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Valorisation of food waste to biogas

Rationale

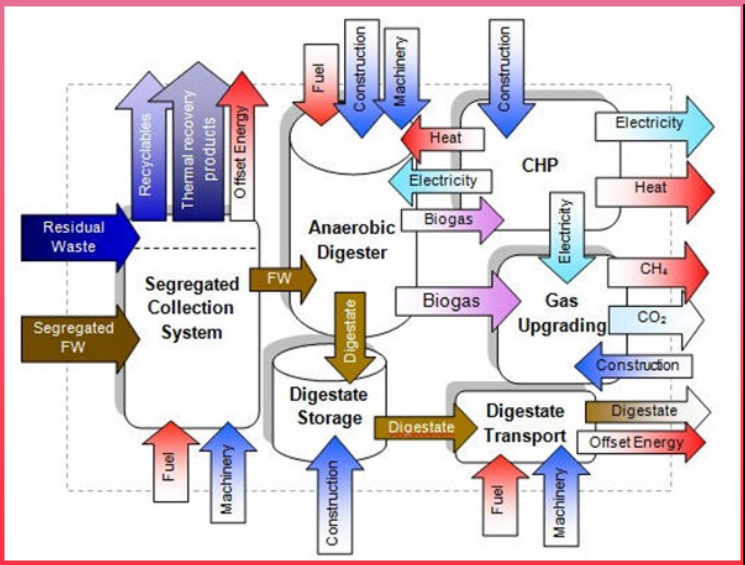
Food waste arising from homes, restaurants and catering facilities, food markets and food processing activities represents a large fraction of the municipal waste stream. Actual proportions vary across the EU, but as an example in the UK food wastes that can be segregated account for around 24% of the total weight of household waste, with an approximately equal tonnage arising from industry and commercial sources.

This material has a very high energy potential but is unsuited to energy generation through conventional combustion processes, as its high moisture content gives it an unfavourable lower heat value. The energy can, however, be efficiently recovered through biologically-mediated routes, provided that the process can be stabilised to deal with the high nitrogen content of these wastes. In terms of overall energy balance and carbon footprint the anaerobic digestion of food waste makes a very positive contribution to energy generation both directly, and indirectly through energy savings.

Benefits and likely impacts of the research

Recovery of food waste through anaerobic digestion

- provides the opportunity for highly efficient recovery of a second-generation gaseous fuel product with multiple applications for the end user.
- captures nutrients present in the waste and allows these to be returned to agricultural use, with associated economic, energy and carbon gains from offsetting requirements for artificial fertiliser.
- reduces moisture content in the residual waste stream, thus improving the calorific value and the efficiency of thermal energy recovery in Energy-from-Waste (EfW) facilities, creating new opportunities for refused-derived fuel (RDF) production and increasing the range of thermal technologies that can be applied.
- enhances opportunities for recovery of commodity grade recyclable materials and of the embodied energy in them by reducing the moisture and contamination levels of the remaining waste and allowing the use of advanced automated sorting technologies in materials reclamation facilities.



Energy inputs and outputs in the anaerobic digestion of source segregated food waste

Key concepts

To valorise the energy from food waste by anaerobic digestion (AD), with full evaluation of the overall life cycle energy balances associated with this process. AD is not a new technology, but its application for energy recovery in the field of municipal waste treatment is only just becoming established in Europe, and only for mixed wastes. The use of source segregated food wastes as substrate is not yet widespread, possibly because of technical challenges linked with collection, handling, pre-treatment and digestion of this material. The research includes a number of closely related components with a common underlying goal: to evaluate and where possible improve the energy production process from the perspective of the overall net energy gain achieved within defined system boundaries that include collection, sorting, processing, and beneficial use of recovered material.

