Electrochemical Reduction of CO_2 to Formic Acid Using Gas Diffusion Electrode Technology

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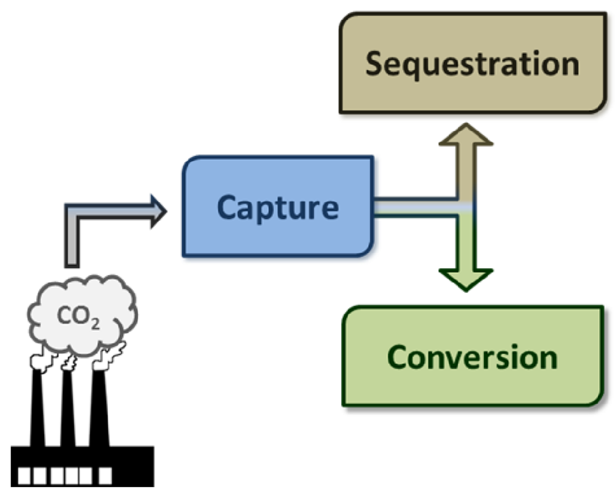
Problem

- New technologies are needed to provide solutions for conversion of captured CO_2 as part of a multifaceted approach for mitigation and maintenance of greenhouse gas production.

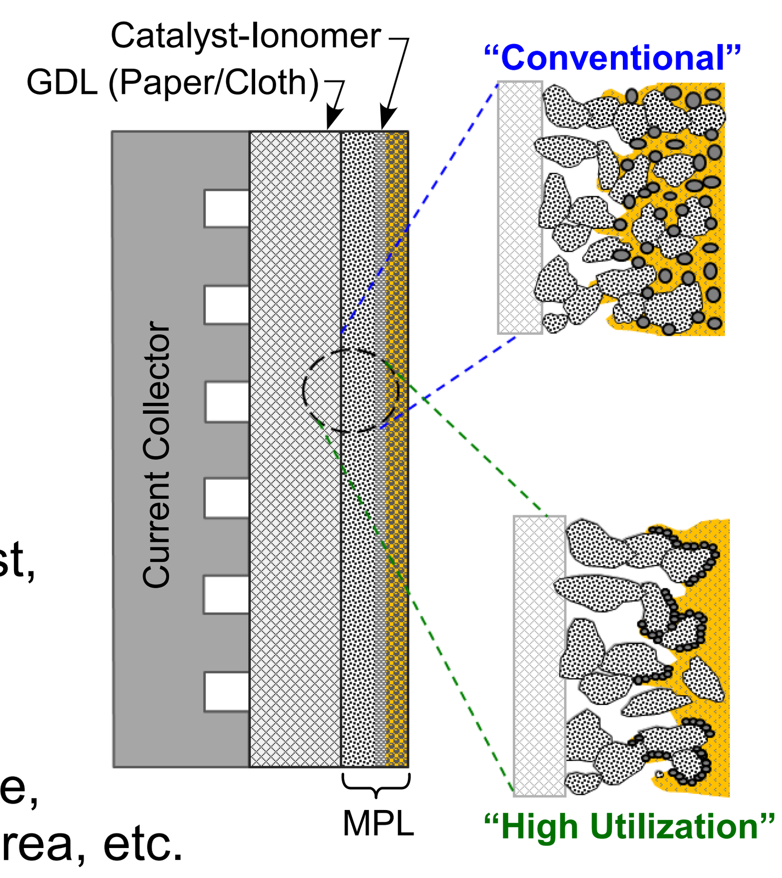


Technical Approach

- Gas diffusion electrode (GDE) based electroreactor for CO_2 conversion to formic acid (FA)
- Tin cathodic catalyst deposited by FARADAYIC® ElectroDeposition (ED)
- Commercial mixed-oxide anodic catalyst
- Exploit scalable, low-cost ED fabrication methods and MIT expertise in electrochemical analysis and reactor fabrication

High-Utilization Tin Catalyst via FARADAYIC® ElectroDeposition

- Conventional methods use catalyst dispersed in ionomer suspension
  - Significant fraction of catalyst isolated from electrical contact and/or far from gas phase
- FARADAYIC® ElectroDeposition intrinsically produces electrically active catalyst = "High Utilization"
  - Smaller mass of applied catalyst, but with significantly enhanced per-mass catalytic efficiency
  - Waveform tuning also enables control over catalyst particle size, microstructure, active surface area, etc.

