Electrochemical Reduction of CO_2 to Hydrocarbons in Microchannel Reactors with Ionic Liquids

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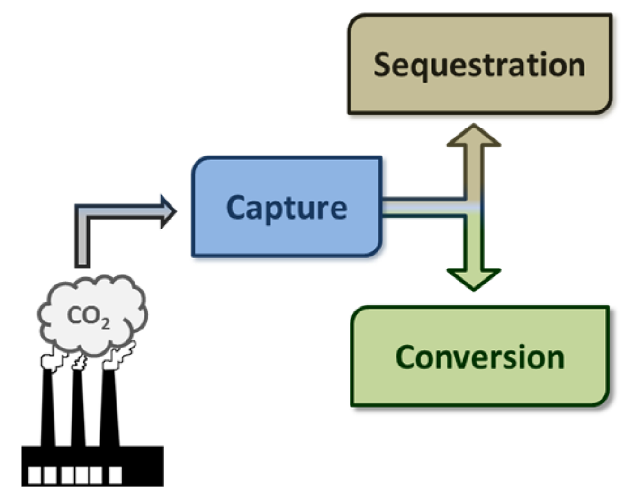
Problem

- Conversion of carbon dioxide to high-value products using low-quality heat sources requires development of efficient conversion methods capable of high rates.

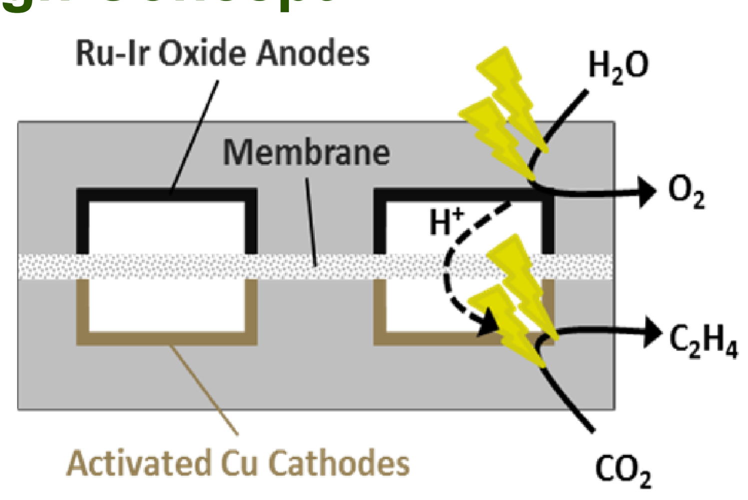


Technical Approach

- Stackable-plate electroreactor for CO_2 -> hydrocarbon (HC) conversion
- Novel activated-copper cathodic catalyst
- Commercial mixed-oxide anodic catalyst
- Exploit scalable, low-cost electrodeposition fabrication methods
- Power via Peltier-effect devices to exploit low-quality energy sources

Electroreactor Design Concept

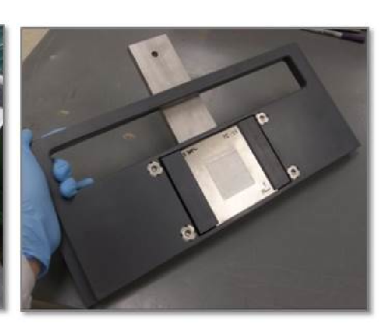
- FARADAYIC® Through-Mask Etching of reactor flow channels
- Cu cathodic catalyst
  - FARADAYIC® ElectroDeposition of copper
  - Optimized literature activation method
- Mixed metal oxide anodic catalyst
  - Standard application method: painting and thermal consolidation
  - Low overpotential for water oxidation



- Ion exchange membrane separator
- Wet ionic liquid electrolyte for enhanced CO_2 solubility and expanded electrochemical window

Copper Electrocatalyst Fabrication

- Deposit Cu on 4"× 4" SS304 panels
  - FARADAYIC® ElectroDeposition Cell
- Section panels into coupons
- Activate Cu by thermal oxidation and electrochemical reduction



