BBSRC NIBB AD Network
All Business Interaction Vouchers: FINAL REPORTS

2014 BIV Final Reports

BIV2014001
Permastore / Dr Sonia Heaven **Testing of anaerobic digester components found in thermophilic digestion of food wastes**

Permastore is the world's leading manufacturer of Glass-Fused-to-Steel tanks and silos, with more than 300,000 structures installed worldwide in over 110 countries. The wide range of applications already includes anaerobic digestion and biogas and biofuels production. The company's aim is to remain at the forefront of development in this field, and to ensure its continuing ability to provide customers with optimum solutions for their containment requirements, and with secure, long-life systems for an expanding range of applications in both anaerobic digestion and novel anaerobic biotechnologies.

The company therefore wished, in association with the Bioenergy and Organic Resources Research Group at the University of Southampton, to develop a testing protocol that would allow materials destined for potential use in advanced applications to be validated. This would include operation at thermophilic temperatures and where harsh conditions are likely to arise in digesters, both in normal operation and where the process becomes unstable or fails.

The testing procedure developed was based on continuous simulation of the digestion process in small pilot-scale anaerobic digesters, and has provided comprehensive data that would not be available from simple batch tests. Trials on samples provided by Permastore Ltd were successfully carried out using source separated domestic food waste obtained from commercial collections operated by UK waste management contractors: this material is itself an interesting and challenging feedstock under thermophilic conditions because it generates high concentrations of ammonia in the digestate, which can be toxic to the microbial consortium that carry out the process. An innovative side-stream stripping process was therefore used to ensure stable operation in the thermophilic temperature range used, and provide a controlled range of test conditions for the trials.

The project allowed the partners to draw on their combined expertise to develop and apply an appropriate in-vivo material testing regime, and to work together on evaluating the results from trials carried out over a period of six months. In addition to providing robust test results, the project has also led to publishable data on the successful operation of ammonia stripping and the performance of thermophilic digestion of food waste in these conditions. Further trials have been commissioned using the same approach and, and the scientific data on digester operation will be disseminated through journal publication.

BIV2014002

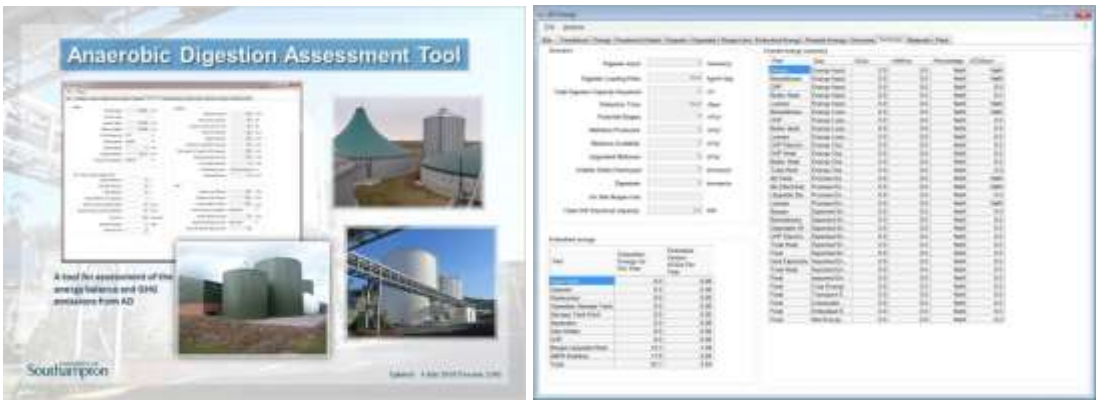
IEA Task 37 / Dr Sonia Heaven

A modelling tool for the UK AD industry

Rapid expansion in the UK anaerobic digestion (AD) sector has created a need for powerful, flexible and readily-accessible modelling tools for the outline design, benchmarking and assessment of AD facilities. The current project took an existing model on which extensive development work has already been carried out, and completed the task of re-configuring it into a user-friendly software package suited to the needs of a wide range of end-users.

An AD modelling tool was first developed as part of the EU FP7 CROPGEN project (www.cropgen.soton.ac.uk) for analysis of agricultural biogas energy systems, and included databases on crop production systems and their direct and indirect energy and nutrient requirements. These were extended with specific data for UK agricultural systems as part of the RCUK RELU programme (www.ad4rd.soton.ac.uk). A version of the model was adapted to accommodate commercial and municipal waste as part of the FP7 VALORGAS project (www.valorgas.soton.ac.uk). It is thus one of the most extensive and rigorously tested modelling tools of its type currently available in Europe. Its major limitation before the current project was that some aspects still relied on the use of Excel spreadsheets, reducing uptake and limiting its adoption to those familiar with this type of application. The current work has re-combined key aspects of the different versions into a software package based on a high-level programming language, and has tailored inputs and outputs to meet the needs of industry and agricultural in the UK. The resulting tool allows prediction of detailed energy and nutrient balances for AD plants, which are also expressed in terms of the greenhouse gas emissions associated with the process.

The combined expertise of IEA Task 37 (UK) and the academic partners was used to develop and test a new user interface suitable for industrial and farm-based applications at a range of scales. This was achieved through close collaboration between industry and academic members of Task 37, who offered their time and expertise as in-kind contributions to achieve the desired goal. The software will be made freely available for download from the website of the Bioenergy and Organic Resources Research Group (www.bioenergy.soton.ac.uk) at the University of Southampton. The modelling tool can be used by industry users and researchers, promoting a common framework for evaluation of new and existing AD plants, and increased collaboration across the UK AD community.



