VALORGAS

Valorisation of food waste to biogas

COOPERATION

Rationale

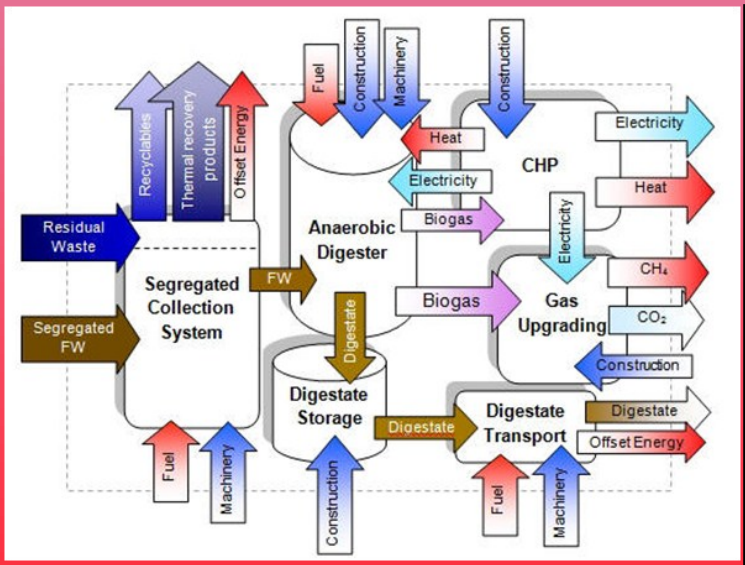
Food waste arising from homes, restaurants and catering facilities, food markets and food processing activities represents a large fraction of the municipal waste stream. Actual proportions vary across the EU, but as an example in the UK food wastes that can be segregated account for around 24% of the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

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

Software tool for collection scheme evaluation

WP2. Collection and sorting/segregation systems

- Waste audit and feasibility studies indicated minimum scales of operation for single and distributed sources of food waste
- Extensive evaluation showed LCA is not currently a suitable tool for comparative assessment of energy and carbon balances, but can provide useful insights on embodied energy and emissions
- The mechanistic model for evaluating food waste collection schemes was extended to cover twin and multi-compartment vehicles collecting a wide variety of waste categories. It is now available as WasteCAT, a software tool that can be used in scoping studies, system design, and benchmarking of performance
- Evaluation of the residual waste stream showed that removal of food waste increased the CV by 9-33% while the weight collected typically decreased by 12-34%
- Even with separate collection of food waste, a significant fraction still remains in the residual stream making it difficult to consider further recovery of high-grade recyclable

WP3. Pre-treatment and technical-scale trials

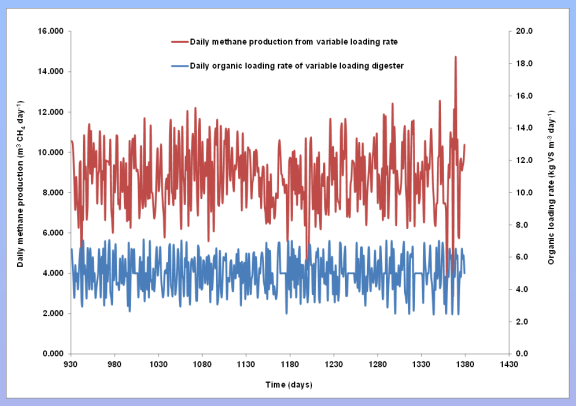
- Completion of lab-scale studies using autoclaved food waste showed it to have a lower specific methane yield. The total ammonia nitrogen (TAN) content of the digestate was lower, however, and the biogas produced had a lower H_2S concentration
- Work at a technical-scale confirmed the above results using a different source of food waste collected over a longer sampling period
- The 300 m^3 digester was run at a high loading and demonstrated a rapid reduction in VFA concentration when dosed with Co and Se supplements, which then ensured continuing stable operation
- Extensive testing of small pilot-scale digesters coupled to side stream ammonia stripping columns showed the feasibility of reducing digester TAN concentrations to below the critical inhibition threshold in thermophilic conditions
- Ammonia removal was also shown to be feasible using a pilot-scale vacuum degassing unit

