The AD Network – a BBSRC NIBB

Achievements

AD NETWORK
Harnessing Anaerobic Digestion

BBSRC
bioscience for the future

Welcome

Welcome to the Anaerobic Digestion (AD) Network Activities Update.

When the Biotechnology and Biosciences Research Council (BBSRC) launched the 13 Networks in Industrial Biotechnology and Bioenergy (NIBB) in 2014, there was the expectation that industrial biotechnology (IB) industries and academia could work together for the benefit of the UK by finding synergies of expertise, overlapping interests and joint opportunities. Networks were given a chance to explore this with funding for events, underlying research and targeted business-friendly support. Since then, the AD Network has been busy striving to live up to the promise! So what have we achieved?

Since its launch in 2014, the AD Network has grown from a small core of supportive individuals into a group of over 600 mixed members covering all aspects of AD. As you would expect from a topic which is inherently cross-disciplinary, the academic component reaches across the UK and covers a huge breadth of different disciplines and departments. Whether you are interested in the intricacies of microbial electrochemistry, modelling non-Newtonian fluids or the challenges of large-scale chemical engineering, we have an academic contact to suit. Not to be outdone, our substantial industry and "other" contingent (about half) range from farmers and operators, SMEs to large companies, start-ups to established "brands", as well as various NGOs and policy members.

Our many events have provided the chance to bring together members interested in specialist topics - to meet, to learn, to network - and hopefully to continue a productive association later. Numerous small Business Interaction Vouchers (BIVs) have helped cement these associations. We would like to think that all those conversations that did not lead to a bid had value – even if it was just to have a useful contact for the future. Through the more "blue sky" Proof of Concept (PoC) awards, we have explored a range of potentially useful ideas and developments – some of which are now feeding into larger grants elsewhere. Joint events with organisations like ADBA, AFBI, FoodWasteNet, IBioIC, NNFCC, REA and SUPERGEN have ensured that we reach out to complementary organisations to cover topics of mutual interest. Finally, our Research Colloquium serves as a freely accessible compendium of the best in current research and we thank all the speakers who volunteer their expertise and time.

Working closely with the Anaerobic Digestion and Bioresources Association (ADBA) has enabled us to reach out to industry members through their R&I Forum and annual Trade Show. Recognition has flowed the other way with Angie Bywater, Network Manager, being awarded "AD Ambassador of the Year" and Prof Charles Banks receiving their "Lifetime Achievement Award" at recent ADBA awards. Our thanks go to the Management Board members who have always been there to guide and support the Network behind the scenes. The impressive level of knowledge, expertise and common sense embodied in the Management Board has been invaluable. Likewise, we could not possibly have reviewed all the entries in our various Calls without the generous donation of time and effort by a multitude of volunteer reviewers.

Looking to the future, we have dedicated a great deal of attention and effort to the Early Career Researcher membership by providing travel bursaries, secondment funds and free access to the annual 2 day ECR Conference. Developed and run as a standard 2-day academic conference, it has been a privilege to see the work being conducted by research groups across the UK. Nurturing this international talent pool can only be beneficial to a future strong UK IB base.

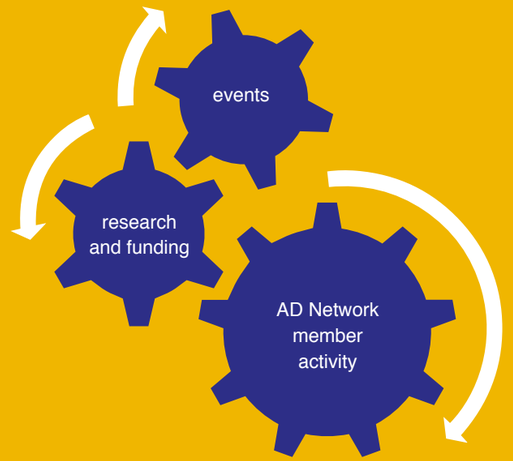
We are optimistic that you will find something of interest in this activities update and hope that it will inspire you to take an active part in our ongoing programme of events if you have not already done so.

Front cover photo courtesy of Dr Stephen Temple, Copys Green Farm.

Back cover photo courtesy of Richard Gueterbock, Clearfleau Ltd.

Prof Charles Banks (PI), University of Southampton and Prof Orkun Soyer (Co-I), University of Warwick.

Network highlights



Supporting the future - Early Career Researchers

The AD Network is proud to have had the chance to meet and support so many early career researchers (ECRs) with a genuine passion for AD. These are future leaders in training who will shape the direction of AD Industrial Biotechnology both the UK and abroad. So far, we have offered grants for over 20 Secondment Bursaries and overseas Travel Bursaries, allowing skills transfer, training and participation in major world conferences to showcase the work of the UK to the widest possible audience. Our annual 2-day summer ECR conference has run since 2015 with between 40-50 attendees. This is not a passive event – each attendee must contribute with presentations and posters – making it not only a great place to network but also the best place to keep abreast of on-going work in research groups across the UK. Our thanks go to all the sponsors and industry figures for the prizes, site visits, inspirational industry-focussed talks and forward-thinking workshops for the attendees. In addition, by participating in joint careers events with other NIBBs, we hope to have opened up the wider possibilities of a career in IB to our ECR members as they look towards the academic and commercial sectors for employment.

Early Career Researchers' Conference 2016 – University of Birmingham

Funding activities

There have been 21 BIV projects so far – lasting up to 6 months each. Dozens of academics and companies have benefited from the chance to work together to solve challenges of IB relevance. With up to £10K provided towards these from AD Network funds and a success rate of 50%, this has been an accessible introduction to joint projects for companies and academics to make the first move towards a continuing association. The necessity of "matched funding" ensures that all projects are of genuine value to both partners and our rigorous review process helps to maintain the quality of these "entry level" awards. Everyone recognises that collaboration is not easy, requiring trust (and bespoke collaboration agreements!) from both sides. Once established, we hope that many of these professional relationships will endure beyond the brief period of the award.

Our 14 PoC awards allocated £720K to investigate "blue sky" novel or innovative projects. With a high quality of applications and a success rate of 20%, it is clear that there is no shortage of good ideas out there. We are starting to see these ideas begin to take off in the form of further funding. Subsequent work includes an IB Catalyst "Biomethanisation of CO_2 in Anaerobic Digestion Plants" (£1,852,567) and an EPSRC grant "Computational Methods for Anaerobic Digestion Optimization (CoMAnDO)" (£341,482). These take time to progress and, as our projects come to completion, we expect to see further progress in the form of published papers and ongoing work beyond the lifetime of the Network.

Additional Industrial Strategy Challenge Fund (ISCF) funding was secured for a further 5 Industrial Biotechnology Catalyst Seeding Award projects amounting to £125K. These are targeted at a higher Technology Readiness level (TRL) level than the PoCs with a view to commercial development.

Information on all projects is posted on the website as it is concluded.

The AD Network has funded Business Interaction Voucher (BIV), Industrial Strategy Challenge Fund (ISCF) Seeding Catalyst and Proof of Concept (PoC) awards through various calls between 2014 and 2018.

Shaping perception

Evidence-based research on environmental impacts and a progressive regulatory regime are both essential to the realisation of the value of IB technologies to commercialisation. Robust tools which underpin research are vital to this work and the AD Network has worked with the International Energy Agency (IEA Task 37) to produce a flexible, robust and independent free tool for the assessment of AD facilities. This tool has been widely downloaded (including by built-environment companies such as Buro Happold), and used to provide a feasibility/environmental study (for the John Lewis Partnership, Leckford Farm), as well as for further academic research in this field. The Renewable Energy Association (REA) worked with Bangor University to evaluate GHG abatement by small farm AD, an area of large potential GHG savings which was presented as a paper to politicians at an ADBA parliamentary event. Further policy work sponsored includes work on a scientific evidence base for public subsidy support of biomethane for transport (Lutra/Bangor University) and provision of a case for support for community based on-site AD (YCLT/Bangor University). In another BIV, Aberystwyth University is currently working with the Severn Wye Energy Agency, Welsh Government, AD suppliers, CLA Cymru and Natural Resources Wales to quantitatively assess agricultural bioresources in Wales with a view to informing combined policy initiatives to improve the uptake of relevant IB technologies.

Our outreach presence ranges from parliamentary receptions, open days, roadshows, science festivals, Countryfile Live and numerous other smaller venues which have reached thousands of people over the last few years. The mobile AD system and rather dramatic Rubens' Tube combination, alongside various circular bio-economy hands-on activities have proven a great draw for all ages. Engagement at this level helps to broaden appreciation for the technology and its application amongst wider society. This is something that the industry, as professionals, takes for granted but which is generally peripheral to public perception.