Screenshots of opening screen and summary tab for Anaerobic Digestion Assessment Tool

2015 BIV Final Reports

BIV2015002
Lutra Ltd / Dr David Styles **Providing a scientific evidence base for public subsidy support of biomethane for transport from waste**
The environmental balance of the Barret's Mill Anaerobic Digestion (BMAD) system to generate biomethane for transport (BfT) from food waste was evaluated using an adapted version of Bangor University's LCAD Eco Screen tool. Scenarios were run for a commercial variant of the BMAD system capable of processing 750 t/y household foodwaste plus 250 t/y of commercial (pubs, restaurants, etc.) food waste, at 30% dry matter (DM) and with biomethane yields of 440 m3/t DM and 450 m3/t DM, respectively. The scenarios assumed that BMAD systems would be deployed to serve the 11.5 million people living in settlements of 5000 – 25,000 people (too small for large-scale AD units). It was assumed that household waste would otherwise have gone to composting, and that commercial waste would otherwise have gone to landfill. Around 300,000 tonnes of CO2e could be saved annually from the deployment of the BMAD system in the UK, avoiding almost 1.9 PJe of fossil energy. Emissions of eutrophying substances would be slightly reduced, but an increase of 224 t SO2e/yr of acidifying emissions, primarily in the form of NH3, could have negative consequences for air quality. Avoided diesel combustion and avoided waste management emissions contribute almost equally to CO2e avoidance, whilst avoided waste management dominates the eutrophication credits. There is some uncertainty about the magnitude of environmental credits (avoided burdens) associated with counterfactual waste management. Despite large fossil resource savings for the national scenario, significant quantities of electricity are required from the grid to supply the digester and upgrade plant. This significantly reduces the overall fossil energy substitution of the BMAD system, but could be mitigated through the use of on-site renewable energy sources, such as solar PV panels, to provide a portion of the electricity requirements. BfT also significantly reduces NOx and particulate matter emissions to air compared with substituted diesel combustion. Approximately £5.5 M/yr of damages from NOx and PM emissions could be avoided through the substitution of diesel with BfT if BMAD systems were widely deployed at the national level. If the CO2e damage costs are also taken into account, considering a range of values between £10 and £50 per tonne of CO2e, then BMAD national deployment could lead to additional savings of between £3 M and £15 M per year. The BMAD system appears to represent an environmentally-sustainable solution to the problem of organic waste management for small towns and rural areas that don't generate enough waste to support more typical large-scale anaerobic digestion plants. Through the avoidance of in-vessel composting and landfilling, the BMAD system can generate transport fuel with a negative carbon footprint, even after electricity requirements for BfT upgrade are accounted for. BfT could be used to power local buses more cleanly than diesel, also reducing local air pollution.

BIV2015003

Renewable Energy Association / Dr David Styles

Evaluating cost-effective greenhouse gas abatement by small-scale anaerobic digestion

This project focused on the benefits of small scale AD largely based on manures/slurries, with particular focus on GHG emission abatement potential and cost effectiveness in abating CO2e emissions when compared with other options. The Bangor University LCAD Eco Screen tool was used to calculate the net GHG emission abatement achieved by one tonne dry matter slurry throughput, considering a range of counterfactual (avoided) manure storage systems (lagoon, open tank, closed/crusted tank). These data were extrapolated up to national scenarios using statistics on farm size and manure management practices.

On-farm AD has significant potential to capture, as a renewable energy source, GHG emissions (e.g. methane) that would be otherwise released by storage and handling of manures and slurries. This means that there are significant GHG savings resulting from anaerobic digestion of manures/slurries due to avoided methane emissions from conventional manure/slurry storage and spreading. Use of methane from manures/slurries (on their own or in combination with crop feedstocks and residues) not only removes a direct source of GHG emissions, but also displaces the use of fossil fuels in terms of energy production also fertiliser manufacture (enhanced fertiliser-replacement value of digestate compared with slurry), thus further reducing net GHG emissions.

Small scale, farm AD largely based on manures/slurries is typically less cost-effective in cost per kWh generated than larger scale electricity generation. However, results of this study demonstrate that, owing to the large GHG abatement from avoided manure/slurry storage, it is much cheaper when looking at it in terms of carbon savings. Results show that each tonne of dry matter of cattle slurry avoids 1449 kg CO2e, and generates 443 kWh of electricity, leading to a GHG abatement cost of £60 per tonne of CO2e saved at a FIT rate of £0.20 per kWh. This compares very favourably with £182 per tonne of CO2e, which is the cost estimated for other renewable electricity generation based on a subsidy level of £0.09 per kWh (previously taken by Government as the maximum level it should pay for renewable energy). Thus, we conclude that even at a FIT rate of £0.20 per kWh, small scale farm AD largely based on manures/slurries would represent cost-effective GHG abatement.

This project showed that GHG savings as high as 1.8 million tonnes of CO2e per year could be achieved in the UK if AD were to be deployed across all dairy farms with more than 133 milking cows. Deploying AD on large dairy farms only would still potentially avoid over 600,000 tonnes of CO2e per year. In summary, GHG savings would be considerable and could significantly contribute to meet UK Carbon Budgets.

In conclusion, small scale, on-farm AD largely based on manures/slurries can play a significant role in GHG abatement in the future and can deliver this cost effectively. However, the current FIT regime is inadequate to support an increase in the uptake of smaller scale AD projects and should therefore be revised to recognise the potential of on farm AD to achieve cost effective carbon reductions and combat climate change.

BIV2015007

William Jackson Food Group/Dr Davide Dionisi
Anaerobic digestion of vegetable waste from the food industry

This study has investigated the anaerobic digestion of vegetable waste provided by the industrial partner in a range of operating conditions.
The VW sample was homogenised using a food processor/liquidiser. The sample was stored in a freezer at -18°C and defrosted before being fed into the reactor. Total and volatile suspended solids (TSS: 21.4 g/L, VSS: 21.3 g/L), chemical oxygen demand (COD: 62.9 gCOD/L) were measured according to standard methods. The initial pH of the substrate was 4.6. The reactors were inoculated with sludge from an existing anaerobic digester. The feed was maintained at 4°C to prevent bacterial metabolic activity and the experiments were carried out at 35°C. The process was monitored by periodic sampling for the analysis of the COD, VSS, total and soluble carbohydrates, pH, ethanol and VFA.
Four experimental runs were carried out in this project:
Run 1: continuous reactor at HRT of 10 days;
Run 2: continuous reactor at HRT of 20 days;
Run 3: continuous reactor at HRT of 20 days with addition of sodium bicarbonate to the feed;
Run 4: batch reactor.

