EBNet
Environmental Biotechnology

Engineering and Physical Sciences Research Council

Biotechnology and Biological Sciences Research Council

ENVIRONMENTAL BIOTECHNOLOGY NETWORK

Bioelectrochemical systems development for environmental biotechnology WG

Bioelectrochemical systems development for environmental biotechnology (BES WG)

Led by Dr Sharon Velasquez Orta, Newcastle University

This WG aims to promote education, collaboration and research by merging microbiology, engineering, materials and biotechnology disciplines in the study of bioelectrochemical systems. This knowledge area continues to expand with environmental applications such as monitoring, waste gas conversion to biocompounds, waste liquids remediation and biohydrogen production.

ACTIVITY SYNOPSIS

This was a hands-on WG which delivered two bespoke training events at Newcastle University in 2023 and 2024 *on Bioelectrochemical Systems.*

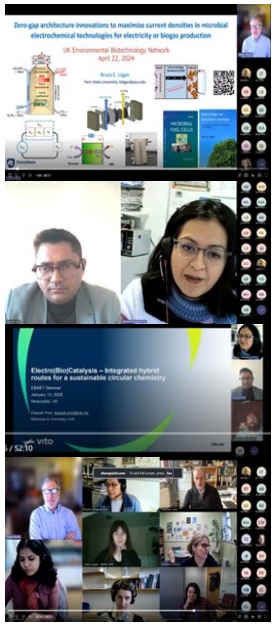
These training workshops resulted from activities to foster collaboration opportunities on this topic. The WG wanted to provide a source for skills development and collaboration that would lead to development of new bioelectrochemical systems, and further understanding of the different aspects of this type of biosystem. The workshops provided participants with fundamental biotechnology, electrochemistry and scientific communication outreach skills. Each event was attended by a cohort of approximately 20 participants from industry and academia.

The workshops provided knowledge transfer on extracting and quantifying DNA from electrochemical biofilm samples using the DNeasy® PowerBiofilm® Kit, Qubit Fluorometer, and Nanodrop. This was followed by sequencing the biofilm genetic material using Nanopore technology. Finally, participants were able to analyse the results obtained from microbial characterisation. Regarding the electrochemical techniques, participants were taught and demonstrated two fundamental concepts: polarisation and cyclic voltammetry. A collaborative dinner was joined by Cap-a-pie theatre company who provided participants with a snip on conducting outreach work and translating difficult concepts into simple sketches.

ACTIVITY SYNOPSIS ctd

The WG ran four webinars with top invited speakers from the Netherlands, USA, Belgium and UK.

Webinar *Bioelectrochemical Development for Environmental Technology*
Webinar *Bioelectrochemical Systems – from fundamentals in robotics to real world applications*
Webinar *Zero-gap architecture innovations to maximize current densities in microbial electrochemical technologies for electricity or biogas production*
Webinar *Electrobiocatalysis – Integrated hybrid routes for a sustainable circular economy*

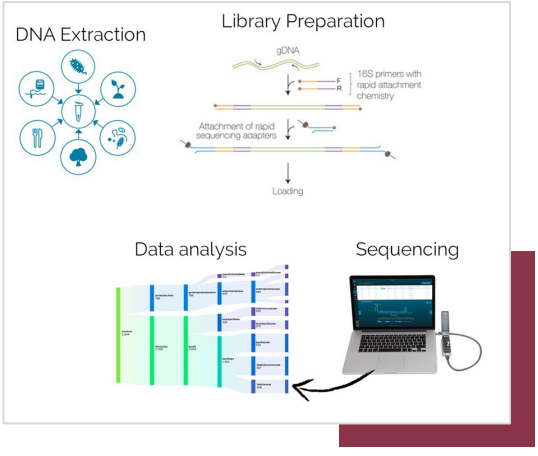


Webinars such as the one featuring Bruce Logan on biolectrochemical systems or Deepak Pant on electro-bio catalysis enrich the community by disseminating knowledge of bioelectrochemical systems for environmental applications. These seminars facilitated understanding of topics like bioelectrochemistry and carbon dioxide conversion, offered opportunities to learn about integrated approaches and advancements in the field, addressed questions with world leaders, and helped engage our community in discussions. Through the seminars, there have also been announcements of opportunities for further education and research, such as PhD positions. They provided an accessible space to discuss the importance of public acceptability and social science views related to these new biotechnologies and products made from waste. Overall, the webinar series provided a convenient way for people to connect and learn about the latest developments in the working group field.