International collaboration

Working with BBSRC through a £20,000 Global Challenges Research Fund (GCRF) Workshop Grant, meetings were held with relevant academics and stakeholders from across Africa in early 2017. Nairobi, Johannesburg and Cape Town provided the venues for scoping meetings – the results of which were fed back to the funder in the form of a report designed to assist impact on International Development whilst meeting ODA criteria.

This level of long term forward planning takes a great deal of effort and commitment on the part of those involved – many delegates flew from countries across Africa to be there – with outcomes potentially years down the line. Each workshop introduced 20-30 participants to the possibility of UK collaboration opportunities and through the use of facilitated workshops, gathered information on research needs, challenges and synergies, with recommendations on how these could be taken forward. It also identified research strengths and priorities for the region in order to further build research capacity.

We direct members to the multitude of international opportunities available for collaborative research. With so many different schemes and funders, we have tried hard to cherry pick and highlight those of specific interest through our regular Newsletter. Such opportunities include Horizon 2020 calls, the IB Catalyst rounds and the 2018 £5M BBSRC: 'Industrial Biotechnology and Bioenergy in the Developing World' call.

Some Funding Stories

"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." – Industry partner

Biomethanation

Currently, it is not unusual for biogas from AD to consist of 40% CO_2 – which must be "scrubbed" out using a costly process before the biomethane can be used as a direct replacement to its fossil fuel counterpart. This biomethanation research aims to develop a hybrid anaerobic digestion process in which hydrogen made from renewable energy sources (e.g. wind and photovoltaics) is used to produce biomethane (CH_4) at more than 95% purity. The process therefore provides an efficient in situ biogas upgrading technique which will maximise the conversion of the available carbon in waste biomass into a fuel product that has a wide range of applications

Results from a 2014 PoC project looking at "Effective mass transfer of hydrogen into digester mixed liquor for biomethanisation of biogas CO_2," (Prof Charles Banks, University of Southampton) proved positive enough to consider further work on this concept. This led to a successful application for IB Catalyst funding on "Biomethanisation of CO_2 in Anaerobic Digestion Plants" with partners from the University of York; University of Leeds; United Utilities; ITM Power; Food and Environment Research Agency.

Further spin-off funding was obtained in the form of an ISCF grant "In-situ bio-methanisation for small-scale biogas upgrading" (with Lutra Ltd). This translational demonstration from academic research to industrial application operated a pilot-scale hybrid technology, developed to combine renewables-driven electrolytic H_2 production with anaerobic digestion. We have also supported a BIV which could potentially extend the use of this technology: "Study into the benefits of the integration of biomethanation of green hydrogen with renewable electricity production from anaerobic digestion and wind power at the Creed Enterprise Park in Stornoway" (University of Sheffield/Western Isles IWM Facility).

Michael Chesshire of Lutra Ltd said, "There is a huge interest across the EU in the concept of Power-to-Gas, as it provides the potential for large scale storage of energy from intermittent renewables using existing infrastructure and appliances. I am very excited to be part of this pioneering project, which I am sure will lead to commercial opportunities for UK business."

AD Profiling

There has never been a better time to investigate the microbial ecology of AD, with tools to examine the genetics and chemistry of mixed cultures getting more sophisticated (and cheaper) every year. But what does all this meta-data mean?

A number of different awards have sought to answer this. In 2014, a PoC funded study "Shotgun metabolomics in anaerobic digestion" was awarded to Dr James Chong, University of York. After painstaking work, he concluded that metabolomics measurements on the timescale of days can provide an accurate reflection of the state of an AD system. Subsequently, he has worked closely with industry through a Seeding Catalyst award "Characterising marine-based microbial communities for commercial anaerobic digestion". Mapping data on to an accurate model requires more work and in 2016, we funded Dr Claudio Avignone-Rossa from the University of Surrey, to examine "Metabolic Modelling meets Anaerobic Digestion (M3AD)" – which aimed to combine a metabolic model that includes the main metabolic features of the microorganisms in the microbial communities with current models of AD (ADM1)".

But surely every digester is different? To examine that question, the AD Network supported a workshop called "Anaerobic Digestion: Science meets Industry" by Professor Orkun Soyer, and hosted at the University of Warwick. His initiative to monitor AD microbiomes is now generating huge, publically available datasets to anchor the science in verified real world situations. (For access to the information see: http://anaerodynamics.com/). By gathering in-depth, weekly data from a number of volunteer commercial plants, the complex relationships between performance and underlying processes can be mapped - grounding future research efforts with an accurate, relevant reference point. Thank you to all the commercial concerns who selflessly offered to help at the workshop.

Higher Value Products

Why stop at methane? It is possible to extract many high value products from biomass. One such group of products are Volatile Fatty Acids (VFAs).

In 2014, a PoC funded study at the University of Southampton examined the concept of producing and removing high levels of these compounds from an unsavoury substrate – blood. Abattoirs routinely dispose of large volumes of this waste, pointing to an untapped potential feedstock with ideal characteristics to test the idea. After investigation through the award "Production and extraction of C3 and C4 aliphatic carboxylic acids from the anaerobic digestion of waste blood as a model substrate", Dr Yue Zhang was able to both publish and springboard the project further with ongoing investigations.

Her work continues through the British Council Newton Fund Institutional Links Grant on "Development of a Biorefinery System for Organic Acid Production, Bioenergy Generation and Nutrient Recovery using Fish Wastes to TUMACO". A PhD project has resulted on "Optimisation of selective butyric acid production from anaerobic fermentation". We wish her luck as she looks to advance this work through further funding applications in order to set up a pilot plant on VFA production and separation, with downstream ammonia recovery and biogas production.

Contacts made from this work were used to help put together the AD Network/Food

Waste Network event “Valorisation of Animal By-products”. This specialist workshop mixed industry and academic speakers alongside a site visit to draw together the disparate groups looking into this under-developed area of waste valorisation.
For further reading, do take a look at the resulting articles:

Plácido, J. & Zhang, Y. *(2018). Production of volatile fatty acids from slaughterhouse blood by mixed-culture fermentation. Biomass Conversion and Biorefinery. Accepted.*

Plácido, J. & Zhang, Y. *(2017). Evaluation of esterification and membrane based solvent extraction as methods for the recovery of short chain volatile fatty acids from slaughterhouse blood anaerobic mixed fermentation. Waste and Biomass Valorization. DOI:10.1007/s12649-017-9952-7.*

Later on, Dr Robert Lovitt from Swansea University received PoC funding to look into a novel separation method with his project “Recovery and purification fatty acids and nutrients from anaerobic digester fluids using integrated membrane freeze-thaw (MFT) processes”. The idea behind this was to investigate a low-cost concentration process that combines the use of membrane technology with freezing to produce concentrated fluids and he has advanced this work through further successful funding applications.

Digestate

Digestate has been regarded as a low value product of AD, primarily destined for land-spreading. But what else can be done with it?

One solution has been developed by Prof Ralph Noble at NIAB EMR, with two AD Network-funded projects on mushroom compost. In 2016, his BIV work on “Optimising the use of separated anaerobic digestate fibre as a substrate for mushroom cultivation” alongside G’s Fresh, a major food producer, served as a springboard for a subsequent Seeding Catalyst award “Determining the influence of feedstocks on the analysis and suitability of separated anaerobic digestate fibre for commercial-scale mushroom substrate production”.

Why mushroom compost? Currently imported at significant cost, this can be partially replaced by existing digestate fibre. By demonstrating the concept and refining the process, there now exists a new market for digestate fibre which has already been implemented by G’s Fresh. Four processing tunnels for converting digestate fibre into mushroom cropping substrate have been designed and installed by G’s Fresh. Savings will be generated for years to come.

“This project has identified the characteristics of digestate fibre that enable it be processed into substrate for growing mushrooms. Digestate fibre from several commercial AD plants has been shown to be suitable for this purpose.” **Professor Ralph Noble, NIAB EMR**

“As a result of this work, G’s Fresh have invested in processing tunnels and ancillary machinery for the conversion of digestate fibre into mushroom cropping substrate. We are planning to start commercial scale production of mushroom substrate in March” **Mr David Walker, Littleport Mushroom Farms LLP.**

In another BIV, David Stainton at the University of Lincoln worked with a consortium of farm AD businesses to investigate the potential of digestate in horticulture. His project, “Improving the sustainability of Anaerobic Digestion by demonstrating the potential of digestate fibre to reduce peat usage in horticultural growing media” aimed to make inroads into the market for peat. Over 1.3 million m3 of peat is consumed annually and it contributes to a market for retail and wholesale horticultural growing media valued at over £400 million.