The main results obtained can be summarised as follows:
- In all the investigated conditions the main process occurring was the conversion of the organic matter to volatile fatty acids (VFAs). Indeed, the total COD of the liquid phase in the reactor was in all cases at least 80% of the total COD of the feed, indicating low conversion to gas products. The low conversion to gas products is explained with the low pH of the feed, which inhibits methanogenesis. The average pH of the reactor varied from 5 (Run 1) to 6.5 (Run 3). The higher pH in Run 3 was due to the addition of sodium bicarbonate to the feed, however this was not enough to stimulate methanogenesis;
- In the continuous runs, degradation of the carbohydrates in the feed was in the range 50-80%, the highest values obtained for Run 3, the lowest values for Run 1. Degradation of the VSS in the feed was in the range 15-40%, the highest values being observed for Run 3.
- In the continuous runs, the VFA production yield was in the range 23-35% (on a COD basis) the highest value being observed for Run 3 and the lowest value for Run 1. The total concentration of VFAs was in the range 10-20 g COD/l, with the highest values observed for Run 3;
- Acetic acid, propionic acid, butyric acid and caproic (hexanoic) acid were the main fermentation products. Caproic acid was only detected in Runs 2 and 3. Acetic acid was usually the most abundant VFA produced. The concentration of butyric acid and caproic acid increased with increasing HRT. Ethanol, up to 1 g/L, was detected at the investigated conditions;
- In the batch run, the yield of products in the liquid phase increased with time, as expected. The final yield was approximately 40%, on a COD basis, and the main products were acetic and butyric acids.
In conclusion, this study shows that, for the vegetable waste considered in this study, the conversion to VFAs is feasible under a wide range of operating conditions. The conversion to methane is more problematic, probably due to the acidic pH of the waste.

"The issue of food waste has a continuing high profile and understanding how best to address individual waste streams is a key concern across the agri-food sector. To succeed in the aim of 'doing more with less' requires detailed understanding of the various options available for any given waste stream, prioritising those which are genuinely unavoidable. In this project we have deliberately focused on such material and have gained a very useful insight into an alternative route beyond the more-established methanogenic AD and animal feed. We are confident that

significant commercial opportunities may arise from continued investigation and hope to collaborate further with Aberdeen University and other academic institutions where we have pursued allied work." Dr Gavin Milligan - William Jackson Food Group

2016 BIV Final Reports

BIV2016001

Roam Agency /Dr Brenda Parker

Comparison of Biological and Mechanical Processes to Generate Value from Digestate

In this research, we compared the performance of two low-cost systems for the remediation of digestate from a small-scale AD plant: a biological cascade (i.e. vermifilter) and a mechanical separation (i.e. ultra scale-down centrifugation). Both systems aim to produce clarified liquor suitable for use in intensive food crop irrigation and algae cultivation. Tiger worms at a density of 1kg per 200 litres bedding substrate were hosted in vermifilters containing different bedding materials and housed in a polytunnel as follows:

- Vermifilter 1 consisted of wood chips (control),
- Vermifilter 2 consisted of worms and wood chips,
- Vermifilter 3 consisted of worms, wood Chips, and clay pebbles.

The bedding used in all vermifilters was a proportional volumetric mixture of materials and each vermifilter had a sump at the bottom for collecting the effluent. Two centrifugation runs were carried out: one equivalent to 50L/h through a CSA-1 disk stack centrifuge, and one well spun sample. The digestate was collected from an AD plant built on a small-scale at The Calthorpe Project in London, fed mainly on catering waste. The vermifilters were fed with 1 litre of diluted digestate (600ml digestate: 400ml water) three times a week over a three week period. The same digestate was used in both systems and analysed for the following nutrients in the influent and effluent: Total Solids, pH, Total Nitrogen, Ammonium Nitrogen, Nitrate Nitrogen, Phosphorus, Potassium, Magnesium, Sulphur, Copper, Zinc, Sodium, and Calcium. The centrifugation of digestate, from both runs, revealed that the majority of Phosphorous, Magnesium, Copper, Zinc, Sulphur and Calcium are all insoluble, and are found, almost entirely, in the solid fraction. Ammonium Nitrogen, Potassium and Sodium are all soluble, and are, for the most part, in the liquid component. Comparing with the vermifilters, most of these insoluble nutrients were either retained or converted to vermicompost. Soluble nutrients more rapidly taken up by plants, such as nitrate, increased as the digestate passed through the system, indicating that nitrification was occurring. Potassium, which is one of the recommended nutrients of the crop to be grown, was not incorporated in the system. The most suitable vermifilter aiming to produce clarified liquor suitable for use in intensive food crop irrigation and algae cultivation was the vermifilter 2. This research shows that there is potential for continuous investigation of different bedding materials and worms species for the remediation of digestate.

Andreas Lang, Director of Roam Agency said *"As a social enterprise, this short trial has been extremely useful in confirming to us the effectiveness of a low-cost organic approach to achieving a beneficial biological pathway for digestate. The results will help inform the development for a hybrid organic/mechanical digestate processing system designed to supply a range of urban agriculture systems, while addressing the challenge of surplus digestate at the decentralised scale; a critical step in realising the urban organic circular economy*."

Dr Brenda Parker, University College London said "*The Business Interaction Voucher from the Anaerobic Digestion Network was vital in this research to investigate low cost solutions to clarify digestate suitable for use in intensive food crop irrigation and algae cultivation.*"

BIV2016003

Tropical Power Ltd./Prof. Charles Banks

Process optimisation of Africa's first commercial grid connected AD plant

Tropical Power is an engineering procurement and construction company building renewable energy solutions for Africa: its focus is on developing utility-scale sustainable energy technologies including anaerobic digestion (AD) and photovoltaics. The Company plans to build renewable power assets producing over 130 MW of clean, distributed power. The first of these was commissioned as Africa's first commercial grid-connected AD plant in 2016. It is situated at Gorge Farm Energy Park in Nakuru County, Kenya and is currently fed on maize stover from baby sweetcorn and trimmings from other high-value vegetables grown for export, mainly to the UK; future feedstocks may also include drought-tolerant plants from non-irrigated marginal lands that cannot be used for food production.

