than £0.5m per annum. This was one of the alternatives, which were either to discharge to the Utility for treatment, to build a conventional tried and tested but carbon intensive plant, or to use the risky, anaerobic digestion technology. Other questions that arose were whether all or only part of their wastewater should be treated and if they should outsource operation of a waste treatment plant.

Analysis of these alternatives started in 2005 against the backdrop of the renewable-energy incentives offered by the UKs commitment to reducing carbon emissions and the enhancement of support for recycling. Unilever enlisted Wheatley's help in their decision-making based on his previous contributions to solving waste problems at this and other sites.

Loughborough's work was fundamental to the feasibility and decision-making meetings at Unilever (2005), at which the main effluent-management options were compared and enumerated. A major contribution was quantifying and reducing the risk from using innovative technology for energy and water recovery. The uncertainty arose because anaerobic reactors had rarely been used for treating industrial wastewater in the UK and where they had, problems were reported. The incentives however suggested site specific work and Unilever fully funded Shelton-Smith at Loughborough **[G4]** to work out what would be required to successfully adapt anaerobic digestion to the Marmite site. Wheatley and Shelton-Smith were able to use the previous research **[R3]** on how to characterise the variable nature of food-production effluents to optimise anaerobic digestion. Monitoring of the waste in this way was used to suggest the best process-flow sheet to achieve reliability and sustainability. Using these data and their experience with anaerobic treatment of other wastes, the research team shortlisted the most promising reactor designs and pre-treatment techniques.

In all, the researchers worked with, contractors and other technical experts from the Unilever group from 2005-2009 to detail the design and commissioning. Extensive testing was crucial to gaining the confidence of Unilever senior management in this untried approach to effluent-treatment. They financed the research and based on the results, investment was approved and £4m spent in 2009 on construction of a plant for energy and water recovery implementing the treatment process developed and established at Loughborough **[R4]**.

Wheatley and Shelton-Smith advised in the competitive procurement process organised by Unilever to select the contractor and subcontractor. Loughborough researcher Theaker was appointed by Unilever in 2008 to lead the commissioning of the plant, which has been operating successfully to date **[C1, C2, C3]**.

The impact and reach of the research extends well beyond the Unilever application. Our innovative procedures provide a practicable and fundamentally different approach to the design of anaerobic wastewater treatment plants. Our approach simplified the reaction rate model through radical changes to waste characterisation and monitoring procedures; (three instead of thirty parameters). The procedure is easy to use and is to be incorporated as an update to the mechanistic International Water Association model and described to the industry by the Foundation for Water Research, the Chartered Institution of Water and Environmental Management and Institution of Civil Engineers design guidelines to new bioreactor designs. These are the standard guidelines for practitioners working in the £500m food waste processing sector.

The research had significant economic impact realised through the new wastewater-treatment plant's production of biogas and clean water. Unilever uses the biogas to produce energy, which currently the company uses directly on site. Unilever have made the business case for further investment for gas storage with the prospect of feeding electricity from the plant into the national distribution network. Water from the treatment plant is pure enough to be recycled for multiple uses. Excluding running costs, the plant saved £0.9m in 2012, a figure projected to increase year on year, particularly with energy price rises.

The new Marmite wastewater-treatment plant also makes a substantial contribution to sustainability including the replacement of fossil fuel from power generation estimated to be more than 10 million tonnes of CO_2 per year **[C1]**. The other environmental benefits are the reduction in the volume and strength of effluent discharged to the sewer, which is reducing the risk of odour, sewer overflows and overloads as climate changes generates more intensive rainfall. Current research focusses on recovery of other materials as well as water and gas, particularly nitrogen and phosphorus from the solids residues.

Unilever are working to extend the approach that we have pioneered at Marmite to other Unilever food-processing plants across Europe, making use of the EU wide incentives for renewable energy. The new procedures adopted at Marmite have delivered a 10% reduction in operating costs through the generation of renewable energy (20% of site use) and lowered effluent-treatment costs by 90% **[C1]**.

Through their participation in the research (doctoral and post-doctoral), five researchers have been able to disseminate these developments in the engineering of anaerobic treatment and industrial effluent management. Shelton-Smith and Theaker were employed by Unilever as a result of these research outcomes and to apply the technology to other company's sites **[C1]**. Fell and two others work for other companies in the water industry.

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

The following sources of corroboration can be made available at request:

C1 Letter of corroboration from Project Leader, Unilever Marmite Foods, Burton on Trent

C2 Letter of corroboration from Managing Director, Aquabio (subcontractor mainly responsible for design and build of the wastewater treatment plant at Unilever's Burton upon Trent site)

C3 Letter of corroboration from the Technical Manager, Unilever Marmite Foods, Burton on Trent