Several farms, 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 AD fibre (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 AD.

Mushrooms growing with digestate fibre

Events

We have delivered over 25 workshops and events for members since we started in 2014 and we have been actively involved with 3 R&I Forums and 4 Trade Shows.

All AD Network-run events are free to members – which is a great incentive to join! Likewise, our joint events with other NIBBs and Research Organisations are free to attend – as are the annual ECR conference and Research Colloquium. Whilst some commercial events with which we work closely may charge a fee, we have tried to arrange discounts and provide the option of bursaries for members, where appropriate.

Events have been carefully planned to range across the entire UK allowing full participation from our geographically diverse membership. Thank you to all the various institutions who have hosted and supported us and to the range of academic and industry speakers and exhibitors who have come and showcased their activities and research. This is very much a community endeavour made possible by members themselves.

Collaboration with the ADBA trade association has resulted in mutual benefits.

Our 2017 Research Colloquium was far from an academic affair as we managed to entice over 40% of attendees from industry. This was a great way for members to take an interest in the cutting edge developments from across the UK and Europe. Combining academic outreach with reciprocal knowledge exchange about the real issues faced by industry is pivotal to making these events relevant.

Selected events

The following highlights give a taste of the subjects covered. Specialist, focussed events were the norm to enable high-quality networking between potential collaborators and enable useful knowledge exchange within some quite niche topics. Supplemented and supported by broader events like the Research Colloquium, there has been something for everyone.

"Huge range of topics covered in depth, yet at an understandable pace. Also, a great opportunity for networking and discussion."

"I enjoyed this event because of having a number of legendary scholars of AD from both HEI and industry."

– Professor Jules van Lier – TU Delft

Anaerobic Membrane Bioreactors for Wastewater Treatment and Energy Recovery

14.1.16

50 participants from 29 different companies and institutions – held at the University of Southampton

The Water and Environmental Engineering Research Group together with the AD Network organised this workshop around the key figures spearheading cutting edge research in the area. Focussing on the most important research advances on AnMBRs, this featured an array of top speakers including Professor Jules van Lier – TU Delft. Talks covered topics from the "Feasibility of AnMBRs for industrial wastewater treatment" and "Kinetic Control of AnMBRs and its influence on operating parameters" to "Understanding the challenges in implementation of anaerobic move based flow sheets". A lab tour to showcase the facilities was also included in the day.

AD: Science meets Industry

10.5.16

68 participants from 42 different companies and institutions – held at the University of Warwick

Featuring the popular "bring a sample from your digester to the meeting and we will analyse its microbial profile for FREE" offer, this informative meeting brought together researchers and operators to hear from experts on the AD process. Attendees participated in an open discussion session and many proceeded to take part in the further initiative to monitor AD microbiomes. As a result, datasets are now freely available from http://anaerodynamics.com/ . This is invaluable in providing an unbiased and transparent source of information on the performance of industrial AD reactors in real time.

Membrane cleaning

20.6.16

26 participants from 9 different companies and institutions – held at the University of Southampton

This specialist event brought together researchers and industry practitioners with an interest in AnMBR operation to discuss approaches to controlling membrane fouling in the reactor, and to exchange ideas and experience on AnMBR application. Participants benefited greatly from the expertise of the guest speaker - Prof Jaeho Bae, Head of the Sustainable Environmental Membrane Technology (SEMT) Lab at Inha University, Korea – who was available for questions and shared his experience in the field.

Microbial Electrochemistry

19.9.16

31 participants from 13 different companies and institutions – held at Durham County Cricket Club

This gathering brought together researchers and industry practitioners with an interest in Microbial Electrochemistry (MEC) to discuss innovations and share expertise in a one day seminar. Hosted by Newcastle University, this included a site visit to Chester-le-street pilot plant and networking opportunities with experts from across the UK and Europe including Dr Albert Guisasola, Autonomous University of Barcelona.

On-Farm Small-Scale Anaerobic Digestion

2.11.16

70 participants from at least 34 different companies and institutions – held at the Agri-Food and Biosciences Institute, Northern Ireland

Hosted by Gary Lyons, AFBINI, this event brought research practitioners and many farmers/operators together to share their expertise and innovations. With a site visit to the AFBI AD plant, this event was a great way for knowledge to spread both ways so that the unique challenges of working at this scale could be fully explored. A good number of participants from across the border showed the broad appeal of work in this area.

Bubbles, biofilms and boundary layers

13.3.17

30 participants, drawn mostly from the existing research group at Southampton University

Dr Mike Mason gave an inspiring talk on the worldwide potential of AD with a particular focus on the potential role of CAM plants in low rainfall areas. However, it was his conceptual analysis on the interface between microbes and their immediate environment which was a compelling reminder of the need for fundamental research. A deeper understanding of the constraints and relationships at this level can only act as a driver for the necessary step changes of this green technology.

Novel Feedstocks for Anaerobic Digestion

6.4.17

48 participants from 34 different companies and institutions – held at the University of Lincoln

Included in the line-up of speakers were Mark Schofield, Lincolnshire Wildlife Trust – “Could biomass harvesting from road verges create highways for better connected wildlife?” and Dr Andrew Ross, Centre for Doctoral Training in Bioenergy, University of Leeds – “Hydrothermal pre-treatment of biomass and the bio-methane potential of road verge biomass”. Other topics covered included biomass supplements; bacterial additives; upland hay meadow vegetation and the quality and consistency of raw materials. A wide-ranging day that highlighted the underutilised biomass resources we pass every day.

Opportunities for food by-product valorisation - joint event with FoodWasteNet

6.9.17

67 participants from 48 different companies and institutions – University of Strathclyde

This was a popular topic with obvious cross-over appeal given the move in recent times to minimise food waste and divert this to productive use. Contributions from Zero Waste Scotland and IBiolC set the scene for the activities in this area in Scotland whilst Richard Gueterbock of Clearfleau gave examples of the existing commercial activity in this field with clarity and insight. A growing field of interest with much more to offer in the future.

Research Colloquium 2017

11-12.9.17

Located at Southampton University with 80 participants.

Members came together for a 2 day intensive programme featuring top International and UK speakers from active research groups who are pushing the boundaries of what is possible. Topics included Fundamental Research and New Concepts, International Projects of Significance etc. The line-up included a mix of invited speakers and also showcased the outputs of several AD Network funded research projects to the target audience.

Integration of chemical, biochemical and thermal process to maximise biomass resource potential - joint event with SUPERGEN

6.2.18

55 participants from 30 different companies and institutions – held at the Priory Rooms, Birmingham

Having this many professors in one room was always going to be a risk but I think we pulled it off with this well-attended event. A full day of quality presentations from speakers across the UK attracted more members than anticipated and required a last minute room upgrade – healthy feedback indicated that members appreciated the effort that speakers put in to make their trips worthwhile and informative.

Valorisation of animal by-products – challenges and opportunities - joint event with FoodWasteNet

7.3.18

40 participants from across industry and academia joined together to look at the issues surrounding Animal By-Products (ABP).

ABP as a feedstock faces particular challenges with regard to safety and handling, regulation and evidence base. This workshop was intended as a platform for industry to share their experiences of the issues faced when working with this type of material and provided academia with an opportunity to share their work in an area which typically garners relatively little attention. Discussion time was supplemented with a site visit to Malaby Biogas – one of a relatively small number of plants already handling this material. It is hoped that the introductions made here will continue to flourish after the event as some of the highlighted research opportunities are pursued.

Saving our Soils: Understanding and Improving Soil Health - joint event with REA and BSSS

20.6.18

Organised by the Renewable Energy Association, the AD Network and the British Society of Soil Science, and held in London, this was an opportunity for policymakers, operators, agronomists, spreading contractors, consultants and farmers to meet the scientists and academics who are undertaking research in the field of soil health and applying organic materials to land. The speakers line-up included: Emeritus Professor Stephen Nortcliff, Reading University; Professor David Hopkins, Royal Agricultural University;Professor Tom Misselbrook, Rothamsted Research; Professor Andrew Whitmore, Rothamsted Research and Audrey Litterick, Earthcare Technical. Application to land of digestate can only be fully explored in the context of current practices and the demands and limitations of soil health. Top talks on a topical subject of value to all AD processes which seek to use digestate as a valuable product.

