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Towards Sustainable Ethene Production: Modified Fischer-Tropsch Synthesis from CO_2 and H_2

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Abstract

Ethene is a key base chemical at the foundation of numerous petrochemical value chains. However, its conventional production *via* steam cracking involves high fossil energy consumption and substantial CO_2 emissions. The *SynGas2Ethene* project addressed this challenge by investigating a modified Fischer-Tropsch synthesis (mFTS) process for the direct conversion of CO_2 and ‘green’ hydrogen into short-chain alkenes. Unlike classical FTS, which predominantly yields long-chain hydrocarbons, this approach emphasizes tailored catalyst and process design to selectively generate light alkenes.

Evaluating Ru- and bimetallic Ru/Fe-based catalysts for their performance revealed that the incorporation of a basic component is critical for enhancing alkene selectivity. Experimental studies in a laboratory-scale tubular reactor highlighted the influence of temperature, residence time, and feed composition on conversion and selectivity. Reaction conditions were optimized to maximize alkene yield, supported by detailed kinetic analyses, including determination of activation energies and rate constants. Aspen Plus™ simulations incorporating reactor kinetics provided the foundation for scenario analysis and virtual scale-up. To guide future process design, life cycle assessments (LCA) were conducted to evaluate environmental impacts, with a particular focus on global warming potential (GWP). Although current process configurations are less ecologically favorable than steam cracking, the analysis shows that, under idealized conditions using renewable hydrogen and CO_2 from direct air capture (DAC), a *cradle-to-gate* carbon-negative ethene process is achievable.

Embedding mFTS into a broader carbon capture and utilization (CCU) infrastructure supports the development of closed carbon cycles, from renewable syngas production to downstream separation and integration with olefin polymerization. This system-level approach highlights the strategic integration of reaction engineering, separation technologies, and renewable energy systems. These findings contribute to the design of integrated value chains for circular carbon utilization in the process industry. Furthermore, the simulation framework developed in parallel enhances process understanding by linking experimental data with predictive digital twins, offering a scalable pathway from laboratory-scale insights to industrial implementation. This integrated approach strengthens the role of ethene as a sustainable carbon vector in a future net-zero economy.