Scaling and Optimizing HUMs for Enhanced Methanation in Sustainable Industrial Applications

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The project focuses on advancing the development, scalability, and application of Hybrid Ultramicroporous Materials (HUMs) as transformative materials for sustainable industrial applications. HUMs, known for their exceptional CO_2 adsorption and separation capabilities, will be engineered and combined with advanced metal oxides to enhance their catalytic performance, particularly for CO_2 methanation and other chemical processes. The project will pioneer solvent-free synthesis methods that align with green chemistry principles, thereby reducing environmental impact and operational costs.

Building on the achievements of the previous phase, this project will focus on scaling up HUMs synthesis to pilot-scale levels, with a specific emphasis on achieving consistent material quality and process efficiency. A key aspect of this phase will involve shaping HUMs through for example pelletization and tabletting, which will facilitate their handling and application in industrial settings. The previously developed methanation reactor will be further optimized to accommodate these larger-scale materials, ensuring that the enhanced catalytic properties of HUMs are fully utilized under industrially relevant conditions. Detailed studies will explore the integration of HUMs with doped metal oxides to improve selectivity and durability in catalytic reactions. This combination is expected to lead to significant advancements in CO_2 conversion efficiency and the development of versatile materials suitable for other high-value chemical processes.

One key advancement will be the implementation of process optimization and mapping techniques to fine-tune the synthesis parameters, reactor designs, and operational conditions. This will ensure that the scaled-up processes maintain or exceed the performance metrics observed in preliminary studies. A new focus will also be placed on validating the durability and reusability of HUMs-based catalysts through long-term testing under various operational scenarios. These efforts aim to bridge the gap between laboratory successes and real-world industrial applications.

Another major component of this phase is a comprehensive life cycle analysis (LCA) to evaluate the environmental and economic benefits of solvent-free synthesis methods. The LCA will also consider the broader impacts of deploying HUMs-based technologies in industrial settings, comparing them against traditional carbon capture and utilization methods.

Globally, industrial CO_2 emissions reached approximately 36.8 billion metric tons in 2022, with sectors like energy and manufacturing contributing the largest share. Addressing these emissions requires innovative solutions such as CO_2 capture and utilization technologies. By advancing HUMs and their applications, this project aims to contribute to global decarbonization efforts while positioning AUB as a leader in sustainable material research. This stage will capitalize on prior achievements to enhance the university's research capabilities, provide opportunities for knowledge transfer, and strengthen its commitment to sustainability and net-zero initiatives. The outcomes will include not only technical advancements but also significant contributions to education and capacity-building initiatives at the American University of Beirut (AUB).