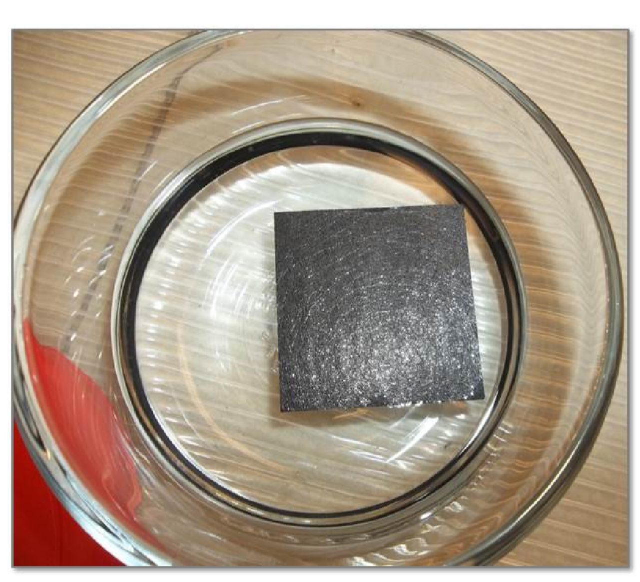


Catalyzed GDE Preparation

- Ionomer Application
  - Sigracet 39BC gas diffusion layer (GDL) with applied microporous layer (MPL)
  - Float 40mm × 40mm GDL square MPL-side down on ionomer dispersion in isopropanol

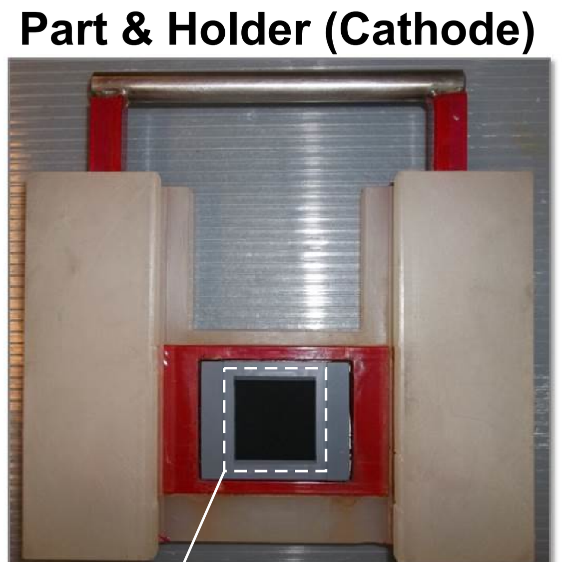
Front Side (MPL)

Reverse Side (Bare GDL)



- Sn ElectroDeposition – FARADAYIC® ElectroCell

Part & Holder (Cathode)



Ionomer-Treated GDL

Sn Sheet (Anode)