Because this type of mixed feedstock has not previously been used elsewhere, there was scope for optimising the plant's performance in terms of its energy use and overall efficiency. To achieve this, the University of Southampton (UoS) has been working with the Company to set up a testing and monitoring laboratory, train staff, and advise on plant operation. This involved spending 3 weeks on site at the Gorge Farm energy park to assess the facilities, and make recommendations on how these could be improved to allow a flexible approach to evaluation of plant performance through testing of feedstock methane potential, monitoring plant stability, and improving feedstock conversion rates.

During the visit Prof Banks had discussions with all members of the plant operational and management staff to decide which the key parameters to monitor were, which could be done continuously, which required additional laboratory facilities and staff training, which should be carried out in Kenya, and which required shipment of samples to external analytical laboratories. As a result the Company invested in some additional equipment which gave a much greater 'in house' potential; and the training and advice provided gave locally-employed staff the ability and confidence to provide the operational team with day-to-day data on the stability of the plant.

Further feedstock samples were taken for analysis to assess any nutrient deficiencies, and as a result a bespoke trace element cocktail has now been supplied to Tropical Power by a UK

company.
Training was also given on how to establish the methane potential of different feedstock types, and the Company has now invested in equipment to give the laboratory in Naivasha the capability of testing a range of indigenous drought-tolerant species that are non-competitive with food crops and could be used as future energy substrates. This part of the work is now continuing with UoS working with Tropical Power on a FCO Prosperity Fund grant.
The BIV also allowed the Company to work with the University partners to identify those parameters that can affect the sustainability of the project, and baseline data has been collected which will be used in modelling of the results to provide further guidance on plant optimisation and improving its environmental performance.

Mike Mason, Chairman of Tropical Power said *"The interaction with Southampton University has helped us overcome many of the technical difficulties associated with the commissioning of a new plant, using a new feedstock, in a country with no other industrial-scale digesters to provide inoculum. It is excellent that we now have a full technical capability in our laboratory. The staff benefitted hugely from the training provided, and this is allowing us to explore the possibility of using new substrates and innovative harvesting and pre-treatment methods".*

BIV2016006

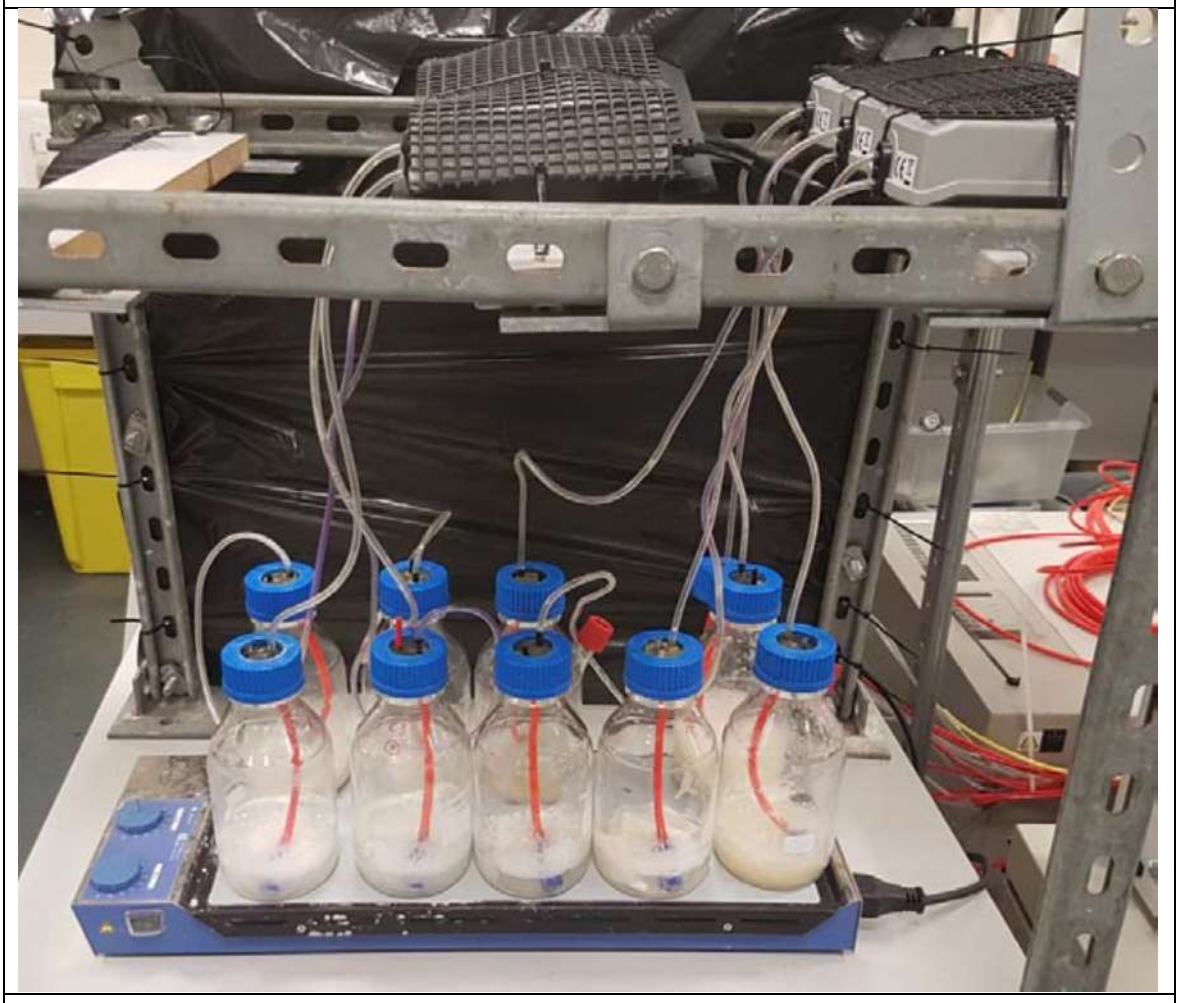
Loowatt Ltd./ Dr Tim Patterson
Evaluation of an integrated aerobic - anaerobic microbial system for enhanced degradation of biopolymers

