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Closing the Carbon Loop: CO_2-to-Fuel via Hybrid Catalysis

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With the European Green Deal, the EU aims to achieve a climate-neutral economy by 2050. The transport sector accounts for around 25% of greenhouse gas emissions (as of 2019) and therefore plays a key role in decarbonization. While electrification is a promising solution for private transport, alternative approaches are required for sectors that are difficult to electrify, such as heavy-duty transport, shipping, and aviation. One promising option is e-fuels - synthetic liquid energy carriers produced exclusively from renewable electricity, CO_2, and water. By utilizing captured CO_2 as a carbon source, e-fuels also demonstrate the potential of Carbon Capture and Utilization (CCU) technologies to close technical carbon cycles and, in the long term, to enable net CO_2 removal from the atmosphere when biogenic or atmospheric CO_2 sources are used. These fuels can be utilized in existing combustion engines and infrastructures and may enable a substantially reduced greenhouse gas footprint when renewable energy sources are employed.

The EU project E-TANDEM aims to demonstrate the direct and efficient production of a novel oxygen-rich e-fuel for use in shipping and heavy-duty transport. The process relies exclusively on CO_2 as the carbon source and renewable electricity as the energy source. The project focuses on the production of long-chain ethers in the middle-distillate range, exhibiting diesel-like fuel properties and the potential for reduced soot emissions. E-TANDEM seeks to validate a novel hybrid catalytic production pathway at Technology Readiness Level (TRL) 4.

To produce the fuel, an innovative hybrid process is being developed that combines three catalytic sub-processes: 1) High-pressure electrocatalytic syngas production from CO_2 and water, 2) Tandem catalytic conversion of the e-syngas, consisting of a heterogeneous Fischer-Tropsch synthesis focused on olefin production and a homogeneous hydroformylation process to produce long-chain alcohols, 3) Subsequent conversion of the long-chain alcohols into long-chain ethers in the middle-distillate range.

These long-chain ethers can be used directly as fuels or as blend components and offer potential advantages in combustion behavior while maintaining compatibility with existing fuel infrastructures. In addition to the technical development pathway, the project also addresses fuel formulation and a comprehensive evaluation of the physicochemical fuel properties, including viscosity, density, ignition quality, and boiling behavior. Furthermore, material compatibility with commonly used fuel and engine system materials such as elastomers, metals, and sealing materials will be investigated, alongside the assessment of potential fuel–system interactions including corrosion, deposit formation, and material aging. Ecological and socioeconomic assessments will complement the technological evaluation.