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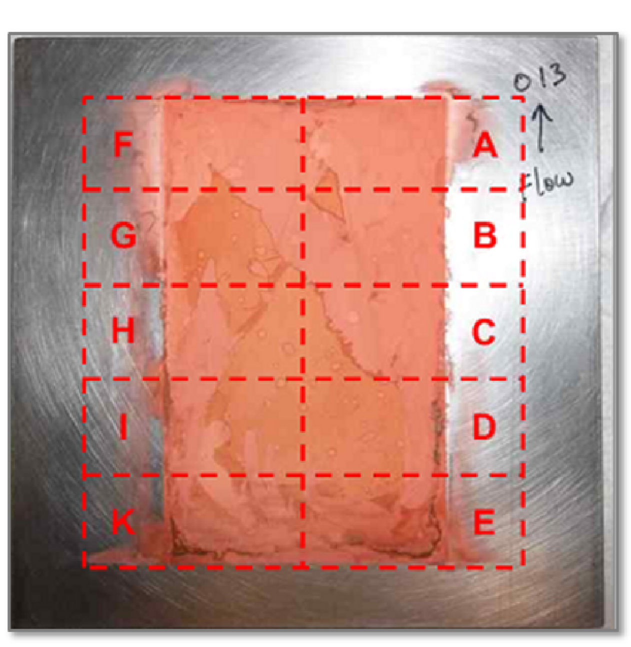
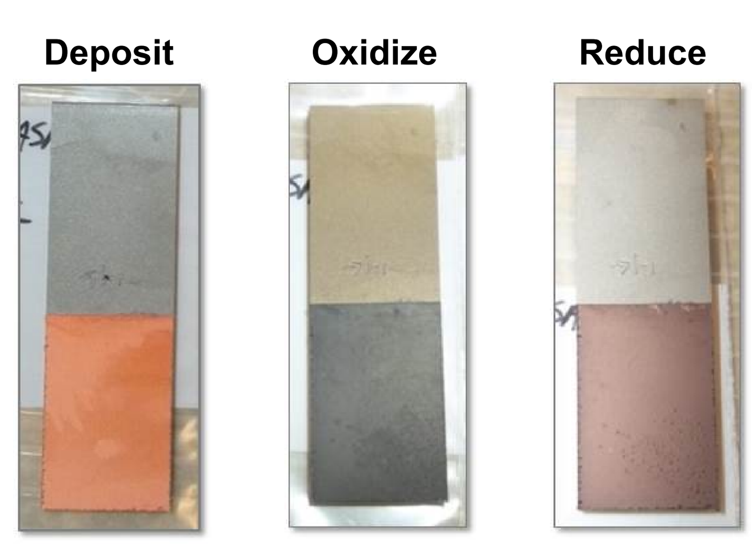




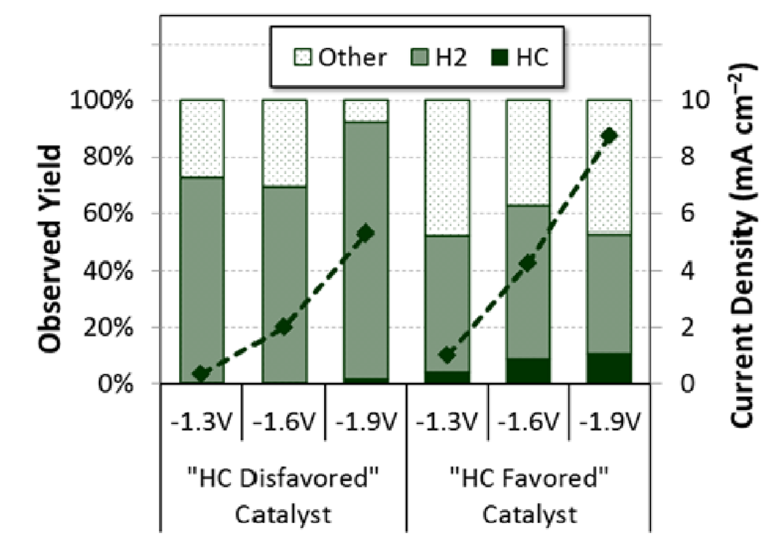
Electrocatalysis Performance Evaluation

- Electroanalysis (CV, CA, etc.)
- GC assay of product gases
- UV/Vis analysis of formate

- Optimization targets:
  - Hydrocarbon selectivity
  - Current density
  - Catalyst durability

Prior Results

- Constant-potential electrolysis in CO_2-saturated 0.5 M aqueous $NaHCO_3$
- Catalyst preparation influences selectivity and total current density
- Hydrogen evolution still appreciable

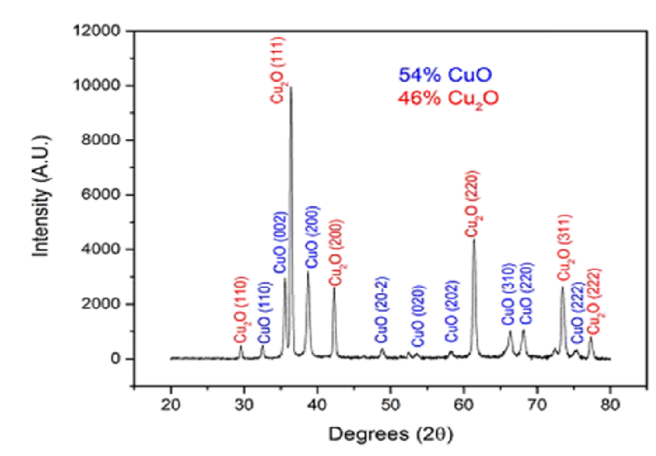


(All potentials vs. Ag/AgCl reference)