Loowatt Ltd. (Loowatt) have developed a waterless toilet system with potential for use at locations where water supply is difficult, such as festivals, construction sites or campsites (Loowatt Ltd., 2016). The Loowatt toilet is lined with a polymer bag. Flushing the toilet feeds the bag into a storage cartridge below, whilst pulling more polymer from a roll to re - line the toilet. Once the roll has been consumed, the cartridge can be emptied for waste disposal. Loowatt aim for the polymer lining used in their system to be made from biodegradable materials, allowing for the entire waste stream to be used to produce energy in a sustainable manner. Loowatt has partnered with the Wales Centre for Excellence for Anaerobic Digestion within the Sustainable Environment Research Centre (SERC) at the University of South Wales (USW) to deliver a 5 month collaborative research project funded by a BBSRC Business Innovation Voucher Scheme as administered by the AD Network (based at Southampton University).
Loowatt had a range of potential polymer materials that could be utilised for their application. The aim of the BIV project was to investigate whether a combination of aerobic pre - treatment followed by anaerobic digestion would provide any significant advantages over anaerobic biodegradation only. Whilst the generation of energy via anaerobic digestion is advantageous to the company, their primary aim is to achieve degradation of the polymer in a practical and economic process.
Work carried out included the following experiments:
1. Pre - treatment using enhanced aerobic cultured designed for breaking down hydrocarbons, followed by anaerobic digestion
2. Aerobic composting of polymers, followed by anaerobic digestion
Results for experiment 1 indicate that aerobic pre - treatment (in the form investigated) does not have a significant impact on the level of biodegradation exhibited by the polymer during subsequent anaerobic digestion.
Results of experiment 2 indicate a significant mass loss for one of the candidate polymers

with no significant mass loss for polymer 2 or 3 during aerobic composting. Addition of preparatory microbes did not appear to impact on results. Biomethane production was lower for polymer 1 material subjected to aerobic composting tests than for material subject to anaerobic treatment only, suggesting a loss of easily degraded compounds during the aerobic stage.

"Our collaboration with USW feeds directly into the development of our long term business strategy – innovation is at the heart of Loowatt's offering of easily mobilised sanitation systems with low environmental impacts. We look forward to continuing our research and development partnership in collaboration with the USW team."
Virginia Gardiner, CEO, Loowatt Ltd.

"Working with Loowatt has provided the USW team with invaluable experience and insight into the process of bringing innovative products to the market. The research has been both challenging and rewarding, and we will be actively continuing our dialogue and collaboration with this exciting and forward thinking company in the future."
Dr Tim Patterson, Project Manager, University of South Wales



BIV2016007

G's Fresh/ Prof. Ralph Noble

Optimising the use of separated anaerobic digestate fibre as a substrate for mushroom cultivation

The processing of separated digestate fibre at controlled temperature (45-49ºC) into a substrate for growing mushrooms was investigated. Initial experiments were conducted using bench-scale solid-state fermentation equipment. Digestate fibre was obtained from two sources of maize/vegetable waste, municipal waste and food waste feedstocks. The samples were analysed for pH, electrical conductivity (EC), dry matter and ash contents, and contents of plant nutrients and heavy metals. The latter two sources of separated digestate fibre had high nitrogen contents and could not be cleared of ammonia within 15 days; they were therefore unsuitable for mushroom cultivation. Significant differences were also found between the sources of digestate fibre in moisture, ash, plant nutrient and heavy metal contents, pH and EC. The two sources of digestate fibre produced from maize/vegetable waste feedstocks had similar analyses.

Processed digestate fibre substrates were added at 33% w/w with commercial Phase 3 mushroom compost and the mushroom yield compared with 100% Phase 3. There was a significant difference in mushroom yield between substrate prepared from the two different sources of maize/vegetable waste digestate fibre; one source produced 97% of the mushroom yield of a commercial Phase 3 mushroom compost, whereas the other source produced 81-85% of the yield. The addition of 5% wheat straw to digestate fibre improved aeration of the substrate, and the addition of 3% gypsum reduced the evolution of ammonia and the time needed to clear ammonia from the substrate.

An insulated tunnel with an underfloor fan ventilation system was obtained by G's Fresh and used to process five tonne batches of digestate mixes. Batches of digestate fibre were processed without amendments, and then with the addition of radish waste and wheat straw. The mixes were processed in the tunnel until clear of ammonia. Suitable processed mixes were blended at 20% w/w with Phase 3 mushroom compost and filled into cropping shelves. The mushroom yields were compared with 100% Phase 3 compost.Large scale processing of digestate fibre mixed with wheat straw and radish waste produced a substrate that was suitable for growing mushrooms. However, natural generation of heat within the mix was very variable indicating that a greater air flow and external heat supply were needed. Changing the analysis of the digestate fibre by manipulation of waste feedstocks and optimizing the rate of gypsum will be required to obtain maximum mushroom yields.

Inclusion of solid digestate into mushroom compost will offer a significant selling point and saving. This work needed to be carried out to identify the optimum process to make the fresh digestate material ready for mushroom production, and the proportion of compost substitution that was most beneficial. – David Walker

This work has shown that it is feasible to process separated digestate fibre into a high value mushroom substrate. The identification of a source of digestate fibre that produces 97% of the mushroom yield of a commercial substrate provides an opportunity both for further research and for the mushroom industry to significantly reduce its substrate cost. – Ralph Noble

BIV2016009

Beeswax Farming (Rainbow) Ltd ; AE Lenton Biogas; Clapgate Farm; R G Farms Ltd; Scrivelsby Biomass Ltd./ David Stainton

Improving the sustainability of Anaerobic Digestion by demonstrating the potential of digestate fibre to reduce peat usage in horticultural growing media.

Five separate agricultural businesses, each involved in the operation of an on-farm AD plant, worked together to form a consortium to pool knowledge gained from a series of experiments aimed at beginning to understand how ADF from agricultural feedstocks might be used as a component of horticultural growing media. A side benefit of this work was to identify a role for ADF in reducing the current use of natural peat within growing media.

The results provided data on:

The stability and consistency of ADF output from farm-based plants using a range of feedstocks

The performance of an AD fibre/peat based mixes over a range of plant species

The impact of typical, commercially relevant irrigation systems on peat/ADF growing media

In the light of the results gained through the BIV the consortium is now considering further work to assess if there is a financially viable opportunity to be taken forward.