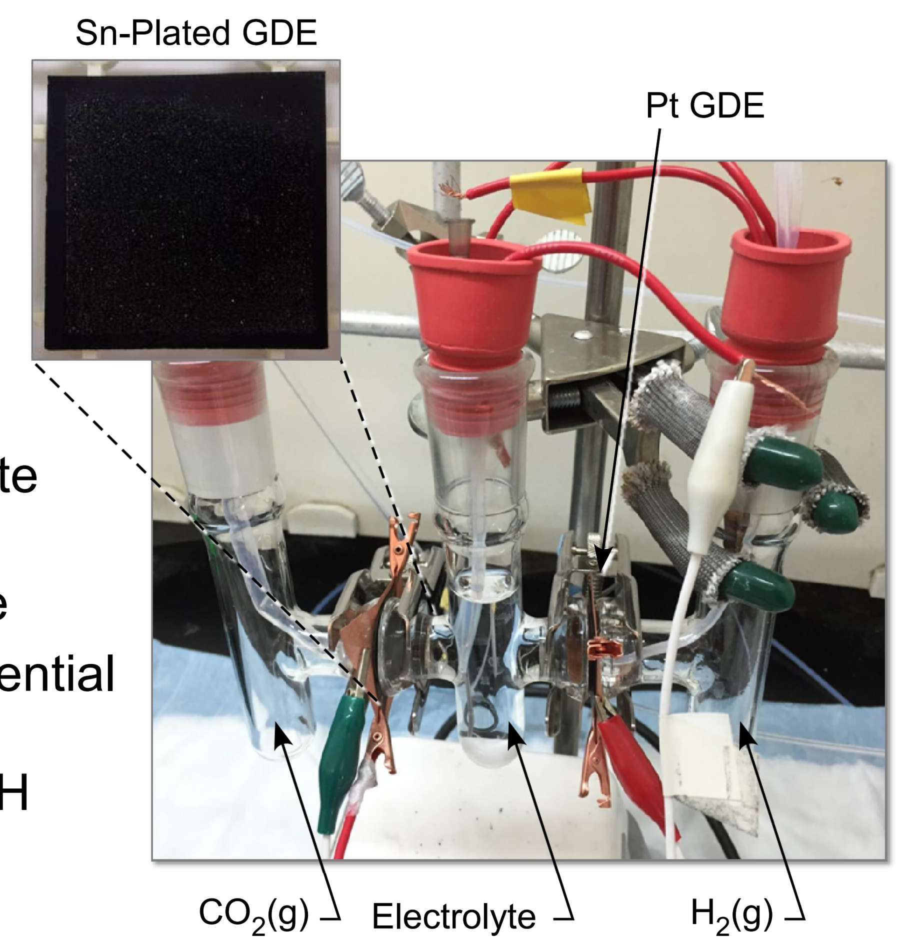
FARADAYIC® ElectroDeposition Cell

Tin Methanesulfonate Plating Electrolyte

Electrochemical Testing

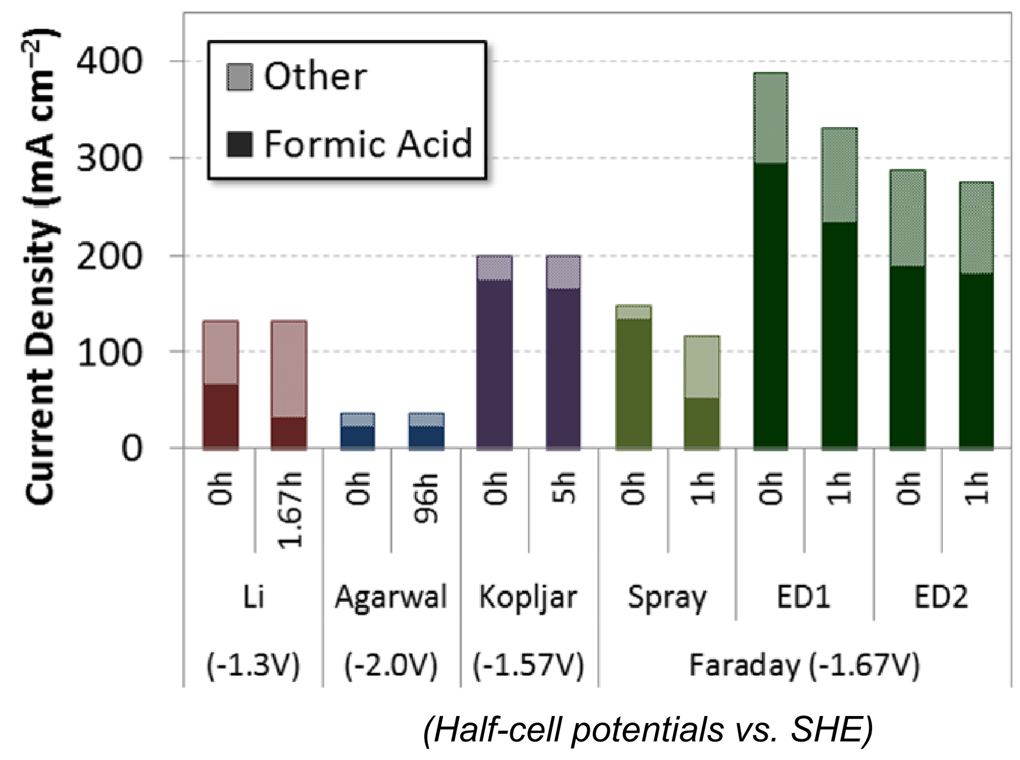
- Perform electrolysis at constant half-cell potential and measure:
  - Total response current
  - Formic acid production
    UV absorbance at 202 nm
- Apparatus Configuration
  - CO_2 flush gas behind GDE
  - Na_2CO_3 + Na_2SO_4 electrolyte (pH ~ 10)
  - H_2/Pt GDE counterelectrode used to reduce total cell potential
- Desired reaction:

$$CO_2 + 2H^+ + 2e^- \rightarrow HCOOH$$



Preliminary Results

- Preliminary **FARADAYIC® ElectroDeposition (ED)** samples show significantly increased total and FA-efficient current densities relative to conventional spray-coating method and literature data
  - $j_{total} \geq 275$ mA cm^{-2}
  - %FA ≥ 70%
- Favorable short-term catalyst durability
- Ongoing optimization
  - Ionomer loading
  - Sn electrocatalyst loading
  - Sn electrocatalyst ED parameters
  - GDE (GDL/MPL) parameters