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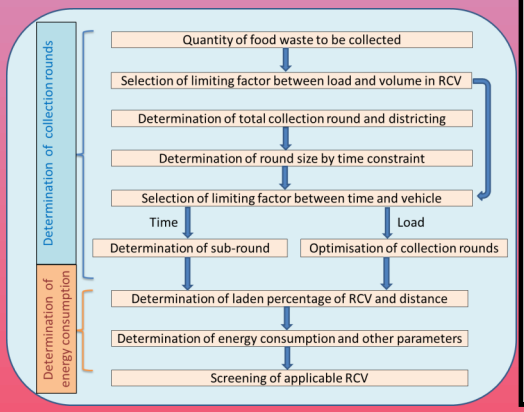
Scientific and technical objectives

- To evaluate the efficiency and yield of source segregated food waste collection schemes from domestic properties, restaurant and catering facilities, food markets and food manufacture.
- To determine the energy and carbon footprint of the biowaste-to-energy process including collection, transport, treatment and final product use, considering both direct and indirect inputs. This provides the basis for full life cycle assessment of the environmental impacts and benefits of this technology.
- To optimise pre-treatment of the source segregated waste stream for biogas production and biosecurity of the residual product by development and trialling of novel cell disruption and autoclaving techniques.
- To balance the digestion process using interventions to improve the carbon to nitrogen ratio for optimal volumetric biogas productivity and added value of the digestate product.
- To gain a deeper understanding of the interaction of fundamental chemical and microbiological factors affecting the potential for energy gain from the substrate, and to convert this into practical operational protocols for stable and effective digestion of high-nitrogen wastes at loading rates that allow maximum volumetric biogas production.
- To achieve a mass and energy balance around two full-scale digesters treating food waste, one at mesophilic and one at thermophilic temperature, which will act as a benchmark for industry in the drive for widespread implementation of the process at commercial scale.
- To further develop low-cost small-scale biogas upgrading technologies and storage systems for application in transportation and local low-pressure distribution systems.
- To estimate the potential for small-scale biogas upgrading in local transportation in the EU and India.
- To evaluate the appropriateness of scale of digestion and end-use energy conversion technologies, with particular reference to matching public and private community needs.
- To evaluate the potential for food waste digestion as a second generation biofuel source across the EU in terms of energy yield, environmental benefit and end user requirements.

Work carried out to date

Deterministic model for collection scheme evaluation



WP2. Collection and sorting/segregation systems

- The extent of food and biowaste collection schemes across the EU 27 has been surveyed by interrogation of web-based information
- Factors affecting collection efficiency have been quantified in terms of fuel usage which ranges from 4 –16 litres per tonne collected
- A deterministic model to allow analysis of the fuel consumption and resource requirements of different types of kerbside source segregated food waste collection schemes is now being used to compare different potential schemes
- Characterisation of the wastes and the waste collection schemes for Lisbon and South Shropshire has been completed
- Surveys on food waste generation in a prison, army camp and two universities are being undertaken
- A survey of food waste collection from commercial hospitality sector companies (restaurants and hotels) is being undertaken at a centralised reception/transfer station

WP3. Pre-treatment and technical scale trials

- Lab-scale work on autoclaved waste has reached steady state, allowing evaluation of this pre-treatment on biogas yield and other parameters
- Acclimatisation of technical-scale digesters to food waste has been undertaken in preparation for comparative testing of autoclaved waste
- Lab-scale work on CO_2 pressurisation has been completed and the process discounted for further technical scale trials
- Extensive testing has been undertaken on ammonia stripping from digestate as an in-situ and side stream process. Technical-scale trials have used a vacuum degasing unit for ammonia recovery
- A range of operating conditions have been tested for hythane production at mesophilic and thermophilic temperatures
- Work in preparing the 300m^3 digester is complete, the unit has been inoculated and environmental permits and planning consents obtained