The use of this BIV has established a new potential research partnership in the ongoing quest to improve the sustainability of Anaerobic Digestion.

The funding received through ADNet has cemented a co-operative partnership between four agricultural businesses and the University of Lincoln. The results of the research trial, optimistically, may lead to diversification for those businesses and added-value to the separated fibre. – quote from industry partner

The BIV voucher has facilitated the collaboration of four independent farming companies with their academic partner, the University of Lincoln. It has increased our knowledge of the AD process, particularly feedstock management; enabled applied academic research and knowledge exchange to take place and potentially resulted in a new growing media for the horticultural industry – David Stainton

BIV2016011

Youlgrave Community Land Trust/ Dr David Styles
Youlgrave Community Land Trust Micro-AD Feasibility Study

Bangor University worked closely with Youlgrave Community Land Trust to evaluate a micro-AD option involving small (6-22 m3) anaerobic digesters coupled with micro-scale combined heat and power (CHP) units (3 to 4 kWe capacity), treating food waste to be collected by YCLT from four local villages. Unfortunately, the preliminary investigations indicated that the micro-AD/CHP scheme was not economically viable.

Subsequently, Bangor University and YCLT evaluated scaled-up (small-scale) local AD options, located either on a local farm or at a local brewery, and involving co-digestion of food waste, manures and industry wastes. These options were scaled to treat all of the local council's separated food waste collections, and seven of the options provided upgraded biomethane fuel available for use in the council's refuse collection trucks. Detailed cost and operating data were collected from five suppliers for ten possible systems (six based on the farm, and four based at the brewery site). All systems involved a CHP plant, and seven of the investigated plants also included biomethane upgrade and compression.

The most profitable options were found to be the simple CHP systems, generating an annualised profit of up to £131,520, reflecting lower capital investment costs than the biomethane upgrade plants and also relatively high gate fees for some wastes that are currently sent to incineration. However, all systems were either profitable or close to breaking even under default assumptions, and we did not consider possible renewable transport fuel obligation (RTFO) certificate income.

The environmental savings associated with the prospective AD systems were evaluated using the LCAD EcoScreen tool. Annual GHG savings ranged from 357 to 661 tonnes CO_2e, reflecting the replacement of fossil-based electricity and heat generation, and transport diesel, along with significant GHG savings achieved through diversion of wastes from counterfactual treatments such as incineration, composting and conventional manure storage. Up to 8,678 GJe of fossil energy could be avoided in total, and up to nine refuse collection trucks exclusively fuelled with the biomethane produced. Substitution of diesel with biomethane may also be associated with significant local air quality improvements, which were not accounted for in the life cycle assessment methodology employed. However, care must be taken to close digestate stores in order to mitigate significant ammonia emissions that can arise from digestate storage, contributing to increased loading of eutrophying and acidifying compounds to the environment under default assumptions.

We conclude that the economic viability of the ten farm and industry biogas plant options evaluated in STAGE 2 of this BIV was positive in some cases, and close to being positive in others. These options are certainly worthy of further investigation – small changes to some of the assumptions could make a significant difference to the economic balance. For example, if fuel duty was not payable on the biomethane produced, or if it was offset by RTFO certificates, then most of the options evaluated would be profitable.

BIV2016015
Algal Omega 3 (AO3)/ Prof. Orkun S. Soyer
Towards engineering microbial communities to treat a defined waste stream

In this pilot project, we explored the applicability of defined and complex microbial communities for treatment of waste originating from a specific bioprocess. The bioprocess of interest, developed by MARA, generates a relatively defined waste stream with high sulfate and phosphate content. A particular aim of the project was to see if microbial communities can be grown on this waste stream and reduce the levels of these two target compounds. Success in this approach would be of high impact to MARA and its production arm, AO3, through reduction in waste handling costs, and can open a scientific path in which we can develop and engineer bespoke microbial communities for specific waste treatment.
The short duration of the project allowed only limited amount of experiments, but these were still highly informative about the potential of the approach. We found that the specific waste stream generated by MARA is permissible to microbial growth both before and after sterilisation. Specific defined and undefined microbial communities were successfully incubated anaerobically using the MARA waste stream and produced organic compounds, carbon dioxide, and hydrogen, indicating active metabolism and growth. This anaerobic cultivation also revealed that sulfate was mostly in bound form in the waste stream, while phosphate levels remained unchanged by anaerobic microbial activity alone. In a second set of experiments, designed particularly to treat phosphate, we found that a specific cultivation regime of alternating aerobic/anaerobic periods allowed a range of defined communities to capture phosphate out of the waste stream and also reduce sulfate levels to some extent. As a comparison, a similarly high phosphate removal efficiency is achieved with specific metal oxide treatment.
These results demonstrated clearly that microbial treatment of MARA waste stream is possible and can provide both reductions in the levels of target compounds and can lead to secondary production routes. Both directions can provide increased commercial benefits to MARA bioproduction programme. From a scientific perspective, the latter direction is particularly interesting, where the 'design' of a specific microbial community can achieve conversion of organics in the waste stream into valuable compounds. The design of such 'synthetic microbial communities' would not only allow benefits in waste treatment, but can also provide important insights into the molecular basis of microbial interactions and the drivers of microbial community stability.

This project demonstrated the technical capabilities of the Soyer lab, providing insight and new learnings. The foundation provided by this project should be built upon by a longer term collaboration. – AO3

This project provided the basis for longer term collaborations with industry, where we can address industrial needs with the scientifically tractable and exciting approach of synthetic microbial community design. – Prof. Orkun Soyer

