SPARK BUGS BIOMETHANE BOOST

Engineered microbial systems are being combined with AD to boost methane output at the expense of CO_2. **Angela Bywater** reports on a breakthrough which has the potential to revolutionise the treatment of some wastes

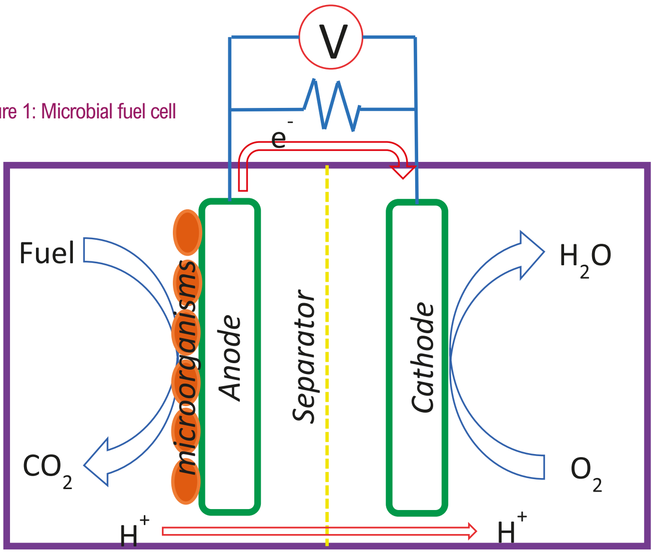
In the anaerobic digestion world, most of us are familiar with the continuous-stirred tank reactor or CSTR. In a commercial situation, such digesters are not usually stirred continuously – i.e., 24/7 – but they are regularly mixed, usually by mechanical means or through gas recirculation. In such a digester, a complex microbial community degrades organic materials into fertiliser and biogas.

But microbial activity can be harnessed in many ways. As long ago as 1910, scientists observed that electrical energy could be liberated during the fermentation/putrefaction of organic materials by micro-organisms. These engineered microbial systems which convert chemical energy intro electrical energy are known as Microbial Electrochemical Technologies (METs) and they can be used as biosensors, and for waste remediation, resource recovery, energy production and more.

Two common types of BES include microbial fuel cells (MFCs) - METs are also called bioelectrochemical fuel cell systems - and microbial electrolysis cells (MECs). Both systems typically contain an anode, a separator/barrier to prevent short-circuiting, and a cathode (see Figure 1) but operate in slightly different ways. MFCs produce a small electric current from the microbial decomposition of organic materials (feedstock), whilst a small electrical current is applied to an MEC (see Figure 2), typically producing hydrogen.

Microbes on the anode (negative) side of the system oxidise the feedstock, releasing electrons. A reduction reaction on the cathode (positive) side causes a reduction-oxidation (redox) potential which drives electrons to flow from a low potential to a high potential in the external circuit, i.e., from anode to cathode. Positively charged hydrogen ions (protons), each of which has lost an electron, will flow through the separator from the anode side of the cell through to the cathode side. In a BES, these H+ ions are cations, i.e., ions which are attracted to the negatively-charged cathode.

Figure 1: Microbial fuel cell



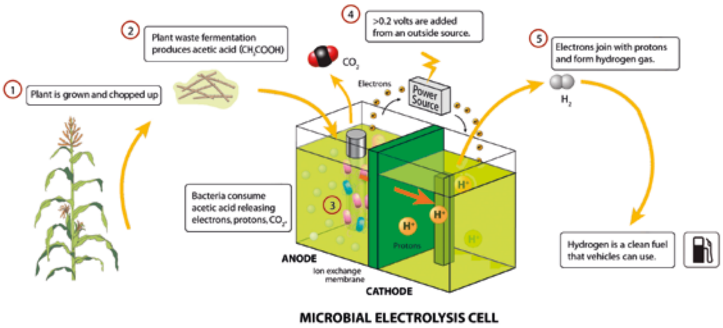


Figure 2: Microbial electrolysis cell

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BES technologies have become increasingly promising, as experiments using different microbial communities, in either pure or mixed cultures, as well as different materials for electrodes, separators (membraneless systems are also in development) and catalysts in various design configurations have provided encouraging performance results: for example the power density of MFCs increased from .01 milliwatts per square meter of anode surface area in 1999 to 2770 milliwatts per square meter in 2012 and performance improvements continue to be made.

