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Ultra-Low Temperature, Electrolytic CO_2 Valorization on Mars

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SPACE RESOURCES ROUNDTABLE

Project Team Members

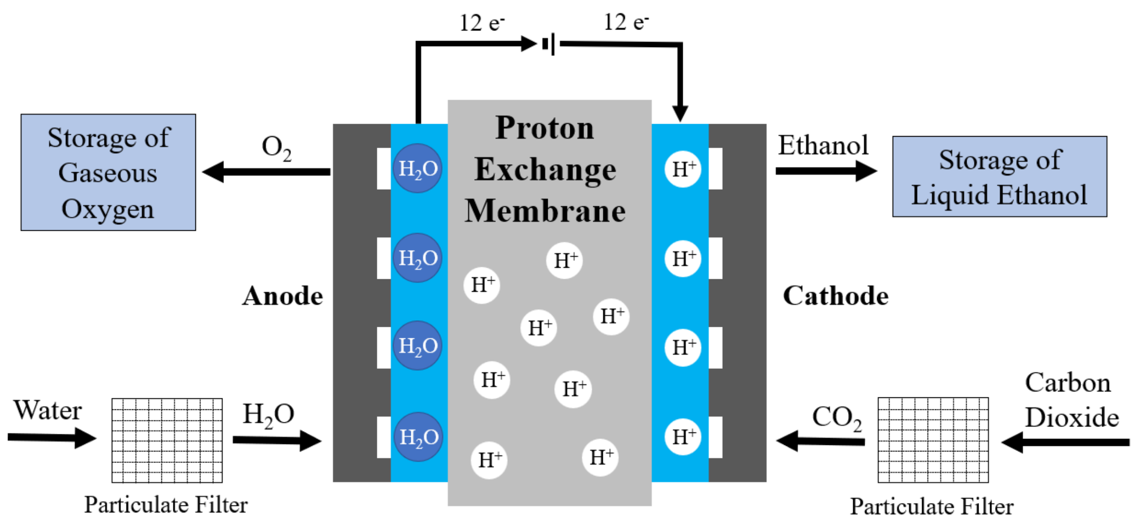
- **Faraday Technology, Inc.**
  - Alex Fertig
  - Guillermo Colon
  - Stephen Snyder
  - Katherine Lee
  - Tim Hall
  - Maria Inman

- **NASA Personnel**
  - Christopher Brady – NASA TPOC for Phase I STTR Project
  - Patricia Loyselle – NASA TPOC for Phase II STTR Project

- **University of Texas at San Antonio**
  - Shrihari Sankarasubramanian, Ph.D.

Bottom Line Up Front

- **Motivation:** enable the ability to produce high-value chemicals, feedstocks, and materials on site at Martian landing site
- Electrolysis of CO_2 in ethanol using electrochemical flow cell
  - Scalable platform, relatively low-cost operation
- Ethanol production is paired with oxygen generation – can be used in life support systems or as fuel oxidant
- Low maintenance required, enables long-term use on Martian surface
- Preliminary results show ability to produce ethanol at high energy-efficiency



Scheme for electrochemical flow cell for CO_2 reduction

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Background – CO_2 Electrolysis

- Reduce CO_2 using electrons for form variety of high-value products
  - Products include fuels, solvents, and feedstocks for further manufacturing

- Electrolytic cells create promising pathway to transitioning technology to commercial scale

- Complex reaction pathways create challenges for scaling up

Reaction			$E^{0'}$
$CO_2 + e^-$	→	$CO_2^{-\bullet}$	—1.90 V
$CO_2 + 2H^+ + 2e^-$	→	$HCOOH$	—0.61 V
$CO_2 + 2H^+ + 2e^-$	→	$CO + H_2O$	—0.52V
$CO_2 + 4H^+ + 4e^-$	→	$HCHO + H_2O$	—0.48 V
$CO_2 + 6H^+ + 6e^-$	→	$CH_3OH + H_2O$	—0.38 V
$CO_2 + 8H^+ + 8e^-$	→	$CH_4 + 2H_2O$	—0.24 V
$2H^+ + 2e^-$	→	H_2	—0.41 V

Standard potentials for CO_2 reduction.[1]

