EBNet Themes

Background

Microbial systems provide a range of environmental protection and bioremediation services, forming the basis for some of the world's largest industries across the Water-Wastes-Soil nexus. Development of such systems to date has been largely empirical and incremental, but the pace is changing in response to the need to match expanding global demand with finite resources. There are also new challenges to address, ranging from the emergence of new micro-pollutants to the requirement for efficient closed-loop systems that combine treatment with resource recovery.

The current revolution in biological and analytical sciences is creating tools that give unprecedented insights into these systems from genetic to community level, and into factors that can potentially be used to control and harness them. At the same time, new approaches allow enhanced measurement and modelling of engineering phenomena such as mixing and mass transfer, while advances in materials science and separation technologies offer the potential for selectively retaining microbial biomass and/or removing final and intermediate metabolic products. These developments thus offer a chance to optimise existing treatment processes and to create more sustainable 'future-proof' technologies in new areas of application. Successful exploitation of these opportunities depends, however, on bringing together an enhanced knowledge of the underlying science with the ability to apply this in large-scale engineered systems, which must meet both societal expectations and increasingly stringent economic and environmental requirements.

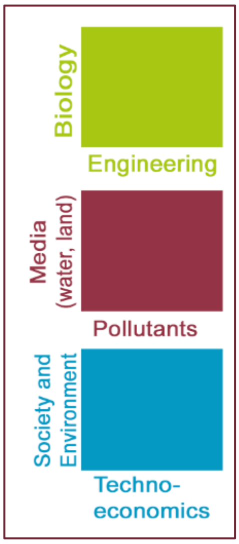
The aim of EBNet is thus to develop and strengthen links between advanced molecular and applied microbiology, engineering and systems optimisation to maximise the societal impacts and benefits. Its overall goal is to take fundamental discovery science towards practical application in key areas of the human/environment interface.

Themes

The EBNet remit consists of 3 interlocking themes. They are:

- Pollutants and media, covering both traditional and emerging pollutants;
- Biosciences to engineering to develop and improve technology for pollution control, resource recovery and bioenergy generation;
- Technology interfaces for process integration, techno-economic and sustainability assessment.

Further detailed information on each theme is provided below. This is not exhaustive, so if your proposed bid, working group or activity does not appear to align, but still falls within the purview of Environmental Biotechnology, do contact the Network Managers.



Context

Over 100 years ago, the UK led the industrialised world in the construction of wastewater treatment plants for the protection of public health and receiving waters. Since that time, these biological processes have been further modified to provide engineered solutions for industrial wastewaters, urban wastes, contaminated land remediation, and more recently for resource recovery and integration into bio-refinery concepts. These empirically-developed unit processes have proved remarkably effective, but it is increasingly clear that they are inefficient in resource recovery, energy consumption, and removal of a range of emerging pollutants. A combination of using new materials and techniques, harnessing newly discovered bio-transformations, and tuning the biology of conventional ones is opening up opportunities to rethink the way we process both municipal and industrial wastewaters and remediate contaminated sites.

Theme: Pollutants and media – Chairs: Dr Tony Gutierrez, Prof Fred Coulon

Pollutants enter the environment from both point and diffuse sources: the former are easier to monitor and control, but still represent significant discharges of priority substances that are not removed in current treatment systems. These are diverse with respect to their molecular structure, chemistry and toxicology, and include emerging pollutants such as microplastics, microfibers, nanoparticles, surfactants, petrochemicals, pharmaceuticals and other endocrine-disruptors. Once out in the environment, they are even more problematic.

There is a worldwide legacy of contaminated land where options for remediation are still limited; more recently, the eyes of the world have turned to the problems of gross contamination by plastics in the ocean, rivers and lakes which has further raised the awareness of the potentially more serious pollution of the biosphere by wastes and recalcitrant breakdown products. The potential for technological solutions is on the horizon and is likely to rapidly develop with increasing public concern and new scientific tools of investigation and a deeper understanding of the issues. It has long been known that microbial communities can adapt to remove certain pollutants (c.f. removal of certain organics in slow sand filtration) Empirical strategies for selection and enhancement of biodegradation of targeted materials are well established, and now we also have the ability to specifically genetically engineer microbes to perform specific functions. Such adapted or engineered communities can also now be contained through physical interventions, such as membrane technologies, biofilm formation on support structures or granulation, and their selectivity and endurance maintained by nutrient or culture condition manipulations. The development of bio-based remediation could provide environment-friendly and cost-effective solutions with advantages over most conventional chemical and physical remediation strategies. There are rapidly expanding fields of interest in this area. For example, for the remediation of contaminated soils the use of nanomaterials in combination with advanced biotechnology have proved successful in translocation of pollutants to a point of treatment, thus making bioremediation techniques more effective. Another emerging field is enhancement of biotechnological methods by combination with electrokinetic remediation where a number of synergistic effects may occur.