With advances in low power consumption electronics, the inclusion of MFC technology has the capability to both treat environmental wastes and to provide useful energy. In 2014, Prof Ioannis Ieropoulos and his team demonstrated the 'Urinetricity' system in India https://tinyurl.com/2p933p7y (see Figure 3) with the first Pee Power® field trial https://tinyurl.com/5n8vw6ex installed at a girls' secondary school in western Uganda in July 2017.

Electricity was used to light up the toilet block. Subsequent work also used MFC's to power an electronic faucet and, in their published paper https://tinyurl.com/4var85dm, the team noted that these systems offer a sustainability energy generation system which could also power an automatic flush, contributing to the hygiene of the toilets and 'leading to a new generation of self-sustained energy recovering e-toilets'.

Figure 3 - Urinetricity bank of reactors with an individual cell (inset)

Wastewater treatment is not a glamourous sector, but it is a very important one – and the statistics for the sector provide some startling reading: 1%-3% of the world's electricity production is used to treat wastewater, but still 80% of the world's wastewater goes into receiving waters untreated.

If scientists could unlock at scale the energy content of wastewater – typically 16.1 kJ/gCOD (kilojoule per gram chemical oxygen demand) – it could easily offset the energy requirement of 2.5-7.2 kJ/gCOD used by the activated sludge process. Unlocking even part of this energy through novel treatment technologies would offset the cost of wastewater treatment.

These amazing biological systems are flexible in their design and application, so it should come as no surprise that anaerobic digestion (AD) can be coupled with MEC. To this end, the EB Network has supported Dr Elizabeth Heidrich's 2022 Proof of Concept proposal to produce pure biomethane – rather than biogas – from a single waste stream. AD results in a mixture of methane (CH_4) and carbon dioxide (CO_2), while anaerobic treatment in a Microbial Electrolysis Cell (MEC) results in pure CO_2 and protons and electrons.

Dr Heidrich's aims to manipulate the bioreactor space using bioelectrochemical and membrane technology. By doing this they will deliberately separate the functionality and outputs of the microbes thus separating the gaseous products into pure CO_2 and pure CH_4. This has the potential to be a simple retrofittable upgrade to all AD reactors which would deliver improved environmental protection and enhanced resource recovery. The approach also has the potential for wide scale use throughout the biotech industry.

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MEC-AD Reactor prize

The poster prize winner at the EB Network Early Career Researcher conference this year was Kyle Bowman, a PhD candidate from the University of Westminster who is also working with the early-stage commercial company WASE. His poster, entitled 'Pilot scale electromethanogenic reactor treating brewery wastewater – progress to commercial implementation', describes their 4000 litre MEC-AD reactor treating brewery wastewater at Hepworth's Brewery, and data from the project hopes to inform the operation of WASE's 24,000 litre and 51,000 litre systems.

The WASE team stress-tested the system under various conditions with retention times varying between 1.8 and 30 days, and organic loading rates between 0.4 and 6.7 kg COD/m^3/day. They observed that an average COD removal of 90% was observed over the 6-month investigation. The chemical oxygen demand of the wastewater was around 16000 mg/L COD and the system achieved a peak stable hydraulic retention time of 2.3 days with 84% COD removal in the primary reactor. Biogas averaged a 70.3% methane content and yielded 0.486m^3 CH_4/kg of COD removed, equating to an average of 65.4 kWh/m^3 of wastewater treated.

Such is the promise of these systems that the EB Network has supported a new BES working group https://tinyurl.com/2p8yzvpk which is free to join for anyone interested in these exciting technologies.
Visit https://tinyurl.com/2p8yzvpk for more information.

NEXT ISSUE

Our next magazine topic will be on Anaerobic Membrane Bioreactors. If you want to learn about these straight from our world-class experts, join us for a short webinar on 'Advances in Anaerobic Membrane Biorectors (AnMBR)' https://ebnet.ac.uk/ebnet-rc22-anmbr on Wed 7 Dec 22 at 13.00-15.00. Presenters include Prof Jules van Lier from Delft University, Prof Bruce Jefferson, Cranfield University and Dr Santiago Pacheco-Ruiz from BIOTHANE in the Netherlands.