1m^3 technical-scale plant used in the auto-clave trials

300 m^3 technical scale plant ready for loading trials

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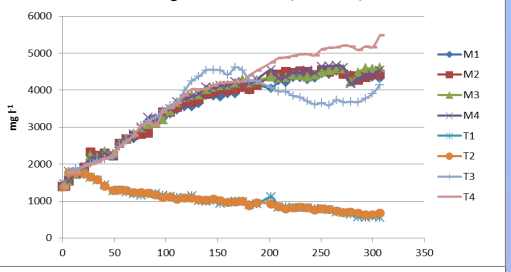
Work carried out to date

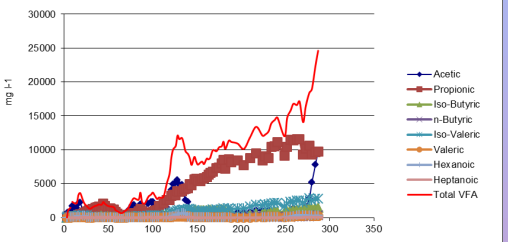
WP4. **Fuel conversion technology optimisation**

- Continued long-term laboratory kinetic testing to establish maximum achievable digester loading and limiting trace element concentrations
- A continuous digestion trial set up to track changes to the methanogenic population under mesophilic and thermophilic conditions using FISH analysis and gene pyrosequencing
- Tracer studies carried out using ^{14}C carbon to confirm metabolic pathway to methane production under high ammonia conditions
- Long term continuous digestion trials underway to determine limiting concentration of ammonia under thermophilic conditions
- Digestion tests carried out using high and low ammonia feedstocks to establish the inhibitory concentration of ammonia to hydrogenotrophic methanogens
- Optimisation of a 2 phase thermophilic food waste digester
- Continued gathering of data for the ongoing mass and energy balance calculations being performed on the South Shropshire and Lisbon food waste digesters
- Development of a new gas chromatographic method for the measurement of long chain fatty acids (LCFA)

Ammonia in mesophilic and thermophilic digesters fed on food waste and low nitrogen food waste (T3 & T4)



Slow accumulation of VFA in a thermophilic digester fed on food waste



Filling station using Metener High pressure absorption system

One of the biogas upgrade plants in India reviewed by IIT (Delhi)

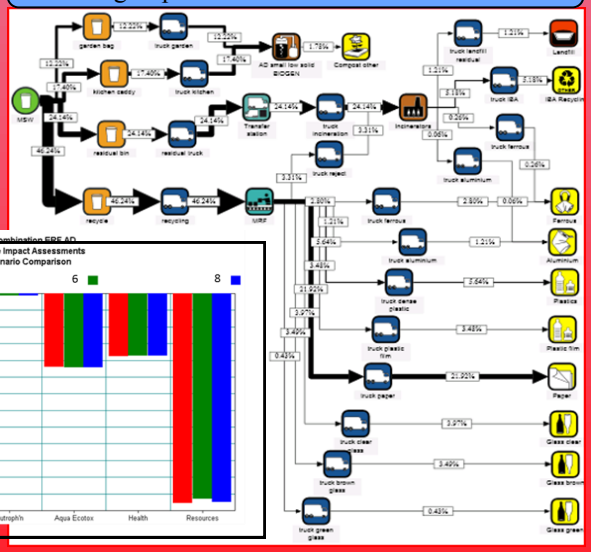
WP5. **Energy utilisation and end user requirements**

- Review of systems for small-scale biogas upgrading equipment completed covering 5 plants in Europe
- Evaluation of existing low-cost gas bottling systems for vehicle use adaptation in developing economies
- Pilot-scale trials carried out on low pressure absorption system for gas upgrading with and without water recirculation
- Performance evaluation of an automated biogas upgrading system in India
- Preliminary modelling of water scrubbing systems using Aspen plus process optimisation software
- Case and feasibility studies in progress on small-scale biogas utilisation for transport in EU and India, as a preliminary step to estimating the potential for low-cost upgrading and use in local transport
- Economic data collected on performance of small-scale high-pressure gas upgrading system for vehicle use