Funding

See what members have investigated with access to our Proof of Concept (£720,000), Business Interaction Voucher (£200,000) and Industrial Strategy Challenge Fund (£125,000) awards.

All bids passed through a thorough impartial review process involving hundreds of volunteer reviews. Thank you to all involved for their professionalism and commitment. Success rates ranged from 1 in 2 for BIVs to 1 in 5 for POCs and the Executive Board was impressed with the high quality of bids across the board.

UNIVERSITIES INVOLVED ARE:

- University of Southampton
- University of Warwick
- University of York
- Newcastle University
- University of Birmingham
- University of Nottingham
- NIAB EMR (East Malling Research Station)
- University of Oxford
- Swansea University
- University of South Wales
- University of Surrey
- University of Leeds
- Aberystwyth University
- Bangor University
- University of Aberdeen
- University College London (UCL)
- University of Lincoln
- Birmingham City University
- University of Sheffield
- University of Edinburgh

Proof of Concept Projects

"exciting research which takes a look at a new idea or process to discover where it leads"

Shotgun metabolomics in anaerobic digestion

Dr James Chong, University of York

Anaerobic digestion (AD) involves a complex network of interactions between a community of microbes which are difficult to accurately monitor. By using modern molecular techniques, it should be possible to identify key indicators of AD performance and health that, in addition to helping operators maximise output from their systems, can be used to populate computer-based models to improve our understanding of the AD process. One such set of indicators that could be targeted for measurement is the complement of small molecules (metabolites) produced in AD. Although the utility of metabolomics in this field has been posited a number of times, this approach requires specialist equipment and knowledge in order to be effectively executed, and is likely to require the development of specific preparation protocols for successful deployment. We propose a shotgun metabolomics approach using a state-of-the-art, ultra-high resolution instrument to determine the speed, magnitude and reproducibility with which soluble metabolites change in a model AD system with the view of generating preliminary data for a larger application making use of this technology in AD.

Effective mass transfer of hydrogen into digester mixed liquor for biomethanisation of biogas CO_2

Prof Charles Banks, University of Southampton

Hybrid technology combining renewables-driven electrolytic H_2 production with hydrogenotrophic methanogenesis to allow the biochemical reduction of CO_2 to CH_4 is possible and has been demonstrated. The concept has primarily been developed using purified component gas streams fed into a bioreactor in which a pure culture is maintained, resulting in a product gas with a CH_4 content >95%. The approach has also been used with biogas as one of the input gases using non-type strain methanogens which adapt naturally under non-sterile conditions; again the output gas stream can be >95% CH_4. What has proved more difficult is the in-situ conversion of bicarbonate in conventional digesters through H_2 injection: this appears to be limited by the effective mass transfer of H2 into the system and by the need to maintain digester buffering capacity. Although CO_2 reduction involves some energy loss, this approach maximises the conversion of the available carbon in waste biomass and would provide an efficient means of in-situ biogas upgrading without additional methane slippage. The issues of energy balance can be addressed through process integration and optimisation, and a favourable overall balance can be shown when both direct and indirect energy inputs are taken into account. The concept explored in the proposed research is whether the use of a specially-designed membrane diffuser can improve the mass transfer of hydrogen into a digester, and in so doing maintain a CH_4 concentration >95% in the product biogas when using food waste at a typical biomass loading as the feedstock.

"Suggestions in the literature about the benefits of membrane diffusers could not be shown experimentally in laboratory trials for any of the hollow fibre types tested. They do not appear to have any great advantage over micro-bubbles, and future work will concentrate on developing effective means of generating these in-situ in anaerobic reactors". **– Prof Charles Banks**

Development of anaerobic biomass support particles for effective membrane cleaning

Dr Sonia Heaven, University of Southampton

There is increasing interest in membrane technologies for anaerobic treatment of both municipal and process wastewaters. These can be configured in a number of ways using membranes of different types. Membrane fouling is one of the key issues

in this type of technology and effective low-cost and low-energy in situ methods are needed to maintain the membranes clean. In conventional aerobic membrane bioreactors, which are now widespread in the water industry, the most common method used is air scouring and gas scouring using recirculated biogas has also been adopted in many prototype anaerobic systems e.g. submerged anaerobic membrane bioreactors (SAnMBR). These cleaning systems can be energy intensive, however, and unlike aerobic systems there is no advantage in circulation of large volumes of gas since there is no requirement for oxygen transfer in the equivalent anaerobic technology. The proposed research looks at the concept of developing biomass support particles of around neutral buoyancy with surface properties such that when pseudo-fluidised around the membrane they will provide a mild scouring effect. In this way the energy input will be minimised to that needed to maintain the support particles in motion. The second advantage of this system is that the support particles will permit higher concentrations of microbial biomass within the reactor and reduce the solids loading on the membrane, allowing operation at higher flux rates.

"The work has clearly demonstrated the effectiveness of particle cleaning of membrane surfaces in anaerobic systems. Now that the POC has established the benefit of this approach, it is being taken forward for testing at a larger scale"

- Dr Sonia Heaven

Dr David Neylan, project researcher, preparing to make polymer

Production and extraction of C3 and C4 aliphatic carboxylic acids from the anaerobic digestion of waste blood as a model substrate

Dr Yue Zhang, University of Southampton

This proof-of-concept project focuses on diversification of anaerobic digestion (AD) into the field of industrial biotechnology through the production and harvesting of butyric and propionic acids as intermediate bulk chemicals. These products have value and existing large-scale markets in their own right, and can also be considered for further bio-transformation and as the basis for an extended biorefinery concept. The research is based on the use of animal blood produced in abattoirs, a negative-value waste material, as a fermentation substrate since its high nitrogen content provides buffering to allow the accumulation of acid products at high concentrations without detriment to the acidogenic population due to low pH.

Part of the research will focus on proving the concept that stable high rates of acid production can be achieved and that reactor operating parameters can be used to manipulate systems biology to produce a high quality output under non-sterile conditions. This builds on and will further contribute to recent advances in understanding metabolic pathways and syntrophy in anaerobic digesters that can lead to acid accumulation, and the mechanisms that control this.

The second part of the work focuses on selection and preliminary testing of potential extraction methods that could be applied at large scales, ranging from conventional solvent extraction to more advanced membrane-based systems that could be used in situ in continuous processes. The research will make a preliminary assessment of issues relating to design, cost and resource requirements and environmental impacts of this novel biotechnology.

"It was a great pleasure to participate in this project. This is a very nice example that further demonstrates the synergy between membrane technologies and anaerobic technologies." - Dr Lina Chi

"This proof-of-concept project focused on diversification of anaerobic digestion into the field of industrial biotechnology through the production and harvesting of carboxylic acids as building block chemicals. It proved that by selection of reactor conditions and substrate type, anaerobic digestion can be directed towards specified intermediate products in concentrations suitable for extraction." - Dr Yue Zhang

Redesigning hydrolysis reactors for the development of high power density advanced anaerobic digestion enabling containerised electricity production from agricultural residues

Prof Ian Thompson, University of Oxford

The rate limiting step of Anaerobic Digestion (AD) of cellulose feedstocks is accepted to be the bacterial hydrolysis of cellulose (Mumme, 2010). These bacteria form a predominant part of the cow microflora. Their activity in terms of hydrolysing cellulose in the cow's first fore-stomach, the rumen, is 10-30 times quicker than man-made AD plant. Oxford University is working to develop a high power density Advanced Anaerobic Digester, mimicking the mechanisms used by cows.

Ongoing theoretical studies have led to our improved understanding of the underlying mechanism by which bacteria, growing as biofilms hydrolyse cellulose, and that conventional AD technologies are far removed from the way a cow operates. Initial work encourages us to believe that there are several pathways to achieving this High Power Density Advanced Anaerobic Digestion (AAD).

A laboratory scale reactor, based on the operation of a cow's rumen has been built and will be used to test these pathways. This reactor represents the first stage in a two stage digester, and is predominantly concerned with improving the rate of hydrolysis of cellulose. The solid fraction of the biomass is retained in the reactor, whilst the interstitial liquid is recirculated. There is no agitation or stirring. Bulk mass and heat transfer are via the recirculation of the liquid. This is much more reflective of how a rumen works. We hope to demonstrate an increase in the mass of feedstock hydrolysed per unit volume of reactor compared to traditional continuous stirred tank reactors (CSTR).

Advanced Anaerobic Digester including a pH feedback loop, and liquid recirculation.