EBNet funded two proof-of-concept (POC) projects in this topic, one of which was at our maximum value of £100k.

POC202207 Pure biomethane – rather than biogas – from a single waste stream
POC202311Simultaneous Bioremediation of Nutrient Pollution and Carbon Fixation Through a Novel, Integrated Anammox and Acetogens-Based Bio-Electrochemical System

In collaboration with the Anaerobic Fermentation WG the group supported an industry-focused study on implications of emerging biotech processes for materials and corrosion, and helped coordinate the *New Biomethane* workshop.



WG Outreach Publication

Spark bugs biomethane boost (microbial electrochemical technologies), by Angela Bywater. EBNet Corner, ADBA Magazine, Issue 54, Winter 2022

Dr Elizabeth Heidrich
Newcastle University

Dr Jan Dolfing
Northumbria University
JOINT POC 202207

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Pure biomethane - rather than biogas - from a single waste stream

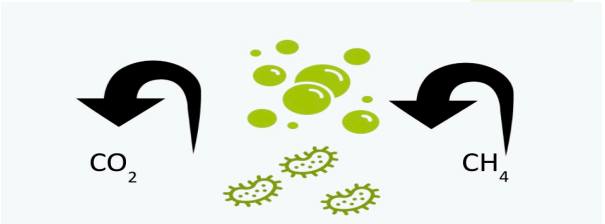
THE RESEARCH

Separation is one of the most challenging aspects of any recycling process, and anaerobic digestion (AD) of wastes is no exception. AD plants produce biogas, a mixture of methane and CO_2. The problem here is two-fold: firstly, biogas upgrading processes can consume 2-13% of the energy produced; secondly 1-4% of the methane can be lost in the off-gas, and it has 28-34 times the global warming potential of CO_2.

Through understanding the state of the art and building on thermodynamic insights, we developed a combined AD and bioelectrochemical reactor set-up which produced higher methane concentrations in the off-gas. The approach is deceptively simple: it allows the thermodynamically favourable biological reactions to proceed as normal; but separates the places in which the stages of this reaction occur, and thus the gaseous products, producing pure bio-CH_4 in one compartment and bio-CO_2 in another compartment of the same reactor.

By using bioelectrochemical membrane technology to manipulate the bioreactor space for a mixed microbial community, we can deliberately and intelligently separate the functionality and outputs of the microbes.

We would like to further develop the technology to work towards pure methane on one side, pure CO_2 on the other. This has the potential to be a simple retrofittable upgrade to all AD reactors which would then deliver improved environmental protection and enhanced resource recovery.



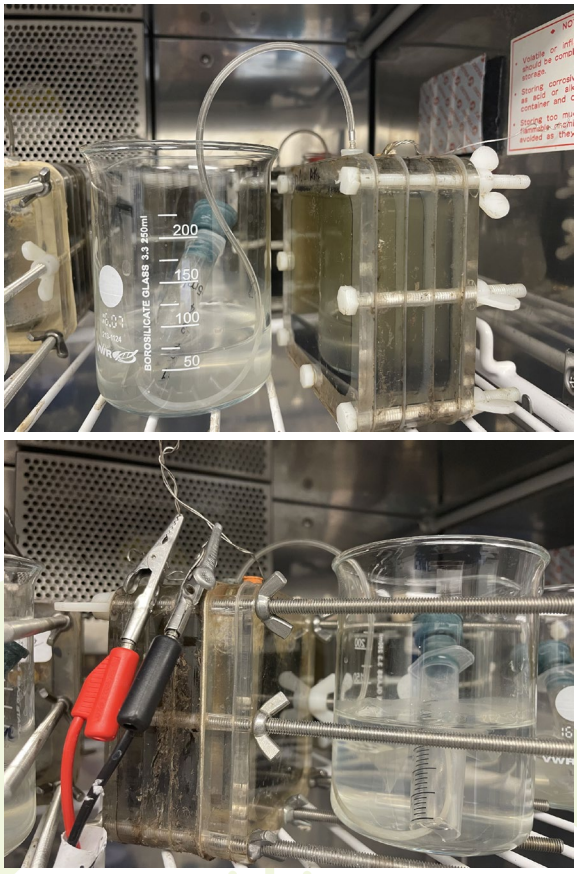


Fig.1. MEC-AD reactor set-up. Top: Stand-alone AD reactor with tubing to collect methane. Bottom: MEC-AD reactor separated by a CEM membrane with tubing to collect gas from the AD side and connected to a Pico logger for voltage measurement.

