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Environmental Assessment of CO₂-based Pathways to Short-Chain Alkenes

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The transition toward defossilised chemical value chains requires resilient processes for the production of carbon carriers, fuels, and platform chemicals independent of fossil feedstocks. Short-chain alkenes are among the most important building blocks of the chemical industry, yet their current production relies predominantly on fossil naphtha and light hydrocarbons. Fischer–Tropsch-type CO₂ hydrogenation offers a promising route to close carbon cycles by converting captured CO₂ and renewable hydrogen into olefinic products. However, the environmental performance of such pathways depends strongly on hydrogen sourcing, electricity supply, process efficiency, and integration into future carbon capture and utilization infrastructures [1].

This contribution presents a life-cycle-based environmental assessment of catalytic CO₂ hydrogenation toward C₂–C₆ alkenes using ruthenium-based catalysts. Experimental data from laboratory-scale investigations were combined with reactor and process simulations to derive mass and energy balances for technically relevant process scenarios. These data served as the basis for a cradle-to-gate life cycle assessment benchmarked against conventional fossil-based olefin production.

The results demonstrate that the environmental impact of CO₂-based alkene production is currently dominated by the energy demand associated with hydrogen generation. Scenarios based on today's electricity mixes and industrial CO₂ sources exhibit higher global warming potentials than established fossil-based pathways. In contrast, scenarios relying on renewable electricity, green hydrogen, improved process efficiency, and closed carbon cycles reveal substantially improved environmental performance. Under favourable conditions, CO₂-based alkene production can approach or even outperform conventional fossil-based routes in terms of global warming potential (Figure 1).

Sensitivity analyses identify hydrogen sourcing, electricity supply, product selectivity, and heat integration as key parameters for reducing environmental impacts. The results demonstrate that catalytic development must be coupled with process design, energy system integration, and life-cycle assessment to unlock the full potential of CO₂ utilization for resilient and defossilised chemical production [2].

References

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[2] Liese, T.; Graef, I.; Heck, F.; Hagen, V.; Müller, T. E. *Produktion von Ethen aus Recycleströmen und erneuerbaren Kohlenstoffquellen als eine nachhaltige und ökonomische Route zu Grundbausteinen der chemischen Industrie*; Technische Informationsbibliothek: Hannover, 2025.

Figure 1: Comparison of fossil and alternative pathways toward ethene production, including indicative carbon footprints of key intermediates and products (kg CO₂-eq. per kg product).