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SYNGAS BIOMETHANATION: OVERCOMING MICROBIAL, REACTOR, AND PROCESS LIMITATIONS FOR A SUSTAINABLE ENERGY FUTURE

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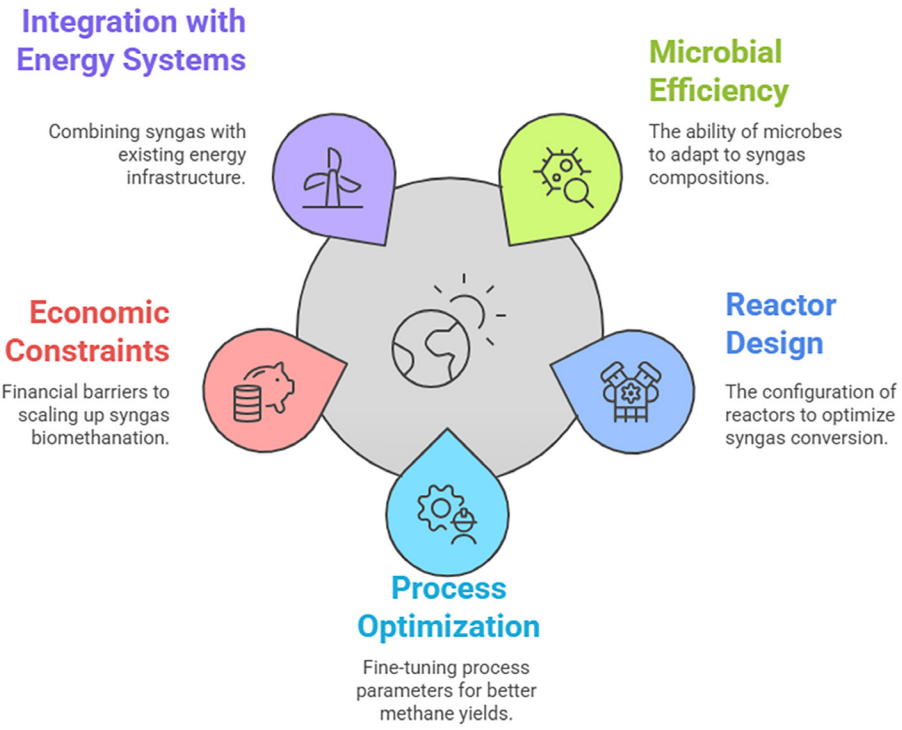
Abstract – Syngas biomethanation has emerged as a promising technology for converting synthesis gas (CO, H_2, and CO_2) into renewable methane, offering a sustainable alternative to fossil-based natural gas. However, despite significant progress at the laboratory scale, the transition to industrial applications remains hindered by multiple challenges spanning microbial efficiency, reactor design, process optimization, and large-scale feasibility. At the fundamental level, mass transfer limitations significantly constrain the biological conversion of syngas, with poor gas-liquid diffusion of CO and H_2 affecting microbial metabolism. Moreover, the adaptation of microbial consortia to varying syngas compositions remains insufficiently understood, particularly regarding the dominant pathways under mesophilic and thermophilic conditions. Reactor design further exacerbates these challenges, with current configurations (continuous stirred-tank reactors, packed bed reactors, and membrane bioreactors) struggling to achieve efficient syngas conversion at high productivity rates. Process parameters such as temperature, H_2/CO ratio, and trace element supplementation also require fine-tuning to enhance methane yields while maintaining process stability. While small-scale experiments have demonstrated promising results, scaling up remains a major hurdle due to economic constraints, reactor operational challenges, and the need for reliable feedstock supply. Additionally, the integration of syngas biomethanation with existing energy infrastructure, including powerto-gas technologies and anaerobic digestion systems, requires further investigation to ensure economic viability and process efficiency. This review systematically explores these multi-scale challenges, from bench-scale research to commercial deployment, highlighting key research gaps and potential strategies to accelerate the transition of syngas biomethanation from laboratory studies to industrial reality.

Keywords – Biomethanation; gas-liquid mass transfer; microbial adaptation; renewable energy; syngas fermentation; sustainable development goals (SDGs); waste-to-energy



Challenges in Syngas Biomethanation