Recovery and purification fatty acids and nutrients from anaerobic digester fluids using integrated membrane freeze-thaw (MFT) processes

Dr Robert Lovitt, University of Swansea

This project will investigate the utility of a low energy, integrated membrane freeze thaw process (MFT) for the recovery of fatty acids and nutrients (N and P) as salt crystals or concentrated fluids. The MFT process is a hybrid process that combines the ability of a RO membrane process to separate water from dilute salt solutions while freeze concentration overcomes the membrane limitations posed by high osmotic pressures

for the concentrated solutions. Thus together the low energy process produces clean water and series of fractionated concentrates. It has few chemical inputs where separation principles are physically based. Preliminary calculations suggest that this process will only require 15% of the energy produced by CHP of digester gases to power the process.

Using fluids from AD systems the consortium will investigate the concentration/ crystallisation process and its potential problems. There are also potential benefits for the MFT process integrated into large scale AD CHP systems and these will be investigated and the costs of the process evaluated. Finally, the quality and value products derived from the fractionation process will be assessed as chemicals or as growth media components. If successful, the study will also open the way for the potential enhancement of digester kinetics by in-situ product recovery and further process integration and optimisation.

"This is an excellent idea and should be invested in further; potentially this approach could revolutionise digestate processing and its potential uses" – **Industry partner**

"This funding allowed the explorations of an interesting idea and has created a practical platform for further research and its exploitation" – **Academic partner**

Microbial Enhancement of Phyto-Active Compound in Digestate
Prof Richard Dinsdale, University of South Wales

The aim of the project will be to improve the quality of anaerobic digestion residues so that the growth rate of crops and plants grown on digestates will be increased. This will be achieved by investigating the ability of naturally occurring microorganisms to produce plant growth promoting factors (i.e plant hormones such as auxins) in the digestate. The improved degradation of plant material in the anaerobic digestion process also may also release plant growth promoting compounds (i e. humic acids/soluble lignins) and the mechanisms to increase the amount of these compounds will also be investigated. The development of the presence of plant disease biocontrol agents in digestates will also be researched. The results from this will lead to an improved product which promotes the enhanced productivity of crops, leading to greater food security and expanded markets of digestate for the UK anaerobic digestion industry.

Novel bioelectrodes for energy positive ammonia removal from municipal wastewater
Dr Jan Dolfing, Newcastle University

Ammonia can cause eutrophication and be toxic to fish and other aquatic wildlife. Thus, the removal of ammonia from wastewater is frequently required as part of general treatment processes, to either protect receiving waters, or as a precursor to N-removal. Conventional ammonia removal technologies use oxygen, and the more ammonia that must be removed, the greater the quantity of oxygen required. This is not merely expensive, but arguably unsustainable as the carbon footprint of the process is such that water companies find themselves "destroying the planet to save the river". The objective of the work proposed here is to develop a novel microbial technology to remove ammonia-nitrogen without a need for oxygen. Rather than consuming energy, the process will actually generate energy. The technology is based on the use of Anaerobic Bacteria Respiring Ammonia, a new group of microorganisms capable of donating the electrons encapsulated in ammonia to an appropriately poised electrode, a process that is of considerable fundamental interest and constitutes a new and unexpected shortcut in the nitrogen cycle. We envisage scope for this technology in the treatment of waste streams with low to medium high ammonia concentrations, where alternative methods aimed at ammonia recovery are economically less attractive.

Electrode interface to control and extend metabolic outputs of AD microbial communities
Prof Orkun Soyer, University of Warwick

AD is a well-recognised green biotechnology. It is underpinned by complex microbial communities, where different species degrade organic matter into a set of metabolic intermediates that are then used by methanogenic microbes to produce methane. Currently, we lack any direct means to control the population dynamics within this microbial world and the ensuing metabolic output types and reliability. This proposal will overcome this major limitation by developing an electrical approach to control and manipulate AD microbial communities.

This approach relies on our understanding of the AD process as a thermodynamically driven conversion system, where the population size of different microbial groups are primarily determined by the availability or absence of strong electron acceptors. By using electrodes poised at appropriate redox potentials as electron sinks and donors, we will aim to foster and maintain specific methanogenic groups. This will result in a direct control of the output levels and reliability of the AD process, thereby making this biotechnology more controllable, tunable and reliable. In turn, this will reduce risk of AD investments and increase production yields. Developed further with additional research, our electrical approach will be applied to other, bespoke communities in which we control their rich metabolic repertoire towards production of desired metabolites.

"This work allowed us to establish easy-to-follow and clear protocols for bioelectrochemical cells, which has been a bottleneck in the field to develop multi-factorial experiments. We are now in a position to develop our work in this area further, towards electrical control of communities." **- Prof Orkun Soyer**

Computational Methods for Anaerobic Digestion Optimization – Act 1 (CoMAnDO1)
Prof John Bridgeman, University of Birmingham

Anaerobic digestion (AD) is often used to treat sludge, via mixing with bacteria that biodegrade sludge, producing methane-rich biogas that may be harnessed via combined heat and power technology for energy recovery. However, there remains a pressing need to optimize digester mixing to maximize energy recovery.

To predict optimum digester mixing, we must determine to what extent biogas output is influenced by AD flow patterns; flow patterns that are determined by digester configuration, inflow mode, sludge rheology and mixing regimes. Research is lacking in this area. Traditional approaches to digester design are rooted in empiricism rather than science, and design standards focus on treated sludge quality, not gas yield and energy consumption.

The challenge is to improve digester performance and maximize biogas yield. An innovative solution is to simulate simultaneously the hydrodynamic and microbiological processes found in AD. We hypothesize there is a direct link between mixing-induced turbulence and biogas yield. Our focus is to simulate these interrelationships in a complex multiphase, non-Newtonian fluid environment. However, to achieve this, there remain several challenges to overcome; viz. computationally efficient hydrodynamic modelling and effective coupling techniques.

CoMAnDO1 will address the first of these limitations and will deliver the proof of concept necessary to develop Lattice Boltzmann (LB) modelling as a robust, rapid alternative to computational fluid dynamics (CFD) modelling to simulate the hydrodynamic environments within digesters. This will lead to a major research project in which LB and biokinetic models will be coupled to control the hydraulic and biochemical performance of AD.

"We recognize the tremendous, untapped potential of renewable energy from liquid and solid waste streams, and see your research as providing valuable and much needed step in the right direction." **– NMCNomenca.**

Metabolic Modelling meets Anaerobic Digestion (M^3AD)
Dr Claudio Avignone Rossa, University of Surrey

AD has been traditionally represented as a black (sometimes grey) box, where a relatively undefined collection of macro-scale processes lead to the degradation and conversion of a complex feedstock into a mixture of products of anaerobic metabolism. For simplicity (and sometimes lack of information or details), this modelling approach has generally overlooked the metabolic processes led by microorganisms. New powerful biomolecular tools, supported by advances in metabolic analysis software, provide now the possibility of including this micro-level in the analysis of AD processes.

This PoC will attempt combining multispecies metabolic modelling (i.e. a metabolic model that includes the main metabolic features of the microorganisms in the microbial communities carrying out the process) with current models of anaerobic digestion (ADM1). Based on metagenomic information from the literature, we will build a metabolic model involving all the physiologically relevant metabolic pathways present in the most abundant species in the community, leading to CH_4, H_2 and VFA production. The metabolic model will be linked to the model presented by Poggio et al. (2016), which (based on a combined biochemical and kinetic approach) combines rigorous feedstock characterisation with ADM1 to represent an AD process.

Our purpose is to demonstrate the feasibility of analysing AD through a multi-scale approach, ranging from the metabolic micro-level to the kinetic macro-level, to simulate and generate predictions for the design and optimization of full-scale processes.

Biobutanol production via bioelectrochemical reduction of butyric acid
Dr Yue Zhang, University of Southampton

This proof-of-concept project focuses on diversification of anaerobic digestion (AD) into the field of industrial biotechnology through the conversion of one of its intermediate bulk chemicals, butyric acid, into butanol using a microbial electrochemical system (MES). Butanol has many industrial applications, and it has received great interest in its use as direct replacement for petrol or as fuel additive. Butanol is superior to ethanol in this regard because it has higher energy content, a higher octane number, lower volatility, is less hydroscopic and less corrosive. Therefore, it has value and an existing large-scale market.

This research will focus on demonstrating that selective butanol production from butyric acid can be achieved using MES and that this MES can be integrated with the AD process for overall energy and material recovery efficiency. The operating parameters will be optimised for butanol production and this will further contribute to recent advances in understanding the mechanisms that control MES. The overall performance of the MES for butanol production from butyric acid will be evaluated in terms of electron and energy utilisation, as well as long-term stability.