BIV2016021

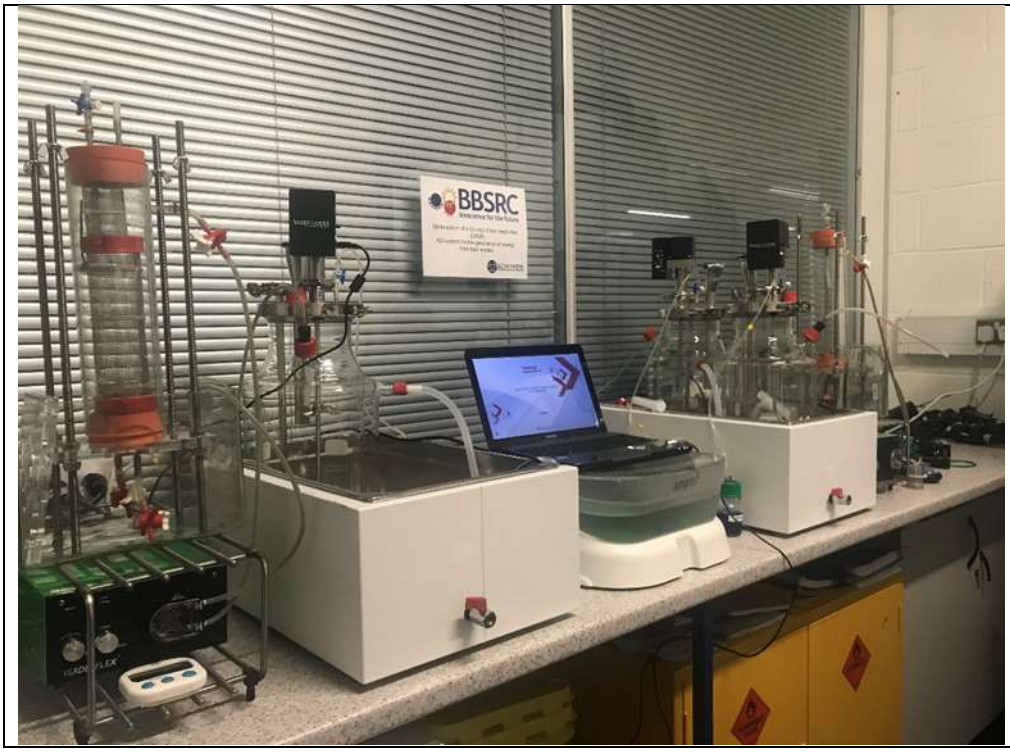
Kingdom Bioenergy Ltd / Professor Lynsey Melville
Optimisation of Counter-Flow Leach Bed (CFLB) AD system for the generation of energy from food wastes.

Kingdom Bioenergy Ltd. offers design and consultancy services to the AD sector across many developed and developing countries. Resolving the problem of food waste is a high priority for many countries and Anaerobic Digestion offers a potential solution. Environmentally sustainable and commercially viable conversion of FW into biomethane for heat and energy requires a good understanding of the biochemistry of AD as well as design and optimisation of

low tech and low cost systems.
Leach Bed Reactors have been used as an affordable pre-digestion step for improving process efficiency and enhancing biomethane production. Digestate from AD is percolated slowly through the food waste and collected before being fed back in to the digester. These systems are effective in leaching the Volatile Fatty Acids from the FW (which in high concentrations can inhibit methane production) but are prone to plugging which leads to reduced contact between the bacteria and the FW.
This project involved the design and testing of a lab scale upflow leach bed reactor (ULBR) for the treatment of FW. Following the design and testing of various prototypes an optimised system was developed comprising a 1 litre reactor with a removable 1mm aperture mesh cage for the retention of the FW. This was found to be effective in improving mass transfer between the inoculum and FW and also made loading and removing residual FW easier. Temperature was maintained at 37oC via heated cables. Ports were included at the top and bottom of the reactor to allow for various configurations and process flows to be tested. A synthetic FW recipe was designed and characterised (TS/VS and BMP) and digestate was collected from an existing mesophilic AD.
The ULBRs were operated in isolation (recirculation mode) and then integrated with a CSTR via intermittent feeding of digestate from the ULBR into CSTR (9 days/trial). Samples were taken daily and analysed for pH, sCOD and VFAs and methane production was measured hourly.
Analysis showed a decline in pH during the early stages of operation (in isolation) and a corresponding increase in VFAs (particularly acetic acid) which was accompanied by a peak in biogas production from the ULBRs. Concentrations of Soluble COD (a further indicator of organic breakdown) also increased over the course of operation to ~27g/l by day 9. Cumulative methane production from the ULBRs was between 2396-2618mls (at 9 days). When intermittent feeding was applied a peak in biogas production was observed in the CSTRs in the hours proceeding the feed indicating rapid conversion to methane. Cumulative methane production from CSTRs was 4799mls.
In conclusion the ULBR was effective as a pre-digestion step as evidenced by leaching of sCOD and VFAs from the food waste. The lower pH and VFA profile of the leachate inhibited methane production after several days in the ULBRs in recirculation mode but resulted in good methane production when fed to the CSTRs. Further work is required to ascertain the optimal configuration and OLR for continuous and semi-continuous feeding from the ULBR to the CSTR.

The results from the work at Birmingham City University have provided a much deeper understanding of the process of two stage anaerobic digestion of food materials that enables Kingdom Bioenergy Ltd to improve the design of a prototype full-scale system built in South India, built by an Indian NGO, SKG Sangha, for a hospital complex CMC Vellore. An optimised design will allow a low cost solution to the conversion of food wastes to energy and compost to be extended to many places across the world. - Kingdom Bioenergy Ltd

Food waste continues to be an environmental issue in both developed and developing countries. Anaerobic Digestion offers the potential to convert this waste into biogas and nutrient rich fertiliser. This project allowed partners to draw on their combined knowledge and expertise to design and develop a low tech and low cost solution for the treatment of food waste. We are looking forward to continuing this collaboration and supporting further development of this technology. - Dr Lynsey Melville



BIV2017003

Northumbrian Water Group Ltd./ Chivas Brothers Ltd/ Prof. Ian M. Head
Development of a Real-Time Water Quality Sensor for Estimation of BOD and Toxicity

This project aimed to assess the feasibility of an innovative microbial fuel cell (MFC)-based biosensor for online monitoring of water quality in wastewater and anaerobic digester plants. The challenge involved translating a proof-of-concept device from a laboratory environment where performance had been previously assessed under controlled conditions to a research facility hosted by Northumbrian Water Ltd where experiments could be conducted utilising real-world waste streams under realistic environmental conditions. Further to this, it was necessary to assess the applicability for monitoring industrial waste streams using whisky distilling wastewater supplied by Chivas Brothers Ltd.

