Integrated Direct Air Capture and Conversion Using Porous Organic Polymers for Efficient and Scalable Carbon Utilization

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Fossil fuel combustion releases vast amounts of CO_2, contributing to over 8 million premature deaths annually, more than those caused by smoking, by intensifying respiratory illnesses, heart disease, and climate-related disasters. While Direct Air Capture (DAC) holds promise for mitigating these effects, most current systems remain expensive, inefficient, and energy demanding. The purpose of this study is to develop and evaluate two advanced Porous Organic Polymer (POP) platforms: one for highly efficient CO_2 capture and another for electrochemical CO_2 conversion into formic acid, a vital hydrogen carrier. The first system features a benzene-based polymer post-synthetically modified with amine groups to enhance direct air capture performance. This modification increased CO_2 uptake by 153%, while maintaining a high surface area of 899 m^2/g and excellent thermal stability, ultimately doubling DAC efficiency and improving real-world scalability. To build upon this breakthrough and to further utilize the captured CO_2, a porphyrin-based POP was developed and then metalated with indium, bismuth, and tin catalysts. This optimized system demonstrated remarkable faradic efficiencies of 73% in a flow cell and 65% in an H-cell, alongside a low onset potential of 0.6 V, substantially reducing energy demands and reducing the cost by 70-90%. By integrating efficient CO_2 capture, conversion, and formic acid storage into a single system, this work advances a practical and scalable path toward a circular carbon economy, reframing CO_2 not as a waste product, but as a valuable resource for clean energy and industrial sustainability.

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