Sustainable hydrogen production through the anaerobic digestion of hydrothermal aqueous waste
Dr Andrew Ross, University of Leeds
(Literature review POC: POC2017001)

Hydrothermal processing produces an aqueous bi-product containing organic carbon. Utilisation of this organic carbon is essential in order to maximise resource efficiency and avoid generation of waste waters. Methane production by AD has been proposed as a feasible recovery option but issues with inhibition are possible. Utilisation of hydrogen in hydrothermal processing improves fuel quality and, as such, production of hydrogen from the aqueous phase via AD may well be more favourable in terms of techno-economics.

A scalable fluidized bioelectrochemical reactor for enhanced anaerobic energy recovery
Prof Alan Guwy, University of South Wales

Bioelectrochemical systems (BES) are a bioelectrochemical process that can be used for the direct harvesting of power as electricity; however, a key obstacle in the development of BES technology is that conversion efficiencies are often rapidly dissipated with scale due to increasing system losses as these processes are increased to commercially relevant scales. In practice, this means that the concentration of electrogenic cells must be increased to simultaneously increase capacity whilst also maintaining small current/counter current pathways. Recent work has shown that direct interspecies electron transfer can occur between the electrogenically active Geobacteraceae species and Methanosaetaeceae, and this can lead to an increase in overall rates of methanogenesis. This project aims to investigate the scale-up of bioelectrochemical systems in a familiar tank-like fluidized bed bioprocess, by using fluidized and freely moving activated carbon particles in an aqueous wastewater to enhance overall energy recovery by harnessing inter-species direct electron transfer. Within the reactor, each carbon particle can act as a small capacitive open circuit anode which can support surface electrogenic biofilm, meaning the particle is continuously charged by the action of the electrogenic bacteria. This means that these charged particles may be discharged at an electrode to deliver an electrical current whilst also providing a direct stimulation to methanogenic activity through the development of specifically structured methanogenic /electrogenic biofilms, and via direct stimulation of methanogenesis in the planktonic phase.

Industrial Strategy Challenge Fund – Projects

"to accelerate the transition from discovery research to translational development projects by supporting preliminary work or feasibility studies to establish the viability of an approach"

In-situ bio-methanisation for small-scale biogas upgrading
University of Southampton/Lutra Ltd

A translational demonstration from academic research to industrial application is planned by operating a pilot-scale hybrid technology, developed to combine renewables-driven electrolytic H_2 production with anaerobic digestion (AD). This allows biogas produced in AD to be upgraded to around 95% CH_4 by biochemical reduction of its CO_2 content. The process uses direct injection of H_2 into the digester and, through continuous monitoring and control, matches this to the available carbon in its oxidised form of CO_2. By adaptive evolution, the systems biology of the digester promotes carbon flow predominantly through hydrogenotrophic methanogenesis, thus maximising the conversion of the carbon present in waste biomass into a useful fuel product, and increasing the CH_4 yield by 40% or more. This approach opens up possibilities for using untapped waste biomass resources, by making better use of the digester's working volume to produce the more energy-dense gaseous biofuel known as biomethane. Although the process could be used at any scale, with potential commercial markets as an energy storage solution for balancing supply and demand in the electricity grid network, the current proposal focuses on smaller-scale applications. This approach has greater potential for integration with on-farm use of digestion and in meeting the sustainability challenges faced in developing countries. In both cases it offers the possibility of supplying local energy needs by producing a storable product for use in low-pressure gas distribution systems, as compressed bottled gas supplies or as a low-pollution vehicle fuel.

Evaluation on thermal pre-treatment to enhance digestibility of an emerging type of sludge-aerobic granular sludge
University of Southampton/CAMBI Group AS

Aerobic granule sludge (AGS) is a novel and promising technology for wastewater treatment in the context of the circular economy. Compared with conventional activated sludge, AGS features with 75% less footprint, 50% less energy consumption, a much more simplified process for carbonaceous pollutants, nitrogen and phosphorus removal and better effluent quality. Because of these advantages, AGS technology has been commercialized very quickly with more than 30 full scale facilities constructed worldwide and 3 in the UK. It is expected that with much less energy consumption, the energy recovery via digestion could move AGS plant towards energy self-efficiency or even net energy output. However, due to distinctive characteristics of AGS such as big size, compact structure, high content of extracellular polymeric substances, and high ash content in the sludge, AGS from some conditions has 58% less digestibility compared with activated sludge although a comparable digestibility was also reported. These contradictory results indicate an uncertainty of AGS digestibility as well as the possible dependence of digestibility of AGS on the characteristics of sludge. To enhance AGS digestibility from different conditions and to reduce the final residual solid disposal, sludge pre-treatment is necessary. Among different sludge pre-treatment approaches, thermal pre-treatment is one of the most commonly used methods. This project will thus evaluate the thermal pre-treatment of AGS to enhance digestibility of AGS and establish the correlation between characteristics of AGS and thermal pre-treatment conditions for digestion enhancement.

Biogas methane as a feedstock for a sustainable bioprocessing
University of Nottingham

The Aim: To explore the feasibility of using biogas methane as a feedstock to produce chemical commodities using methane-consuming bacteria as a process organism in gas fermentation.

The Need: Biogas methane, the main product of anaerobic digestion (AD), is an energy-rich feedstock with an energy density of 55.7 MJ/kg at 1.013 bar, 15 ºC. Raw AD biogas is roughly 60% methane and 29% CO_2 with trace elements of H_2S. The methane concentration is insufficient for direct use as fuel gas for machinery and the H_2S is highly corrosive to the mechanical components. Considerable money and effort has to be expended in the purification of methane and for its combustion to generate electricity. Consequently, in many cases, it is not cost-effective to use raw biogas as a fuel for electricity production and is flared at the site, causing Green House Gas emissions and environmental damage.

The Solution: We shall convert biogas methane through a biological process to the polymer, polyhydroxybutyrate (PHB), which can be easily converted into a wide variety of different plastics. From a business standpoint, it makes more sense to use methane as a feedstock than to burn it for power production. PHB sells for $3 to $4 a kilogram on today's market, while methane burned for electricity production would return as little as 40 to 80 cents a kilo.

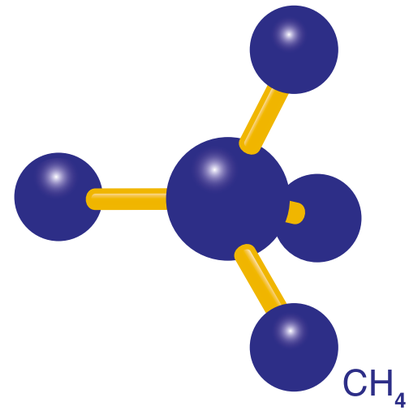
The Delivery: The successful completion of this project would represent the essential initial step in the development of a potential future sustainable bioprocess at industrial scale.

Determining the influence of feedstocks on the analysis and suitability of separated anaerobic digestate fibre for commercial-scale mushroom substrate production
NIAB EMR/G's Fresh

G's Fresh is a major producer of fresh vegetables and mushrooms. It has a 3 MW, two-stage mesophilic AD plant at Littleport, Cambridgeshire which processes over 50,000 tonnes of maize and rye, 8,500 tonnes of vegetable wastes and 2,000 tonnes of chicken manure annually. This produces over 6,000 tonnes of mechanically separated digestate fibre, accredited to PAS 110, and currently disposed of to land. Adjacent, it has the UK's largest and most advanced mushroom farm, which utilizes 25,000 tonnes of imported substrate to produce 8,000 tonnes of button mushrooms annually. An AD Network BIV project (2016007) has shown that the digestate fibre can be converted into a mushroom cropping substrate, potentially saving up to £1.5M annually on imported mushroom substrate. G's have invested in the construction of bulk processing containers for this purpose. This project will determine the influence of AD feedstocks and the additions of gypsum and different straw types on the analysis and suitability of the separated fibre for producing a mushroom substrate component. The UK mushroom industry currently uses around 300,000 tonnes of mushroom substrate annually. In Europe, more than 4M tonnes of substrate are produced annually. This project has the potential to develop a new, high value market for separated digestate fibre, thus improving the economic viability of AD and separation of the liquid digestate which is easier to apply to crops than whole digestate.