At the Northumbrian Water BE:WISE research facility (https://research.ncl.ac.uk/bewise/) a feeding manifold was set up to enable wastewater to be drawn into the biosensors at a manageable flow rate (from the facility feed of 6 L/s). MFC-based sensors were installed and additional environmental monitoring of pH, conductivity and temperature was set up. The outcome from the initial testing has provided valuable insights into the typical real-world environmental variations which can be expected and enabled enrichment of a stable MFC biofilm generating measurable signal from the unamended wastewater. It has also cemented relationships between researchers and site operational staff which will be vital for taking this research forwards to determine long-term performance and validation.

With Chivas Brothers distillery wastewater a MFC biofilm was enriched and preliminary experiments have ensured the signal responds to variations in water quality (BOD). Initial attempts to enrich an active anode with ‘Pot ale’ and ‘Spent lees’ waste streams from a

distillery were unsuccessful. However an inoculum from the distillery wastewater treatment plant led to successful enrichment of an active anode that shows promise for monitoring distillery effluents. Historical data was provided from a range of distilleries operating different treatment systems and this has formed a basis for identifying the most appropriate compatible waste streams and selecting the working ranges required for effective monitoring purposes.

Going forward we have recently been awarded a two-year BBSRC Super Follow-on Fund and we are fortunate that both Industrial Partners have again provided Letters of Support. This new project will enable this innovation to be further developed towards Technology Readiness Level (TRL) 7. With the on-site trials these will continue to determine real-world performance and establish design criteria for a 'version 2' prototype which will be manufactured in collaboration with colleagues form the University of South Wales.

"We are delighted that this project has successfully shown that this novel sensor can be deployed in the very challenging operational conditions. This has been a necessary first step in the application of this sensing approach in municipal wastewater treatment. The project has contributed to the ongoing success of the Newcastle University / Northumbrian Water strategic partnership and to the close working relationship between researcher and operators." - Northumbrian Water

"This project with Newcastle University has helped to move forward the technological readiness of a reliable inline BOD monitor for effluent treatment systems. Such systems have the potential for enhanced performance, efficiency and compliance by using live BOD data to manage effluent stream mixing rates and flows through their treatment stages in future. Quote from Academic partner" - Chivas Brothers

"Developing our novel BOD sensing technology with two highly engaged partners from the private sector has opened up new doors in applied research and provided fresh perspective on where the system may be effectively deployed. We are looking forward to working with them as we follow on from our initial successful collaboration, with the aim of producing a system that can be developed to a commercially viable product." - Newcastle University

- MFC Sensor

BIV2017004

Blue Sky Bio Ltd./ Dr Andrew Free
DNA Sequence-Based Characterisation of Microbial Community Development in a Novel 7-Stage Anaerobic Digestion System

BlueSkyBio Ltd. is a renewable energy start-up firm, which has developed a novel seven stage anaerobic digestion system. After developing the system to pilot stage (500 litre volume), the company recently evaluated the digestion of both seaweed and grass as a form of renewable feedstocks for the production of biomethane, biohydrogen and volatile fatty acids (VFAs). In order to understand better the microbiology of this high-rate fermenter (ABR), 16S rRNA gene amplicons from digestate samples were sequenced using the Illumina MiSeq to conduct a metataxonomic analysis during this project. The data indicate that feedstock composition has the biggest impact on the make-up of the reactor's microbial community, followed by the progression of the stages along the reactor. Interestingly, as the breakdown of feedstock progresses across the reactor stages, the communities degrading both grass and seaweed digestate converge and become more similar to each other, due to the feedstock-specific degradative steps occurring in the earlier stages. This can be seen as the number of common bacterial genera that dominate the reactor's microbiology increases. For instance, only two of the ten most abundant bacterial genera from stage 1 of the fermenter are shared across grass and seaweed digestate samples. In contrast, 7 out of the 10 most abundant bacterial genera are both found in the final stage of the grass-fed and seaweed-fed reactor.

Furthermore, the abundance of Archaea differs significantly between digestate samples from the two feedstocks. Across all stages of the reactor, Archaea on average make up 3.6% of microorganisms found in grass digestate and just 0.5% in seaweed digestate. As methanogenic Archaea convert the intermediate products of anaerobic digestion into methane, these results could suggest a difference in biomethane production depending on feedstock, which have not yet been measured in the company's reactor at pilot stage. While methanogenic communities in digestate samples of both feedstocks are dominated by Methanosarcina and Methanobacterium, the relative proportions differ significantly. In detail, Methanosarcina makes up 41% of all Archaea in grass digestate, while Methanobacterium makes up 37%. Conversely, seaweed digestate samples show that 48% of archaeal species are Methanosarcina while only 17% of species are Methanobacterium. As Methanobacterium mainly performs hydrogenotrophic methanogenesis, this could indicate a difference in the availability of hydrogen and carbon dioxide depending on the feedstock. Also, the third most common archaeal species in seaweed digestate (Methanosaeta, 9% of all Archaea) is virtually absent from seaweed digestate samples. As Methanosaeta exclusively digests acetate, this could hint to a difference in the abundance of VFAs as a result of feedstock choice.

As previous data from BlueSkyBio have shown the increasing breakdown of biomass along the reactor, the role of bacteria that increase in abundance alongside this process remains to be investigated. Herein, this study offers a starting point for further exchange between the academic and industrial partners, who aim to handpick specific microbes and optimise their genetics and environmental conditions to produce biomethane and biohydrogen.

Quote from Industry partner
"This award allowed us to complete a full scan of the microbial community present in our fermenter. This work is the cornerstone of our new research program looking producing high values product from organic waste from a modified microbial community. This successful collaboration with Dr. Free and the University of Edinburgh was the first step on a long collaboration."

Quote from Academic partner
"This award enabled us to achieve our aim of identifying the key microbial species in each stage of the BlueSkyBio multi-stage reactor, and how they are affected by changes in feedstock. We will now use this information, via an EPSRC CASE studentship awarded to Dr. Horsfall and Dr. Free, to isolate, characterise and optimise specific species from these microbial communities for the production of biomethane, biohydrogen and volatile fatty acids in this bioreactor system."

- Samples before and after fermentation through the Blue Sky Bio HygenBioReactor