"These POC grants allow us to explore risky and interesting ideas with a view to taking the ideas further if they work. We gained valuable insights in this project which will help the development of bioelectrochemical menthane production technologies."
- Dr Elizabeth Heidrich, Newcastle University

Dr Ahsan Islam
Loughborough University
POC202311

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Simultaneous bioremediation of nutrient pollution and carbon fixation through a novel integrated anammox and acetogens-based bio-electrochemical system

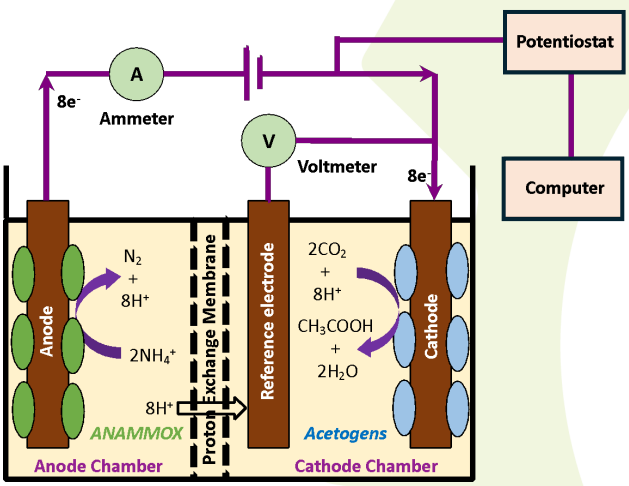
"The novel ANAMMOX and Acetogens-based integrated, one-pot bio-electrochemical system can be instrumental in addressing both environmental sustainability and decarbonisation challenges for the UK's chemical industry sector". **Dr Ahsan Islam, Chemical Engineering, Loughborough University**

AIM

The carbon and nitrogen cycles are two of the Earth's most important biogeochemical cycles due to their integral roles in the Earth's living systems.

Although both cycles are seriously affected by harmful anthropogenic activities, the later cycle received less attention from the scientific community in terms of its proper management and recovery from the damage caused. Improper management of the nitrogen cycle is also associated with the accumulation of fixed nitrogen compounds, i.e. nutrients, causing severe environmental pollution, including eutrophication, acid rain, red tides, and rapid destruction of the ozone layer.

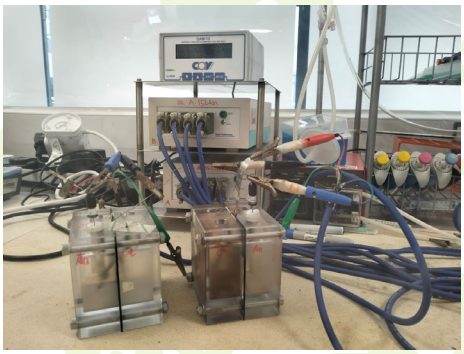
This project thus aimed to develop a novel bio-electrochemical system for simultaneous management of both nitrogen and carbon cycles by removing excess nutrients and CO_2 from the environment.



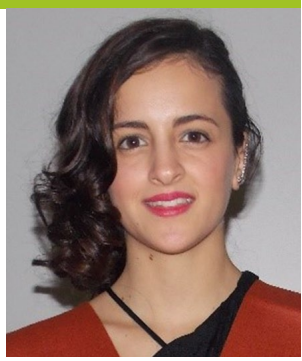
RESULTS

This PoC award was used develop a novel proof-of-concept bio-electrochemical system (BES) for simultaneous management of both nitrogen and carbon cycles by removing excess nutrients and CO_2 from the environment. The work employed both microbial anaerobic ammonium oxidation (anammox) by ANAMMOX bacteria and CO_2 reduction by acetogen-enriched microbial consortia in an integrated, one pot BES to produce nitrogen gas and organic acids simultaneously by supplying electricity. The electroactive microorganisms in the integrated BES oxidised nutrients such as ammonium (NH_4) into inert nitrogen gas and reduce CO_2 into high-value organic acids, including acetate, propionate and butyrate; thereby contributing to the simultaneous bioremediation of both nutrient and carbon pollution.