The matrix of pollutant type, environmental medium and treatment choices is large, and much of the work in this this theme is to: identify key pollutants and potential emerging technologies for their treatment; to prioritise the research and develop a road map and white paper for implementation; and to identify and interact with all stakeholders in promoting solutions and influencing policy. The theme links closely to the Bioscience to Engineering and the Technological Interface themes which concern the development of environmentally acceptable, sustainable and cost effective remediation and preventative technologies to completely degrade pollutants, recover them or transform them into less damaging forms.

Theme: Biosciences to engineering – Chairs: Prof Tom Curtis, Prof Sonia Heaven

The current pace of change in biological and analytical sciences amounts to a revolution in our ability to see into microbial systems and creates an urgent need for improved understanding across different disciplines.

All current environmental biotechnologies and many (although not all) plausible future ones are open systems comprising microbial communities that are immensely powerful, but also immensely complex. This complexity arises from a challenging combination of numbers (>1018 in a typical commercial bioreactor), taxonomic diversity and trophic interaction. As these systems depend on the concerted activities of many microbial species, they are difficult to optimise; nevertheless, they are likely to continue to dominate wastewater and waste treatment as well as bioremediation of soil and water. The combination of low-cost sequencing and novel visualisation technologies, together with an enormous increase in the quality, capability and accessibility of bioinformatics tools is now allowing us to begin to characterise these mixed communities. This is turn is leading to a variety of approaches on how to deal with the resulting expansion in data availability.

It is possible that, even if one day we can achieve a complete census of the organisms present, we will still not fully understand the community or be able to predict how it will work based simply on this information. One approach to overcome this is to develop a universal body of theory to describe such systems. This does not suppose a complete understanding, but it may permit the development of predictive models and thus tools to aid in design and management of complex microbial systems.

The way forward is to find solid quantitative measures that can be empirically linked to outcomes or used in validation of theory as a basis for design. The toolkit to do this is expanding as quantitative methods become available and affordable, resulting in a shift towards more effective and impactful research. These changes will be further accelerated by the increasing 'commoditisation of sequencing' through ongoing investments by BBSRC and others such as the European Bioinformatic Institute (EBI) in providing online automated bioinformatics tools.

Another approach is through hypothesis-driven research that considers the physiology, metabolic pathways and thermodynamics of the reactions involved. A significant number of studies exist on the metagenomics of treatment. Despite this effort, however, there are still only a few examples where population structure has been linked to anything more than broad functionality, although changes in community structure can in some cases be directly linked to process failure. Mapping the relationship between the gene sequences that determine the phylogenetic characteristics of a group and its metabolic functionality is still proving to be an elusive goal. Metatranscriptomics, when directly associated with metagenomic data, identifies those genes that are actively transcribed by a community, and therefore potentially allows prediction of active metabolism in response to spatial or temporal environmental gradients. Metaproteomics allows us to identify the actual microbial proteins that are post-transcriptionally regulated and translated under particular conditions and thus provides a tool that allows us to explore new biochemical pathways, as well as monitoring metabolic activities within the community. Metabolomics provides an instantaneous snapshot of metabolic profile of cells and this technique, along with mass spectrophotometry, is currently being applied to better understand the reactions in anaerobic digesters. There is thus potential in using these advanced biomolecular tools for mapping of functionality in treatment processes or even to develop rapid diagnostic bio-molecular markers for monitoring performance and stability.

Current advances in engineering and materials science, while not as dramatic as those in biological and analytical sciences, are providing new tools for measurement and modelling of e.g. mixing and mass transfer, while advances in materials science and separation technologies create the potential to retain biomass and/or selectively remove final and intermediate metabolic products. This is a highly interactive process, since such changes will profoundly modify the reactor environment in which microbially-mediated reactions occur. The need to link factors such as flow regime and boundary conditions with the nature and performance of microbial communities adds another layer of complexity in understanding these systems, and one in which we have only begun to scratch the surface, but also offers further routes to process innovation and improvement.