Characterising marine-based microbial communities for commercial anaerobic digestion
University of York/Algal Omega 3 Ltd

A major consideration prior to increasing the scale of production at Algal Omega-3 (AO3) is disposal of produced waste. From a proprietary saline-based fermentation ca. 85% of the volume is discharged as waste rich in nutrients and solid cellular material. Discharge or treatment of this waste has an associated cost, both fiscal and environmental. Anaerobic digestion of this waste has the potential to (i) reduce costs, (ii) recover value (to offset production costs) and (iii) reduce environmental impact. This project will explore whether a marine-tolerant microbial community can carry out effective anaerobic digestion of this high salt waste stream. We propose to carry out a lab scale (30L) study to identify a suitable salt tolerant microbial community for AD of AO3's waste material. We will also quantify the ability of that community to remove 'billable' content from AO3's production waste with the aim of rapidly implementing a viable solution at their production site in Liverpool.



Business Interaction Voucher Projects

"aimed at connecting industry and academia together - via a defined project by an academic partner for an industrial partner"

These diverse, trust-building projects are a great example of the way shared activities can connect industry innovators with expertise available across the UK research community in order to carry out commercially valuable projects. Due to the number of these projects, they are listed below, with more detailed information on the website: www.anaerobicdigestionnet.com.

Overleaf: Tropical Power AD Plant, Kenya. Photo courtesy of Dr & Mrs Mike Mason

BIV projects

- Testing of anaerobic digester components found in thermophilic digestion of food wastes.
  Permastore Ltd/Dr Sonia Heaven, University of Southampton
- A modelling tool for the UK AD industry IEA Task 37/Dr Sonia Heaven, University of Southampton
- Providing a scientific evidence base for public subsidy support of biomethane for transport from waste.
  Lutra Ltd/Dr David Styles, Bangor University
- Evaluating cost-effective greenhouse gas abatement by small-scale anaerobic digestion.
  Renewable Energy Association/Dr David Styles, Bangor University
- Anaerobic digestion of vegetable waste from the food industry.
  William Jackson Food Group/Dr Davide Dionisi, University of Aberdeen

"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**

- Comparison of Biological and Mechanical Processes to Generate Value from Digestate.
  Roam Agency/Dr Brenda Parker, University College London

"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." **– Andreas Lang, Director of Roam Agency**

- Process optimisation of Africa's first commercial grid connected AD plant.
  Tropical Power Ltd/Prof Charles Banks, University of Southampton

"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". **– Dr Mike Mason, Chairman of Tropical Power**

- Evaluation of an integrated aerobic-anaerobic microbial system for enhanced degradation of biopolymers.
  LooWatt Ltd/Dr Tim Patterson, University of South Wales

"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

- Optimising the use of separated anaerobic digestate fibre as a substrate for mushroom cultivation.
  G's Fresh/Dr Ralph Noble, NIAB EMR

"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." **– Dr Ralph Noble, NIAB EMR**

- Improving the sustainability of Anaerobic Digestion by demonstrating the potential of digestate fibre to reduce peat usage in horticultural growing media.
  Beeswax Farming (Rainbow) Ltd./David Stainton, University of Lincoln

"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, University of Lincoln**

- Youlgrave Community Land Trust (YCLT) organic waste micro-AD feasibility study and case for support.
  YCLT/Dr David Styles, Bangor University
- Evaluating the feasibility of fish waste co-digestion with MSW in Stornoway.
  Western Isles IWM Facility/Dr Sonia Heaven, University of Southampton
- Towards engineering microbial communities to treat a defined waste stream.
  Algal Omega 3 Ltd/Prof Orkun Soyer, University of Warwick

"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, University of Warwick

- Leckford Estate organic waste AD feasibility case study and environmental impact analysis.
  John Lewis Partnership/Dr Yue Zhang, University of Southampton
- Optimization of a Counter-Flow Leach Bed (CFLB) AD system for the generation of energy from food wastes.
  Kingdom Bioenergy (KBE) Ltd/Dr Lynsey Melville, Birmingham City University
- Study into the benefits of the integration of biomethanation of green hydrogen with renewable electricity production from anaerobic digestion and wind power at the Creed Enterprise Park in Stornoway.
  Western Isles IWM Facility/Prof Mohamed Pourkashanian, University of Sheffield
- Development of a Real-Time Water Quality Sensor for Estimation of BOD and Toxicity.
  Northumbrian Water Group Ltd/Prof Ian M. Head, Newcastle University

"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

"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

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

"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." **– BlueSkyBio Ltd.**

- Investigation of the Role of CreChar® in Direct Interspecies Electron Transfer During Anaerobic Digestion.
  Carbogenics Ltd/Dr Andrew Free, The University of Edinburgh

"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." **– Dr Andrew Free, The University of Edinburgh**

- Optimisation of H2 injection for in situ biogas upgrading.
  Lutra Ltd/Prof Charles Banks, University of Southampton
- Spatial optimisation of farm-scale AD and biorefinery developments in Wales.
  CLA Cymru/Prof Peter Midmore, Aberystwyth University

"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."

– Chivas Brothers

Selected travel bursaries

2015: IWA World Congress of Anaerobic Digestion, Viña del Mar, Chile

"…this opportunity allowed me to engage with researchers and scientists, getting insight into technological progresses around the world, engage in scientific discussions and building professional relationships which may facilitate future collaborations." - *Hitesh C Boghani, Faculty of Computing, Engineering and Science, University of South Wales*

"…The work … obtained in its peer review one of the three highest scores of the conference. For this reason, it was acknowledged with one of the awards for best oral presentation in the conference…" - *Rebeca Gonzalez Cabaleiro, School of Chemical Engineering and Advanced Materials, Newcastle University*

2016: Biogas Science, University of Szeged, Hungary

"…I gave a presentation about my research with the topic 'Implementation of non-adsorbent granules in gas-spared anaerobic membrane bioreactor for fouling mitigation' in process technology and life cycle analysis session."- *Pakpong Sriprasert , Faculty of Engineering and the Environment, University of Southampton*

2016: The European Biogas Conference, Ghent, Belgium

"…More than 200 delegates attended the event including stakeholders from European policy-making, industry, academia and trade associations coming from 29 countries. This conference was selected for presenting our work on methane losses from biogas production due to the diverse audience and range of important stakeholders that attend…" - *Paul Adams, Department of Mechanical Engineering, University of Bath*

2017: The International Conference Progress in Biogas IV, Stuttgart, Germany

"…As a member of UK ADNET, I also realized that UK ADNET is at the forefront of new developments, adding to the practical implications in the field of AD and Biogas. I am appreciative of the support Anaerobic Digestion Network (ADNET UK) extended for providing travel grant to attend the International Conference." - *Muhammad Farooq, School of Engineering and Physical Sciences, Heriot-Watt University*

2017: 15th IWA World Conference on Anaerobic Digestion (AD-15) Beijing, China

"…I gave an oral presentation in font of about 300 people that was successfully received by the audience attracting many questions of interest. Furthermore, I participated in the poster competition that was really tough in which more than 180 posters were displayed with interesting a diverse topics related with AD. At the end I got award for one of the best posters of the competition. I would like to express my gratitude to the AD Network for allowed me to disseminate part of the research that we are conducting in UK and to live this completely new experience." - *Christian Israel Aragon-Briceno, School of Engineering, University of Leeds*

"…The conference was a huge opportunity for an early career researcher like me to expand and experience the international level of presenting own work, receive and contribute to the extension of knowledge in the AD area. The conference was a one off learning environment where I could meet my peers, experts and also my role models. " - *Roshni Paul, Faculty of Computing, Engineering and the Built Environment, Birmingham City University*

"…Having recently completed a PhD using AD technologies, my attendance to the conference gave me the opportunity to showcase my research and present my findings to a dedicated group of scientists with similar goals and interests. Being surrounded with a vast range of projects with relevance to my own work allowed me to further broaden my own ideas and potential avenues of research and to meet and make new connections with potential future collaborators." - *Julian Pietrzyk, School of Biological Sciences, University of Edinburgh*

"…Attending talks and discussing projects with people at the poster session was fascinating and probably provided enough ideas to re-do my PhD! Each of the ECR bursary recipients said that this experience was invaluable in increasing our knowledge of AD systems and current trends as well as in developing our networks with each other and peers from around the world. Personally, without this grant I would not have been able to travel to this bi-annual conference (I was also unable to attend the last one) so the bursary money enabled me to showcase my work and discuss with others what Newcastle University can offer."- *Andrew Zealand, School of Engineering, Newcastle University*

Supporting the Future

Our secondments and bursaries have supported numerous researchers to obtain new skills, exchange knowledge and make new connections. Nurturing the enthusiasm and talents of our Early Career Researchers (ECRs) is the best way to ensure sustained future growth in AD capabilities. This relies upon the continuous upskilling of existing researchers and ongoing professional development of the next generation. Examples of the kind of activities we have supported through the years include travel bursaries for UK events and overseas conferences as well as training visits and placements.