Pilot digesters coupled to ammonia stripping columns

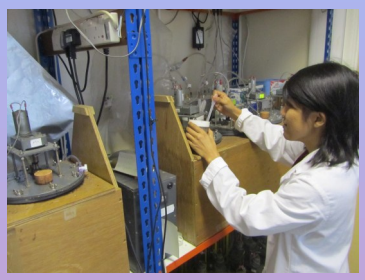
Work carried out to date

WP4. **Fuel conversion technology optimisation**

- Experiments to determine the maximum achievable digester loading reached steady state at 8 kg VS m^3 day^{-1} without loss of stability or significant reduction in specific methane yield
- Changes in the methanogenic population structure occurred at a concentration of ammonia known to trigger digester instability
- Tracer studies carried out using ^{14}C carbon showed ammonia-stressed digesters using a hydrogenotrophic route to methane formation, confirming the results of the microbial population structure analysis
- Long-term continuous digestion trials to determine the limiting concentration of ammonia in thermophilic conditions found this lies between 2.5-3.5 g N l^{-1}
- Digestion tests carried out with high and low ammonia feedstocks to establish the inhibitory concentration of ammonia to hydrogenotrophic methanogens under mesophilic conditions showed this was ~8 g N l^{-1}
- Mass and energy balance calculations were completed for the South Shropshire and Valorsul food waste digesters, and a standard methodology established and documented.
- It was recommended that Se and Co concentrations of 0.2 and 0.35 mg l^{-1} should be maintained in the digester to ensure stable operation at an OLR of up to 5 kg VS m^3 day^{-1}



Fluctuations in gas production in response to random changes in loading between 2.5 -7.0 kg VS m^3 day^{-1}



Feeding lab scale digesters

Biogas car at ITT. The vehicle was supplied by MNRE Government of India

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

- Metener produced a full-scale prototype gas upgrading unit capable of delivering CH_4 at 99.6% purity with full water recycle, coupled to a vehicle refuelling appliance (VRA)
- Metener developed a drying system with a dew point of –50°C
- IIT produced a fully automated system that was able to meet the new Indian biomethane standards, including PSA drying to give a moisture content of < 20 mg m^{-3}
- IIT contributed to the development of IS Standard 16087: 2013 – Biogas (Biomethane) Specification
- A finite element model for low-pressure gas upgrading was developed and validated against real plant
- A road map for biogas upgrading and bottling technology in India was proposed to MNRE and a set of recommendations to promote biomethane in local transportation in Europe was and circulated to EU stakeholders

Metener's full scale prototype biogas upgrade plant and VRA in action

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

- Food waste digestates shown to meet standards for heavy metals and pathogens and have a significant economic value
- Digestates gave excellent growth yield based on their NH_4-N content, but autoclaved waste showed reduced mineralisation and plant availability of nitrogen
- Anaerobic Digestion Model 1 has been linked to Aspen Plus to provide an integrated modelling platform for full process simulation, including sidestream ammonia stripping
- ADtool was developed to calculate GHG emission balances and can be used with WasteCAT to allow rapid modelling of a wide range of scenarios for valorisation of food waste to biogas.
- The ADtool showed overall energy and GHG emission balances to be positive for all AD production and gas upgrading scenarios. This result shows the development of small-scale systems is worth pursuing
- An ILCD node was set up for dissemination of LCA datasets generated in the project and elsewhere

Examples of energy balances for different scenarios and outputs

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Major achievements at the end of the third reporting period

- WP2: Detailed work on analysis of collection systems has played a major role in the further development of the mechanistic model, which has now been implemented as a software package providing a robust and powerful tool for comparative assessment of the energy consumption, GHG emissions and resource use of collection schemes.
- WP3: Pilot and technical scale trials have demonstrated the feasibility of removing ammonia from food waste digesters opening the way for operation under thermophilic conditions without risk of ammonia toxicity. Trace elements have been proven to control VFA build up and allow stable operation in an operational food waste digester. Technical-scale trials were able to confirm unexpected results seen in earlier laboratory trials on autoclaved waste, providing an opportunity for exploitation of this type of pre-treatment where low N and S availability is advantageous.
- WP4: A major scientific contribution has been made to the understanding of interactions that take place in mesophilic digestion at high ammonia concentrations, and the theory put forward at the beginning of the project is now considered correct. This knowledge has been effectively disseminated and has made a major contribution to building industrial confidence in the process. Energy balances for the full plants studied have shown these to be positive, and identified where improvements could be made. Detailed information on tolerance levels of digesters to ammonia are now available for both mesophilic and thermophilic systems.
- WP5: Metener has built a low pressure biogas upgrading system and vehicle refuelling appliance with a quick-fill storage system. IIT's experimental biogas plant was run for over 200 days and showed the effectiveness of the continuous monitoring and drying which enabled full automation. The plant provided the fuel to run a test vehicle for 15,000 km. Implementation plans for biogas upgrading and bottling technology in India have been proposed and recommendations to promote biomethane in local transportation in Europe were circulated to stake holders

Dr Saija Rasi of MTT speaking at IIT's International Workshop on biogas upgrading and bottling in India and EU

Results and impacts

- The research outputs will contribute to meeting the EU targets for both second generation biofuel and renewable heat and power
- It is expected 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
- Residual streams still contain a high proportion of food waste even after segregation but their calorific value is enhanced
- 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

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**