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Editorial

Anaerobic Fermentation—A Biological Route towards Achieving Net Neutrality

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Increasing greenhouse gas levels have led to the international community pledging to curb the mean global temperature increase to less than 1.5 °C. While the commitment to such stringent targets gained an increased support by the COP26 (November 2021) community, actions to achieving this have not been effective. The end of COP26 coincided with the launch of this Special Issue targeted towards "Net Neutrality" via "Anaerobic Fermentation" to understand the current status of research in this compelling area. With increased interest amongst the research community to contribute to this Special Issue, the final submission deadline was extended to November 2022, which coincided with COP27. The lack of stakeholder commitment seen in COP26 initiated the traction towards climate financing, leading to the 'Adaptation Fund' and the 'Least Developed Countries Fund' to help support needy countries to meet short-, medium-, and long-term climate action plan targets. This also led to the conversations of achieving net zero emissions rapidly as opposed to revisiting transition targets. As the guest editor, I feel extremely proud that a key takeaway from COP27—'nature-based solutions'—was addressed in this Special Issue to an extent and, therefore, I would like to thank all the authors for their valuable contributions.

Achieving net neutrality has to follow a sustainable circular economy pathway, and anaerobic-fermentation-based biological routes have a significant role to play in this remit. The Special Issue was vastly successful in capturing this research, with studies focused on the fate of enzymes, microbiomes and metabolic pathways, new product streams, and intensifying fermentation using engineering optimisation, as well as identifying routes for sustainable biorefineries via anaerobic fermentation.

Anaerobic fermentation is well established at a commercial scale in wastewater treatment plants around the globe. However, the removal of key nutrients such as orthophosphates is not often possible with conventional anaerobic digestion (AD) systems. Khumalo et al. investigated an aerobic–anaerobic sequencing batch reactor to tackle this problem and improve orthophosphate removal rates [1]. Conventional AD often focuses on biogas production for energy recovery from waste. While this aspect is commonly exploited for recovering value out of a variety of waste, its intensification for enhanced value addition is still lacking. On this front, Miftah et al. reported the use of choline chloride monoethanolamine as the most effective deep eutectic solvent to recover a cellulose-rich residue from sugarcane leaves upon pre-treatment [2]. Intensified biomethane production was observed alongside biohydrogen, leading to maximum energy recovery from the waste feedstock. In contrast to pre-treatment, Shin et al. investigated the use of additives, especially food-waste-derived biochar, for enhancing the biomethane yield [3]. Adding enzyme cocktails to AD reactors is a promising new strategy to enhance hydrolysis and methane production rates. However, this may not always result in positive biomethane yield enhancements due to a number of reasons, with enzyme stability being the predominant factor. Küchler et al. investigated this phenomenon and reported that lignocellulose-degrading enzymes had a half-life of ~1.5 h when added to an AD reactor [4]. They established a workflow to monitor the stability of such enzymes, which is crucial in determining the efficiency of the process. Buriánková et al. investigated the microbial communities found in underground gas reservoirs, examining their unique metabolic pathways [5]. Rigorous qPCR- and sequencing-based methods were utilised to decipher the novel communities (from water samples taken over a two-year period). They concluded that such reservoirs could behave as natural fermenters for the bioconversion of CO_2 and H_2 to CH_4. However, engineered fermenters are still the state of the art. One of the limitations of commercial fermenters is achieving an appropriate mass transfer enabled via overcompensated mixing. Such cases would lead to excessive energy use for the fermenter's operation. Singh et al. investigated the significance of intermittent mixing by employing a helical ribbon impeller in the digester for the production of biogas [6]. They determined that volatile fatty acids (VFA) accumulation in addition to the specific power consumption by the digester considerably reduced, leading to an enhanced biogas yield as a result of intermittent mixing.

Beyond biogas, Robazza et al. investigated the anaerobic co-fermentation of the pyrolysis aqueous condensate and syngas to produce L-Malate, an important high-value biochemical [7]. Their work showed the potential of simultaneous detoxification as well as valorisation. Pinto et al., on the other hand, optimised an open microbiome towards biobutanol production as opposed to pure culture-based fermentation [8]. The problem with identifying multiple fermentation by-products was correlated to the highly diverse microbial community due to the use of an undefined microbial inocula (via 16S rRNA amplicon analysis).

VFAs are key intermediates in AD, which are of high value when obtained in high concentrations. Therefore, these products present a potential opportunity. Highlighting the importance of VFAs in a biorefinery, Nzeteu et al. presented a review on the potential valorisation routes of waste biomass to VFAs, followed by key products such as bioplastics and other high-value biochemicals [9]. The potential is truly unique, as many fossil-fuel-derived chemicals can be replaced via the VFA-based biorefinery routes. While Nzeteu emphasized this, Nagarajan et al.'s review on the production facets of VFA added another dimension to the Special Issue. The production of VFAs have to be intensified to be able to make the valorisation pathways economically viable. Nagarajan et al. discussed these perspectives in light of biohydrogen and VFA production by critically analysing the available pilot-scale state-of-the-art examples [10].

Overall, the Special Issue can be viewed as having three sections: (i) progressing the understanding of anaerobic digestion across disciplines; (ii) highlighting the potential for new products via anaerobic digestion; and (iii) identifying the suitable valorisation pathways for enabling a circular bioeconomy via VFAs. These 'nature-based solutions' inline with COP27 takeaways reassure us that the scientific community is progressing in the right direction towards achieving net neutrality. The leap to 'achieving net zero' from the current 'transition' mindset however still requires significant efforts from political, scientific, and commercial stakeholders to ensure financial viability.

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