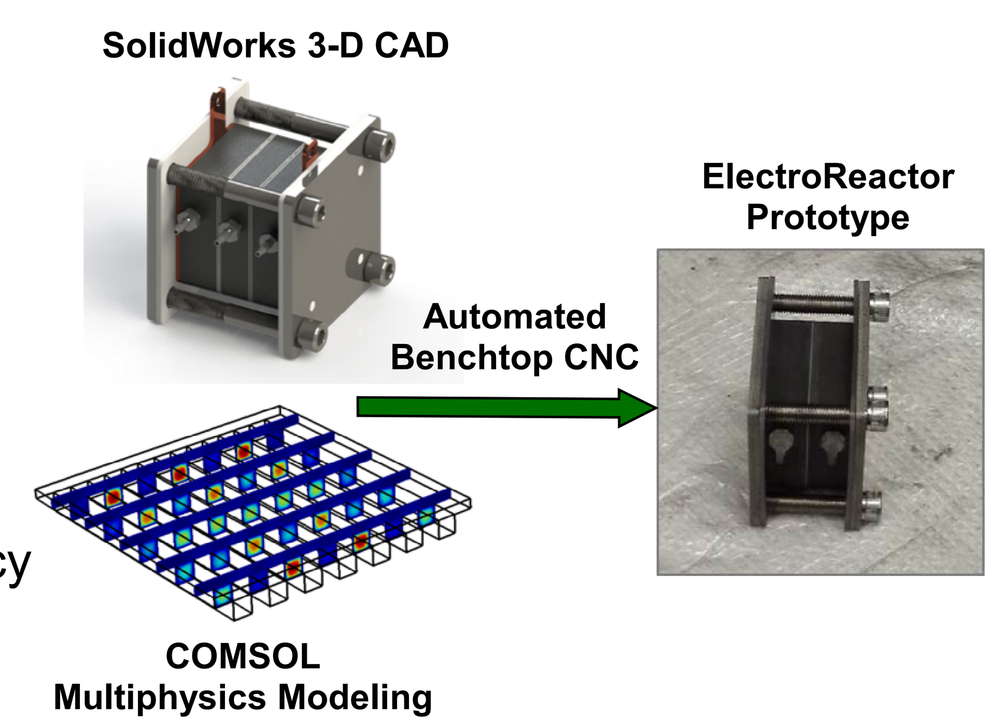


(Half-cell potentials vs. SHE)

Li and Oloman. J Appl Electrochem 35: 955, 2005
Agarwal et al. ChemSusChem 4: 1301, 2011
Kopljgar et al. J Appl Electrochem 44: 1107, 2014

Alpha-Scale Electroreactor

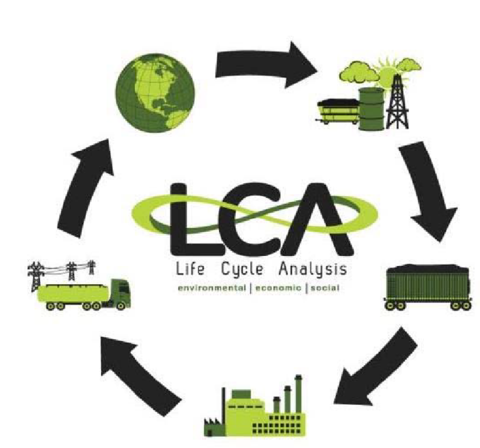
- Electroreactor design previously developed by MIT for $CO_2 \rightarrow CO$ conversion studies
- COMSOL modeling facilitates rapid design optimization to:
  - Increase energy efficiency
  - Minimize pressure drop
  - Maximize conversion



Economic / Scale-Up Analysis

Life Cycle Analysis

- Standard methodologies
  - EPA, DOE/NETL, etc.



Scale-Up Analysis

- Technology evaluation
- Market-entry / pre-commercial analysis