Further optimisation and scale-up can be used to develop cost-effective and energy efficient wastewater treatment processes. Such a novel system can therefore be used to address both environmental sustainability issues and decarbonisation challenges in the UK's chemical industry sector.



PLANNED PUBLICATION:
Coupling ANAMMOX and Acetogenic CO_2 reduction for simultaneous bioremediation of nitrogen and carbon pollution.
By: Abbas A, Islam MA. In preparation for ACS Electrochemistry.



Implications of Emerging Biotechnologies for Bioreactor Materials

Report prepared by Dr Maria Ramos Suarez, University of Southampton

Supported by EBNet AF and BES Working Groups

The need for this study arose from a discussion early on in the Network between EBNet academic and industry members about the implications of emerging industrial and environmental biotechnologies for producers and users of industrial bioreactors.

This topic is relevant both to EBNet's Anaerobic Fermentation (AF) WG and to the Bioelectrochemical Systems (BES) WG because of the relevance of Microbially-Induced Corrosion (MIC) in this context. Further discussions led to a joint-funded PhD and an extensive desk-based study, carried out by postdoctoral researcher Maria Ramos Suarez in conjunction with experts from industry and the University of Southampton. The full report covers multiple scenarios and consists of 40 pages incorporating 217 references.

Report

The report examines major emerging bioproduction processes in industrial and environmental biotech, based on the top 10 bio-based products - as selected by market size and research importance. It looks both at the conditions likely to occur during production and their significance for different bioreactor materials. Finally, it also looks briefly at the ranges of conditions likely to be in use as a result of extremophile exploitation, and at the significance of MIC.

As few studies have performed immersion tests of metal and polymer specimens within a bioreactor environment, and the information on corrosion and abrasion mechanisms is still limited, it is timely to identify any areas of inadequacy in the light of such emerging processes & conditions. The IB sector is expanding rapidly, necessitating such advancements in bioreactor materials to withstand corrosion and wear.

The full report is currently embargoed whilst a journal paper is in preparation but, once the paper is published, the report will be made freely available on the EBNet website.

Top 10 bio-based products
Biomethane
Biohydrogen
Bioethanol
Biobutanol
Lactic acid
Volatile fatty Acids (VFA)
Succinic acid
Biosurfactants
Polyhydroxyalkanoates (PHA)
Enzymes

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AF WG https://ebnet.ac.uk/wg-details/wg-af
BES WG https://ebnet.ac.uk/wg-details/wg-bes

For further information on outputs from this activity see Resources. https://ebnet.ac.uk/resources

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IMPLICATIONS OF EMERGING BIOTECH FOR BIOREACTOR MATERIALS

TOP BIO-PRODUCTS

CH4, H2, VFA, LACTIC ACID, ETHANOL, BUTANOL, SUCCINIC ACID, SURFACTANTS, PHA AND ENZYMES

CONDITIONS

PH 5-8
T 15-80°C

AGING MECHANISMS

CHEMICAL CORROSION (CHLORIDES AND ACIDS)
MICROBIALLY INDUCED CORROSION (MIC) BY BIOFILMS, CO2, H2S, ACIDS AND ALCOHOLS
ABRASION (SOLID SUBSTRATES)

CURRENT MATERIALS

STAINLESS STEEL, CARBON STEEL, GLASS FUSED TO STEEL, EPOXY COATINGS

Current IB

ACCELERATED TESTS

- IMMERSION TESTS
- SIMULATED ATMOSPHERE TESTS
- ELECTROCHEMICAL TESTS

Biroeactor materials

Industrial biotechnology (IB)

Material testing

IDENTIFIED PROBLEMS

- STANDARD TESTS IGNORE MIC
- LACK OF COMBINED ABRASION AND CORROSION EFFECTS

FUTURE MATERIALS

POLYMER COMPOSITES, FIBRE-REINFORCED PLASTICS, CERAMIC

Next generation IB

BIOREACTOR STUDIES

LIMITED NUMBER OF MATERIALS AND BIOREACTOR CONDITIONS

ENZYMES, PHA, LACTIC ACID, CH4,ETHANOL, SUCCINIC ACID, BUTANOL, SURFACTANTS

BIO-PRODUCTS PROVEN AT LAB SCALE

PH<4 OR PH>9
5M SALT
T<15°C OR T=50-90°C

EXTREME CONDITIONS

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