WP6. **Energy, environment & life cycle evaluation**

- Work on assessing the biosecurity of food waste digestates has started using material with and without pre-treatments
- Fertilising value of digestate from laboratory digesters has been tested and the results fed into the footprint model via a purpose built module
- Alongside the development of 'in-house' energy/carbon/nutrient footprinting models proprietary software is also being used, including the UK Environment agencies WRATE model
- A comparative assessment of WRATE and a simple energy balance approach has been used for evaluation of an anaerobic digestion scheme
- The reproducibility of a testing protocol for digestate stability has been statistically evaluated

WRATE scenario map and graphic output showing impacts for an AD scheme



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Major achievements at the end of the second reporting period

- WP2: Results obtained from a comprehensive web-based survey of 27 EU countries on waste management practice for the collection of food and biowastes. Construction and testing of a mathematical model to quantify fuel usage and other parameters for different collection schemes. Analysis of compositions and contaminant levels associated with collections from commercial premises indicate that wastes are more contaminated but compositionally very similar to domestic food waste. Preliminary results suggest participation in food waste collection schemes does not drop off as the scheme matures.
- WP3: Larger-scale digesters running and trials begun on autoclaved waste (1 m^3) and TE addition at high loadings (300 m^3). Ammonia stripping can be achieved with vacuum unit or by use of a stripping column and scrubber. A model for ammonia stripping has proved to be valuable for selecting the appropriate technological approach. Hythane production established in 2-phase digesters, and problems with ammonia toxicity in thermophilic conditions overcome.
- WP4: Proof that in digesters with high ammonia concentrations, methane formation is by the combination of CO_2 and hydrogen and not directly from acetic acid. An upper limit has been established for the ammonia concentration at which stable operation of digesters is possible. Trace element addition allows high organic loadings to be achieved producing 2.5 m^3 of methane per day for every 1 m^3 of digester. Advanced gene sequencing used to analyse the microbial population in the digester. Further refinement of mass and energy balances for two full-scale digesters treating source segregated food wastes.
- WP5: The Wobbe index H-quality for upgrading biogas can be met at a pressure of only 2 bar using fresh water. An more efficient CO_2 desorption system and water cooling is needed to meet Wobbe index LL-quality target with water recycling. Metener's high pressure absorption system and filling station uses around 1.2-1.4 kWh kg^{-1} gas upgraded and pressurised. Water use is 0.05-0.1 m^3 kg^{-1} of gas produced. Maintenance costs are estimated at 0.04-0.08 € kg^{-1} of upgraded and pressurised gas. Methane content of upgraded gas is 92-95 % CH_4.

Partners visiting Metener Oy, Finland as part of the VALORGAS sponsored Jyväskylä *summer school on biogas*

Expected results and impacts

- The current research will contribute to meeting the EU targets for both second generation biofuel and renewable heat and power
- It is expected to confirm that food waste digestion in Europe could replace 12.86 Mtoe of vehicle fuel
- Digestate recycling will help to close the loop between urban and agricultural nutrient cycles
- Separation of food waste will help to reclaim other commodity-grade recyclables from waste
- Recycling of food waste will result in an overall reduction in greenhouse gas emissions through fossil fuel substitution, fertiliser replacement and landfill diversion

Project partners

AnDigestion Ltd, UK

Aerothermal Group PLC, UK

Eco-Solids International Limited, UK

Foundation for Innovation and Technology Transfer, Indian Institute of Technology, Delhi, India

Greenfinch Ltd, UK

Jyväskylän Yliopisto, Finland

Metener Oy, Finland

Maa Ja Elintarviketalouden Tutkimuskeskus, (MTT Agro-Food Research), Finland

University of Southampton, UK

Università degli Studi di Verona, Italy

Università Ca' Foscari di Venezia, Italy

Veolia Environmental Services (UK) Ltd, UK

Valorsul - Valorização e Tratamento de Resíduos Sólidos das Regiões de Lisboa e do Oeste, S.A., Portugal

Project website: **www.valorgas.soton.ac.uk**