Electrocatalyst Materials Analysis

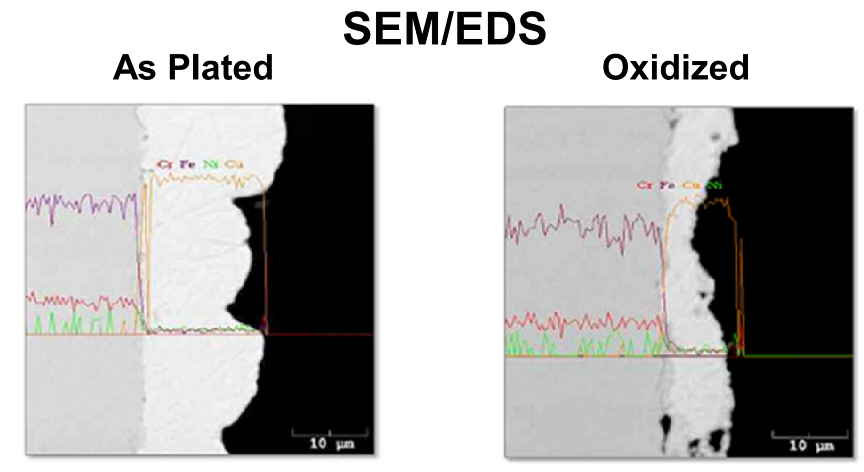
- XRD – Cu / Cu_2O / CuO content of films

XRD



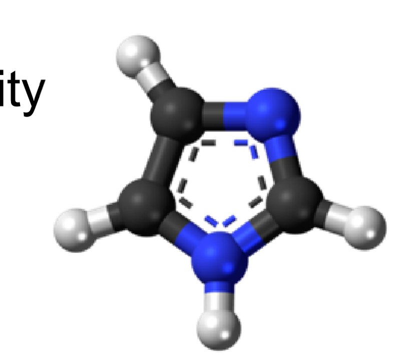
- SEM/EDS – Morphology and composition

SEM/EDS

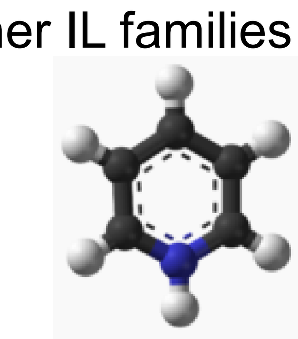


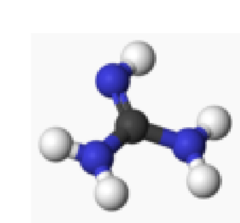
Ionic Liquid Selection/Evaluation

- Imidazolium family selected for Phase I experimentation
- Key properties include:
  - Physical: Rheology, CO_2 solubility, HC solubility
  - (Electro)chemical: Stability, Potential window



- Preliminary research on other IL families
  - Pyridinium
  - Guanidinium
  - Others





Thermal/Electrical/Economic Analysis

- Develop spreadsheet model for power, material, etc. inputs
  - Estimate stack performance, footprint, etc.

	A	B	C
1			
2	Assumed Overpotential Required:	0.5	V
3	Assumed Current Density	2	mA/cm^2 active area
4	Thermodynamic Potential Limit:	1.06	V
5	Electrons transferred per CO2 converted:	8	e/CO2
6	Coulombs to convert basis:	222.4559674	C/s
7	Power Required	347.0313091	W
8	Energy Consumed	347.0313091	J/s
9	Energy Consumed	29983.5051	kJ/day
10	Energy Consumed	8.328751418	kWh/day
11	Solar Panel Area Needed	17.35156545	m^2
12	Active Area of Catalyst	11.12279837	m^2
13	Est'd active channel wall part-perimeter	3.2	mm
14	Total channel arc length required	3475.87449	m

- Apply spreadsheet CapEx / OpEx model

Production Scales	EA/pCP	LRIP	MRCP
	OpEx		
	Part Geometry & Preparation		
Plates per Panel Row	3	4	4
Rows of Plates Per Panel	3	5	5
Panel Size	15"x15"	18"x24"	18"x24"
Stock Material Size	18"x18"	24"x24"	24"x24"
Metal cost per stock sheet	$38.97	$121.40	$121.40
Panels per sheet	1	1	1
Pre-Etch cuts per panel	2	1	1
Post-Etch cuts per panel	16	29	29

OpEx Outputs

Per-Plate Materials	*$15.08*
Per-Plate Active Labor	*$1.39*
Per-Plate Idle Labor	*$0.01*
Per-Plate Shipping	*$0.40*
Per-Plate Electricity	*$0.06*
Per-Plate Total	*$16.94*

CapEx Outputs

Rectification	*$580,430*
Tank(s) / Fixturing	*$40,000*