Position statement from the EBNet/Carbon Recycling Network Joint Workshop

Advancing Gas Fermentation Technologies: A multi-disciplinary challenge

Gas fermentation technologies have the potential to revolutionise sustainable bioproduction, providing effective routes to carbon capture and utilisation and a transformative contribution towards net zero. Some pioneering examples are already at commercial scale, but to deliver their promise in full several key research and implementation issues need to be addressed. These challenges include interactions between complex microbial and engineering factors, as well as the importance of scale-up and technology transfer.

In the field of microbiology, there is a pressing need to enhance our understanding of fundamental systems biology, with significant knowledge gaps to be filled. Non-model organisms in particular offer massive untapped potential; but the necessary cultivation protocols and genetic tools are poorly developed. The potential of mixed cultures and microbial communities also warrants more extended investigation, including understanding the trade-offs between synthetic biology and wild-type organisms.

Metabolic aspects play a crucial role in gas fermentations. More detailed understanding of inhibition is needed, and of the effects of mixing and external conditions on microbial metabolism and community structure. Key metabolic factors include electron transfer, electron donor selection, and electron bifurcation systems. Exploring spatial structure in microbial cultures, including biofilm development and maintenance, is also essential to optimise these processes.

Limitations in gas-liquid mass transfer pose significant design challenges, necessitating better understanding of such processes. Improved insights will enable more efficient design of scale-down experiments and better prediction of performance at larger scales. Additionally, the impact of fermentation broth properties, such as viscosity and surface tension, on gas-liquid-biomass transfer and hydrodynamic characteristics needs to be experimentally assessed.

Multi-scale modelling approaches are needed that can simulate bioreactors with integrated biokinetics in order to elucidate microbe-microbe and microbe-environment interactions. These models must cover genetic, cellular and community levels, as well as incorporating thermodynamics and hydrodynamics across relevant scales. Such approaches, supported by advances in real-time monitoring, will aid in design and operational decision-making, allowing 'what-if' scenarios to be explored.

Scale-up is a major challenge limiting development in the field. Scale effects can significantly influence mixing and mass transfer, and thus microbial metabolism and system performance. To address this knowledge gap, better access to gas fermentation scale-up facilities is required, along with targeted funding. Empirical and theoretical studies are needed to support cost-effective designs for high mass-transfer bioreactors. Improved methods for hygienic operation of biofilm reactors must be developed, as well as cost-reduction strategies for sterile or pure culture operation where required.

Development and diversification of feedstock, process and product choices are interconnected issues. Open and honest discussions are needed to determine which bioprocesses and products to focus on. Techno-economic assessment and carbon footprinting of bioproduction methods for different classes of bioproducts are vital to support informed decision-making. Consideration must be given to the impact of gas quality, purification requirements, and intermittent renewable energy patterns. Process selection for target products and recovery methods requires further work, particularly in the recovery of non-volatile products from fermentation broths. Modelling, including AI and machine learning approaches, can aid in process optimisation and control.

Two-stage processes using gases converted by chemical catalysis into soluble form (e.g. formate, methanol) also merit attention as they eliminate some difficulties associated with gaseous substrates. Many of the key issues identified above also apply to these processes, and will benefit a much wider range of industrial biotechnologies.

To implement these advances, multi-disciplinary approaches are essential. Better understanding and communication across specialisms and disciplines is vital to support a new generation capable of engaging effectively in this field. Talent acquisition and retention can be facilitated through promotion of interdisciplinary work and training. Funding plays a crucial role in progressing gas fermentation technologies, and targeted cross-disciplinary, cross-sector opportunities are needed. Support for industry/ academic collaboration is essential, as is industrial engagement for informed appraisal and techno-economic assessment.

As experts, we believe that addressing these key research and development issues will unlock the full potential of gas fermentation to contribute to national and international sustainability and net-zero targets.

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This position statement was produced as part of a workshop on microbial systems with gaseous feedstocks run jointly by the Environmental Biotechnology Network (EBNet, www.ebnet.ac.uk) and the Carbon Recycling Network (https://carbonrecycling.net) on 27-28 March 2024. The goal was to identify key questions and knowledge gaps, R&D needs for technology progression and transfer, and actions that should be undertaken to promote progress and alleviate any obstacles.

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