

Research Project #10

Engineering CO₂ Electroreduction to Value-Added Products with Tailored Anion Exchange Membranes (IET-1 & PGI-6)

Motivation and State of the Art

The electrochemical reduction of CO₂ (eCO₂R) is a promising technology for producing value-added products (e.g., carbon monoxide, formic acid, methanol, ethanol, ethylene) required for a circular, renewable-based economy, while simultaneously mitigating further CO₂ emissions by converting the most significant anthropogenic greenhouse gas into a valuable feedstock. To improve energy efficiency and selectivity toward the target product, technological improvements in key components, such as electrodes, catalysts, cells, and membranes, are fundamental. Anion exchange membranes (AEMs) are of special importance in the eCO₂R by enabling operation in alkaline media, allowing the use of non-precious metal catalysts, and suppressing the competing hydrogen evolution reaction (HER).¹ However, the variety of AEMs remains limited, as their development is largely controlled by industrial companies, where limited knowledge sharing slows innovation in membrane research. ***This project focuses on synthesizing new polymers for dual applications: As ionomers in gas diffusion electrodes and as AEMs in the eCO₂R to carbon monoxide.***

Key research goals for the project

WP1: *Identify and synthesize monomeric scaffolds.*

Based on existing studies on the alkaline stability of cationic groups (e.g., Marino & Kreuer²), suitable monomer structures will be identified and partially synthesized. The focus will be on potential ionic conductivity and chemical stability.

WP2: *Polymerization of monomeric units.*

The identified monomers will be polymerized and optimized with respect to functionalization and molecular weight distribution, as molecular weight strongly influences the stability.³

WP3: *Membrane and GDE fabrication.*

Membranes and GDEs will be produced from the developed polymers using appropriate techniques (e.g., casting, spray coating). Parameters such as thickness and homogeneity (membrane), catalyst loading, and ionomer content (GDE) will be optimized.

WP4: *Application of fabricated gas diffusion electrodes and AEMs in the eCO₂R to carbon monoxide: Evaluation of key performance indicators.*

The fabricated GDEs and AEMs will be tested in dedicated setups to evaluate their performance (e.g., Faradaic efficiency, cell voltage, energy efficiency).

WP5: *Analysis of structure-performance correlation.*

The developed membranes will be analyzed using structural characterization methods (e.g., AFM, SEM, TEM, SAXS). The aim is to identify structural features (microphase separation, ion density, morphology) that contribute to high electrochemical performance. Both pristine and post-test membranes will be examined to determine possible degradation effects.

Gaining expertise and career prospects via the project

The proposed project will benefit from the synergy of two institutes within Forschungszentrum Jülich working on a project that builds expertise in organic and inorganic synthesis, polymer chemistry, electrochemistry, and material chemistry. PGI-6 brings its expertise in inorganic/organic synthesis, which is essential for WPs 1–2. IET-1 provides its expertise in electrochemistry and material chemistry for WPs 3–5. At IET-1, the research activities are further strengthened by hands-on experience in membrane fabrication and scaling, gained through direct involvement in industrial environments. The

established and successful collaboration between PGI-6 (Prof. Kögerler's group) and IET-1 highlights the effective synergy between both institutes. Prof. Kögerler, also serving as a group leader in RWTH Aachen (Institute of Inorganic Chemistry), will make available additional advanced instrumentation required for the project. Regular interaction between PGI-6 and IET-1 will expose the applicant to different methodologies, such as advanced spectroscopic and electrochemical characterization techniques, as well as membrane fabrication and upscaling strategies rooted in industrial practice. This interdisciplinary framework not only ensures high scientific output and publications in leading journals but also equips the applicant with the practical and strategic skills required to bridge academic research and industrial innovation in the field of electrochemical technologies.

Expected Outcomes & Impact

The anticipated outcome is a high-performance, long-term stable AEM specifically engineered for CO₂ to CO electrolysis. Furthermore, by combining molecular-level materials design with application-driven electrochemical validation, design guidelines will be developed. These guidelines will accelerate the development of next-generation membranes applicable to CO₂ electrolysis.

Location of the HITEC Fellow	Forschungszentrum Jülich, Institute of Energy Technologies - Fundamental Electrochemistry (IET-1), Director: Prof. Dr. Rüdiger- A. Eichel https://www.fz-juelich.de/en/iet/iet-1
Partners of the HITEC Project	Forschungszentrum Jülich, Peter Grünberg Institute – Electronic Properties (PGI-6), Director: Prof. Dr. Claus Michael Schneider, Partner: Prof. Dr. Paul Kögerler (https://www.koegerler.ac.rwth-aachen.de) https://www.fz-juelich.de/en/pgi/pgi-6
Specific requirements	Master's degree in chemistry, materials science, chemical engineering, or related field. Fluency in English is required; German proficiency is desirable.
For project-specific questions, please contact	Sven Sören Hartmann, IET-1, s.hartmann@fz-juelich.de Dr. Sergio Calvo, IET-1, s.calvo@fz-juelich.de

- (1) Lin, J.; Zhang, Y.; Xu, P.; Chen, L. CO₂ electrolysis: Advances and challenges in electrocatalyst engineering and reactor design. *Materials Reports: Energy* **2023**, *3* (2), 100194.
- (2) Marino, M.; Kreuer, K. Alkaline stability of quaternary ammonium cations for alkaline fuel cell membranes and ionic liquids. *ChemSusChem* **2015**, *8* (3), 513–523.
- (3) Hartmann, S. S.; Schalenbach, M.; Schestakow, M.; Eichel, R.-A. The effect of ionomer molecular weight on gravimetric water uptake, hydrogen permeability, ionic conductivity and degradation behavior of anion exchange membranes. *International Journal of Hydrogen Energy* **2025**, *151*, 150126.