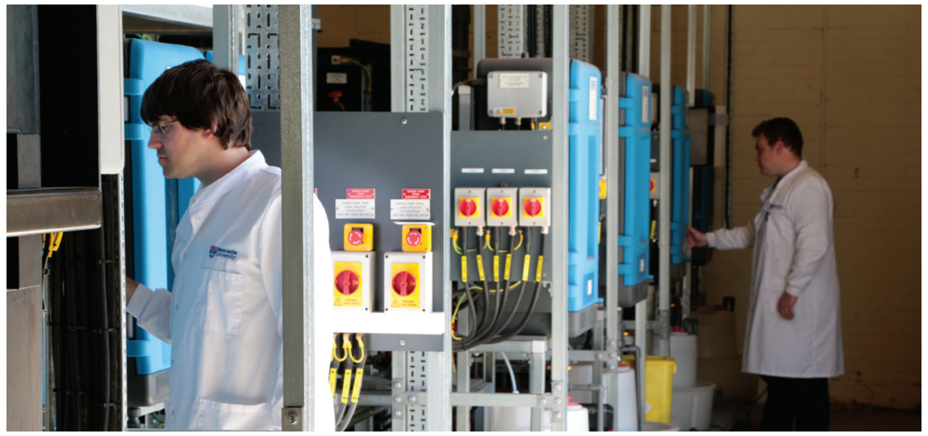
Engineering biology for the circular economy in water resources

At present, wastewater treatment plants play a vital role in the circular economy by treating and recycling water to the natural environment. In the future they will also act as low-carbon energy generators and facilities for recovering and producing materials useful to society.

By Dr Russell Davenport, Dr Martin Spurr, Professor Ian Head and Brett Cherry

Wastewater treatment technology is exciting for a variety of reasons. The UK and other rich nations are in the privileged few, where nearly all the water collected to make it potable is treated and returned to the environment, which in 98.5% of cases is compliant with environmental standards set out in EU directives. Globally, 80% of wastewater is discharged to the environment untreated. It is estimated that, across the world, for every £1 invested in water and sanitation services £5-£46 is returned in economic benefits due to health and environmental improvements. However, wastewater treatment is energy-intensive and energy-negative accounting for 1.5% of total UK electricity use; the largest single use of which is for aeration.



Imagine in the future if we not only met the standards for environmental quality of our rivers and streams affected by wastewater discharge some of the time, but all of the time, while also producing useful energy and products. While wastewater treatment has improved since the days of the first treatment technologies in the late 19th and early 20th century, the main technologies have remained relatively unchanged since that time. However, using knowledge and tools from biological engineering could change all of this.

BE:WISE (Biological Engineering: Wastewater Innovation at Scale) is an advanced collaborative wastewater treatment research facility in partnership with Northumbrian Water that is located in Birtley, Gateshead. It is paving the way for future wastewater treatment and transforming how we treat wastewater through engineering biology. It adds to the North East's legacy as a pioneer in water engineering, which includes mine water treatment, blue-green infrastructure and Bio-Electrochemical Systems (BES). BE:WISE combines multiple wastewater treatment units into one facility and welcomes proposals for collaborative research projects between the water sector and academia.

What makes BE:WISE particularly unique is that it receives wastewater from a population equivalent of 40,000 Northumbrian Water customers located in Birtley. Wastewater is piped into the facility from the main inlet source and is received by multiple treatment units onsite. It is in a sense not one but multiple labs in one. The facility provides an opportunity to test exciting innovations in water resource technology at scale. One example is a real-time biosensor for measuring BOD, which is still widely used in the wastewater industry as an important indicator of the amount of organic pollutants in water. This is the first time our BES sensing technology has been tested with a continuous feed of wastewater from a treatment plant.

The sensor is essentially a microbial fuel cell (MFC) made from cheap materials with a biofilm grown from bacteria found in the wastewater on a carbon anode and an air-breathing chemical cathode. As the bacteria grow they give up electrons via the anode and release a proton that goes through a membrane to an aerated cathode chamber generating an electrical signal. The voltage is proportional to the BOD of the wastewater entering the anodic chamber. Unsurprisingly these were originally explored for generating energy, but in this case they are for self-powered, accurate, real-time monitors of BOD.

A biosensor for monitoring BOD could potentially save the water sector in terms of time and cost. The five day BOD (BOD_5) test used by treatment plants since 1912 has many shortcomings that impact wastewater effluents. Even when BOD is found to be too high – it's often too late to reactively manage – because the effluent will have already been discharged. BOD_5 is also inaccurate with readings typically having an error of ±15%. Other tests in use today such as for Chemical Oxygen Demand (COD) take less time but use hazardous chemicals, which makes them less than ideal, and does not specifically measure the biodegradable component of organic matter that is of interest to wastewater treatment practitioners.

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In the UK wastewater continues to mainly be treated aerobically. The energy and cost of doing this is substantial. More advanced should not mean more expensive – it should mean cheaper, with enhanced precision and sustainability. The sensor can act as a cheap early warning system providing a real-time signal for process control -- potentially allowing for reductions in aeration for wastewater treatment. Instead of using it 100% every day, aeration could be modified based on the amount of BOD in the influent. At the moment we are currently validating the BOD sensor to prove that the electrical output from the device correlates with actual BOD_5, similar to the original proof-of-concept in the lab.

The BOD sensor is a potential sustainable solution for preventing wastewater discharges where BOD is high, relieving pressure on ecosystems and aquatic life. It could help bring industry one step closer to managing wastewater in a way that continues to ensure the future of sustainable wastewater treatment.

Testing the BOD sensor at BE:WISE grants us the opportunity to understand how it responds to a range of environmental variables present in wastewater, including toxic chemicals. Since it's a biosensor anything that affects biological processes could affect it, but in the case of conditions like pH and temperature (which are readily measured online already) it is possible to work around them using calibration models that compensate for variations.

In the circular economy, wastewater could also be a source of low-carbon energy generation; there is nearly ten times as much (chemical) energy in wastewater than the energy we currently use to treat it. This provides opportunities to circumvent aeration and turn wastewater treatment systems from net-users to net-contributors of energy. If we treat wastewater anaerobically it would significantly reduce the cost of treatment and could generate low-carbon energy at the same time. Three such technologies are MFCs that directly generate electricity, microbial electrolysis cells (MECs) that generate hydrogen or other valuable chemicals, and anaerobic treatment using low temperature-adapted microbes for the production of methane. These technologies use the influent itself rather than water treatment residual (sludge) for anaerobic digestion to generate energy carriers.

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If found technically viable hydrogen production from wastewater could be a boon for the UK water sector, and we are working with Northumbrian Water Group to explore the technical and economic feasibility of the technology.

In the near future BE:WISE will be testing more microbial electrolysis cells (MECs). Newcastle University researchers will continue the next phase of their work in testing cold-adapted microbes for producing biogas at low temperatures using wastewater as the substrate.

At BE:WISE we are combining expertise in microbiology, electrochemistry, environmental engineering, and other fields. We encourage collaborations with colleagues in industry and academia that want to make innovations in biological engineering and BES systems a reality for the water sector.

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