Integrating Experimental Insights into Process Models for Circular Bioeconomy Systems Analysis

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The circular bioeconomy demands biorefining systems that are not only economically viable, but also resource-efficient, adaptable, and environmentally sustainable. Achieving this requires process models that capture the complexity of biological and chemical transformations across scales. However, many current process simulations rely on simplified representations that limit their ability to guide innovation in upstream design and system integration. Processes driven by complex microbial communities such as anaerobic digestation and other waste valorization bioprocesses are particularly challenging due to intricate biological mechanisms.

In this work, we present modeling approaches that integrate mechanistic models such as reactor dynamics and mass and energy balances, and experimental data including that from omics approaches, into broader process simulations. We presenta case-studies for anaerobic digestion and methane biofiltation. We incorporate experimental results from anaerobic digestion of lignocellulosic biomass into a biorefining techno-economic model, allowing us to evaluate the influence of process parameters and microbial communities into broader feasbility implication.

This integration enables dynamic exploration of how experimental parameters influence mass and energy balances, process feasibility, and downstream impacts. By linking lab-scale insights with system-scale analysis, this approach supports more robust process design, accelerates innovation, and promotes informed decision-making in the development of circular biomanufacturing systems.