



Global Climate & Energy Project
STANFORD UNIVERSITY

Nanostructured Copper Electrodes for Energy-efficient Conversion of CO₂ to Fuel

Investigator

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Objective

The goal of this project is to develop copper electrodes that are efficient catalysts for the reduction of carbon dioxide (CO₂) to fuel. Understanding how these catalysts work will help provide a clear strategy for developing other catalysts for sustainable fuel synthesis and identifying, for the first time, viable candidates for electrolyzer cathodes.

Background

Global energy demand currently exceeds 16 terawatts (TW) and is projected to more than double by 2050. Renewable energy resources are sufficient to meet this demand, but their intermittency necessitates the need for energy storage at massive scale. Chemical fuels are naturally suited to large-scale storage because of the high energy density of their chemical bonds. Carbon-based fuels possess a combination of high energy density, versatility and portability. One way to store renewable energy in the form of carbon fuels is to power a CO₂-fixing electrolytic device with a source of renewable electricity. Despite decades of research, however, an efficient CO₂-reduction catalyst suitable for long-term use in an electrolytic device has yet to be realized. This research will focus on electrodes that efficiently reduce CO₂ to formic acid at rates suitable for electrolytic synthesis. Formic acid has tremendous potential as a fuel for fuel cells and as a liquid hydrogen (H₂) carrier.^{1,2} Enabling the development of formic acid-producing electrolytic devices would constitute a major step toward closing the anthropogenic carbon cycle by producing carbon fuels more efficiently than what is required to extract or prepare them from fossil-derived sources.

Approach

This project aims to reveal the structural properties that are responsible for high CO₂-reduction efficiency. The work will use a recently discovered method for preparing Cu electrodes that are exceptionally active and stable CO₂ reduction catalysts. Specifically, Cu electrodes resulting from the reduction of thick Cu₂O layers require 0.5 V less overpotential than standard polycrystalline Cu electrodes to reduce CO₂ at a higher rate than H₂O. Furthermore, the CO₂ reduction activity of these electrodes is maintained for several hours whereas polycrystalline Cu deactivates within two hours under identical conditions. This research aims to elucidate the essential features of these catalysts that are responsible for efficient CO reduction, develop additional catalysts applying similar synthetic strategies and address the key issues for operation in an electrolytic device.

Structural characterization efforts will include a thorough high-resolution scanning electron microscopy study of electrodes (Figure 1) resulting from reduction of copper oxide (Cu₂O) layers prepared under different annealing conditions. An assessment will be made of the role of copper (Cu) nanoparticles in electrodes that exhibit high CO₂-reduction efficiency.

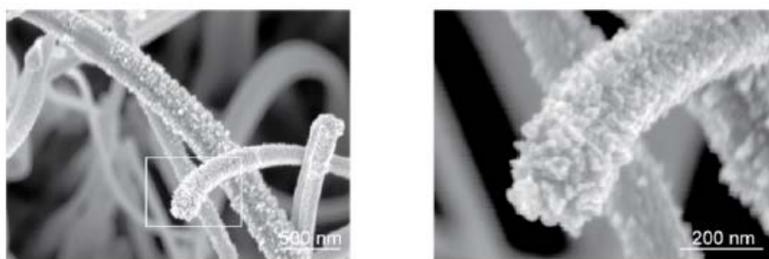


Figure 1: High-resolution scanning electron microscopy (SEM) images of a copper electrode after electrolysis.

Gas diffusion electrodes (GDEs) that are made of a porous hydrophobic layer in contact with catalyst particles will also be used to study these catalysts (Figure 2). This technique will allow new insights that cannot be gained through solution-phase studies; for example, how a nanostructured-catalyst surface might impact properties, such as the current density relative to solution-phase electrolyses at the same overpotential, product selectivity and product distribution under alkaline conditions.

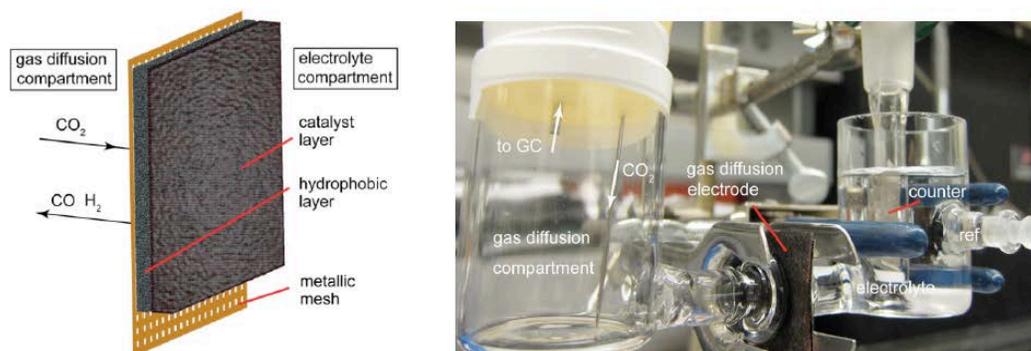


Figure 2: Schematic of a gas diffusion electrode (left) and cell design for evaluating gas diffusion electrodes (right). The catalyst layer containing nanostructured electrocatalysts faces the solution. CO_2 passes through the mesh and diffuses through the hydrophobic layer. Gaseous products diffuse out and are quantified by a gas chromatograph.

The successful development of an efficient formic acid-producing electrolyzer would constitute a major advance toward the development of electrolytic technologies that produce carbon fuels with higher energy density. The fundamental insights gained into the requirements for efficient CO_2 reduction by the proposed research will help provide a foundation that ultimately enables sustainable use of carbon fuels on a grand scale.

References

- [1] Rees, N. V.; Compton, R. G. *J Solid State Electr* **2011**, *15*, 2095.
- [2] Zhu, Y. M.; Ha, S. Y.; Masel, R. I. *J Power Sources* **2004**, *130*, 8.