The goal of this theme is therefore to facilitate the translation of advances in fundamental science into technological solutions and process enhancements. The planned activities involve bringing scientists and engineers together to foster understanding and exchange of critical concepts and information. Every core member of the proposed Network has a story of how outstanding figures in one field sometimes lack even a basic comprehension of limiting parameters in another, or of how these will affect the application, performance and, in some cases, even the feasibility of the process under study: this is all the more critical given the highly interlinked nature of microbial processes with the environment they occur in. The theme aims to make these interdisciplinary connections and identify the most promising interactions where knowledge exchange could move discovery science towards higher TRL. This will require close interaction with the Pollutants and Media theme on priorities, the Technology Interfaces theme on feasibility and acceptability of proposed innovations, and with industry end-users on effective means of technology translation and implementation.

Theme: Technology interfaces – Chair: Dr Jhuma Sadhukhan

This theme brings together the critical areas of process integration and techno-economic assessment with societal and environmental aspects.

Process integration modelling is a powerful tool for optimising energy and materials usage in industry, and has become imperative in any complex process system. Tools such as Pinch Analysis for heat, water, hydrogen and carbon integration, and computer-aided process engineering using the industry-standard Aspen Plus® simulation software for full process energy and utility stream integration have, however, only rarely been applied in optimisation of the complex process trains used in the water and waste management industries. Adopting and adapting these tools would provide a means of establishing a baseline, against which process development and optimisation can be benchmarked. Process models should also be developed to accompany translational research on new or optimised processes, to give valuable insights into commercialisation potential and to build business confidence to invest in transition technology to a more circular economy. A circular economy model, as a way of maintaining “the value of products, materials and resources in the economy as long as possible” and minimising “the generation of waste” (EU Circular Economy Action Plan, 2015) could be embedded in biotechnology businesses by applying the concept of process integration in the form of integrated bio-refineries. One essential function of the Network will therefore be to create and strengthen links between data-owners and process systems modellers.

The environmental biotechnological processes with which EBNet is concerned are at the interface between human activity and the environment, protecting our water, land and atmosphere whilst also offering the potential for resource recovery and circulation from wastes and wastewaters. To date, life cycle sustainability assessment (LCSA), encompassing the (environmental) life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA), (ISO14040, 14041, 14044 and 26000) has been the most powerful and holistic methodology to design and optimise a ‘whole intertwined system of value chains’ based on optimal trade-off between the three pillars of environmental, economic and social sustainability, respectively. In spite of the whole system holistic aspect of the LCSA methodology, complexity and limited resources have constrained its widespread adoption and adaptation. Applying the LCSA methodology is essential to embark upon a robust circular economy and also for the implementation of global commitments taken by the United Nations, such as the 17 Sustainable Development Goals. The system boundary has to step up from a linear process or product life to a circular life by consideration of upgradability, recyclability and the identification of added value resources (at least by-products) rather than wastes. The substitution of alternative large-scale technologies to replace 'conventional' systems and the use of novel biotechnological remediation and value addition techniques requires wider scrutiny of the societal impacts of these changes. Current and future developments also require direct economic analysis of the processes, which can be further linked to a wider systems boundary taking account of LCC and the regulatory and economic instruments (e.g. renewable obligation, effluent and landfill charges etc.). Such assessments are important tools in establishing and controlling policy drivers and for setting appropriate regulation, and must go hand in hand with technology developments and new market opportunities. Impacts on society and individuals from successful technology implementation cover a range of real or perceived risks associated with the development of modified or synthetic biological communities: pollution incidents, fugitive greenhouse gas emissions and intrusion from new biotechnology plants; transport logistics, odour from plant operation and disposal of residual biosolids; and also include new opportunities for business and social entrepreneurship.

This theme will therefore interact strongly with both Pollutants and Media, in terms of contributing tools and insights for policy support; and with Biosciences to Engineering, to allow replacement of empirical relationships in the modelling of bioprocesses with improved descriptions of process behaviour and functionality.

Contact Details

For any queries, please email the Network Managers, Angela Bywater/Dr Louise Byfield at EBNet@EBNet.ac.uk or telephone 02380 591281. Post can be directed to us at Building 178, Room 5019, Boldrewood Innovation Campus, University of Southampton, Burgess Road, Southampton, Hants. SO16 7QF