Hitesh Boghani, Rebeca Gonzalez Cabaleiro, Santiago Pacheco-Ruiz at the 14th IWA World Congress of Anaerobic Digestion in Viña del Mar, Chile; 15-18th November 2015

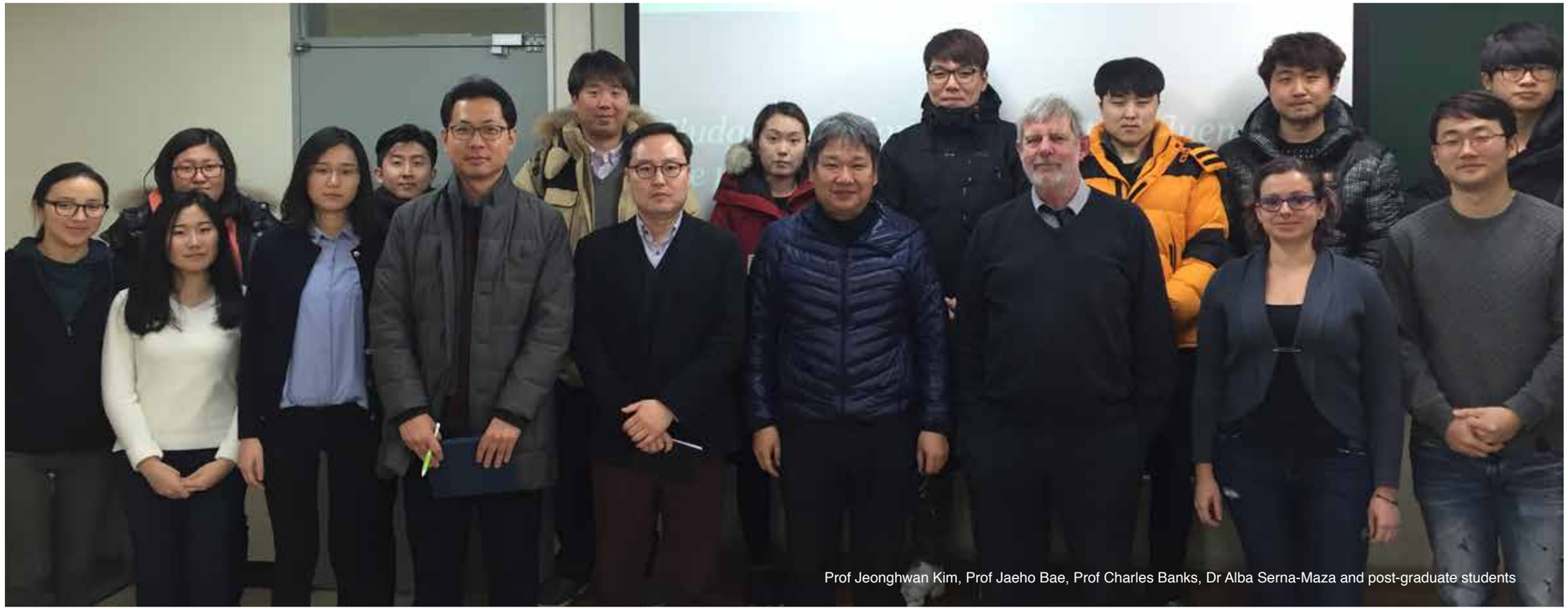
Christian Aragon-Briceno, Alba Serna-Maza, Andrew Zealand, Julian Pietrzyk, Roshni Paul and Chihiro Masusawa

Selected secondments

Technical visit to the Department of Environmental Engineering, Inha University, Incheon, Republic of Korea

The Sustainable, Environmental Membrane Technology (SEMT) Laboratory at the Department of Environmental Engineering, Inha University (Republic of Korea) is expert on submerged membrane bioreactors (SAnMBR) including understanding hydrodynamics and fouling control. This research group has developed the anaerobic fluidized membrane bioreactor with granular activated carbon (GAC) as membrane scouring system not only at lab scale but also at pilot scale (0.77 m^3).

"The requested bursary has enriched our knowledge on SAnMBRs operation using granular activated carbon as a membrane fouling control measure at lab and pilot scale for optimization of anaerobic digestion processes for low strength wastewaters. Additionally, the ability to build membrane modules to be installed in lab scale bioreactors and to quantify membrane performance after chemical cleaning has been broadened." **- Alba Serna-Maza - Faculty of Engineering and the Environment, University of Southampton**



Prof Jeonghwan Kim, Prof Jaeho Bae, Prof Charles Banks, Dr Alba Serna-Maza and post-graduate students

Workshop on Quantitative Laws II – Fondazione Alessandro Volta, Como, Italy

The aim of the workshop was to bring scientists from a diverse set of backgrounds together, including statistical physics, mathematics, evolutionary ecology, bioinformatics and evolutionary genomics, whose research contributed to the understanding of relevant empirical data.

"I was exposed to new areas of research and learned about different methods, techniques and approaches that will be invaluable in my career. This workshop has given me food for thought and it will be reflected in my future research" **- Andrea Martinez Vernon, School Of Life Science, University Of Warwick**

Aarlborg University (Denmark) - to learn additional methods for AD metagenomes analysis

The main aim of my secondment visit was to acquire bioinformatics "hands on" experience using the Environmental Biotechnology (EB) group at Aalborg University (Denmark) expertise in data analysis.

"During my research visit to Aalborg University, I have gained confidence in effective data handling and analysis that will speed up the progress on my project. This secondment has opened possibilities for future collaboration and knowledge exchange and it has provided invaluable experience that will enhance my career prospects"
- Anna Alessi, Department of Biology, University of York

The OpenLB Spring School, Karlsruhe (Germany)

This grant allowed me to attend the OpenLB Spring School where I was provided a formal training in LBM theory and OpenLB core code within its official releaser. The school's activities consisted of lessons on theoretical and practical aspects of LBM, classes on OpenLB's functionalities and working, guided exercises/practical simulation runs with OpenLB, and individual guidance on OpenLB and LBM.

"The best-spent money on my academic career" **- Davide Dapelo, School of Civil and Structural Engineering, University of Bradford**

Dr Anna Alessi with her host Associate Professor Mads Albertsen

Dr Dapelo at the OpenLB Spring School

The Executive Board:

The Executive Board are responsible for undertaking delivery of the Network aims and the Management Board guide priorities, shape strategy, and assess applications for funds. An International Advisory Group provides further expertise, advice and a pool of expert referees.

Contact:

Angela Bywater/Dr Louise Byfield
Email: adnet@soton.ac.uk
Tel: 02380 591281
Web: www.anerobicdigestionnet.com
Address: Room 2017/Building 15
Highfield Campus
University of Southampton
SO17 1BJ

Professor Charles Banks (Primary Investigator) is an Emeritus Professor within Engineering and the Environment at the University of Southampton. His current research projects include Biomethanisation of CO2 in Anaerobic Digestion plants, part of the IB Catalyst programme; the BBSRC ERA-Net AmbiGAS project on AD of high-volume low-strength wastewaters; All-Gas, Europe's first industrial scale demonstration of sustainable algae cultures for biofuel production, led by Aqualia SA and the Supergen project on integration of AD and pyrolysis.

Professor Orkun Soyer (Co-Investigator) is a systems and synthetic biologist leading a research group at the University of Warwick. He is PI of a BBSRC strategic LoLa grant in Synthetic Biology and is involved in an Isaac Newton Institute Research Programme which will focus on combining mathematical and experimental approaches for research on microbial communities. He edited the first book on the Emerging of Evolutionary Systems biology, a Current Opinion in Biotechnology special edition on systems and synthetic biology and is a fellow of EGENIS, an interdisciplinary research centre for Genomics in Society.

The Anaerobic Digestion Network Team

"ADNet has been a great resource for both academia and industry. It brings people together and has promoted AD in many ways enabling projects and research that wouldn't have been undertaken without it."

Tropical Power AD plant, Naivasha, Kenya courtesy of Dr Jem Woods, Imperial College London

The Anaerobic Digestion Network
T: 02380 591281
E: adnet@soton.ac.uk
W: www.anerobicdigestionnet.com