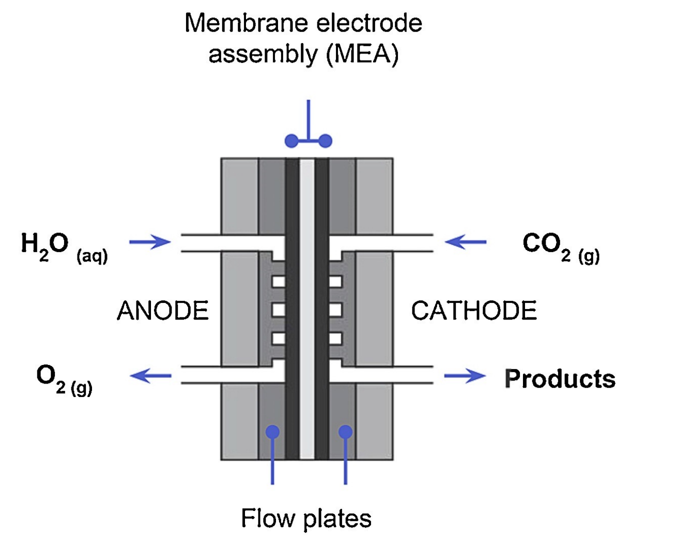
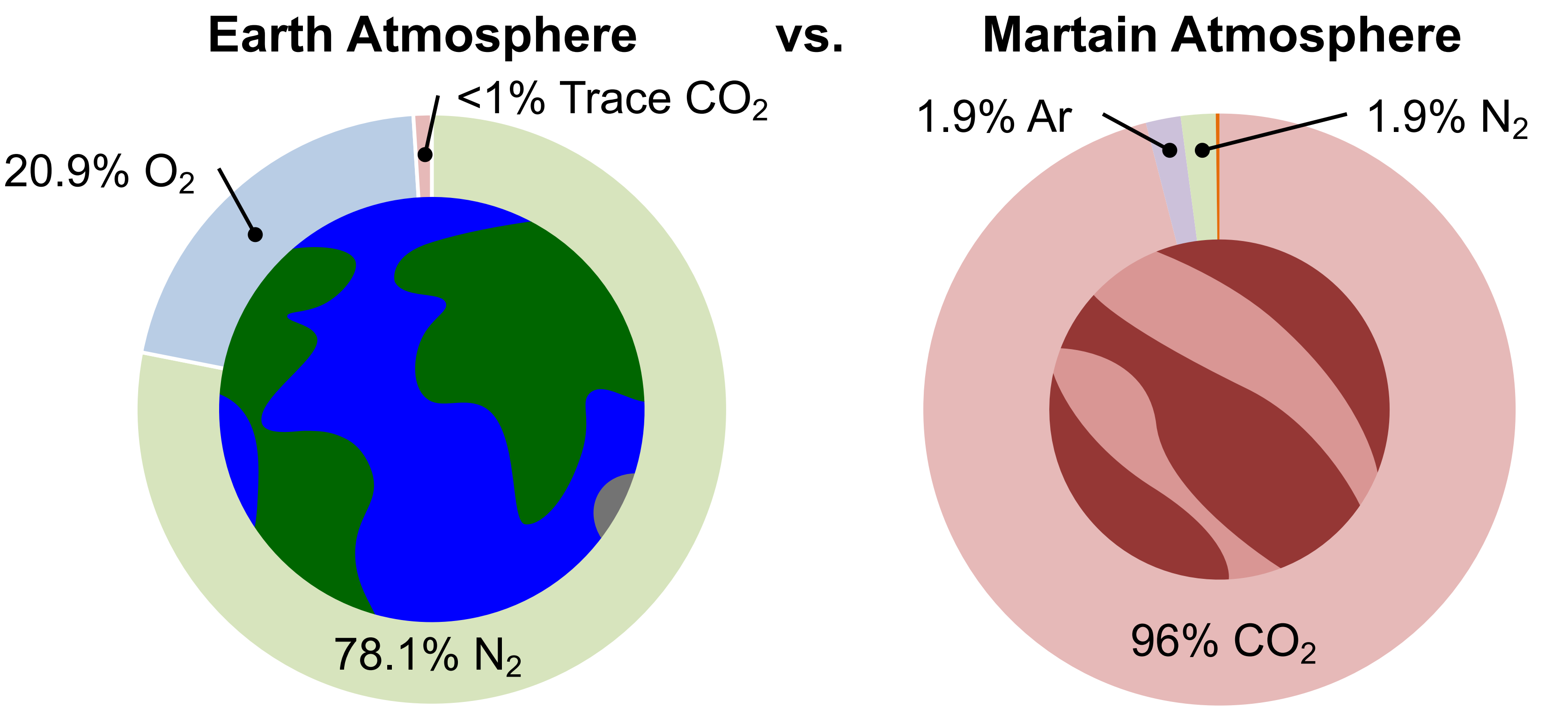


Diagram for gas-liquid phase electrolytic cell for CO_2 reduction into various products.[2]

1. Karamé, I., et al. Carbon Dioxde Chemistry, Caoture, and Oil Recovery, 2017
2. Weekes, D. M., et al., *Accounts Chem. Res.*, 2018, 51, 910-918

Background – Martian Atmosphere



- **Push to produce high-value chemicals with materials at Landing Site**
- High concentration of CO_2 on Mars is favorable to DAC
- Relatively low concentrations of other gases
- *Low temperatures and pressures*

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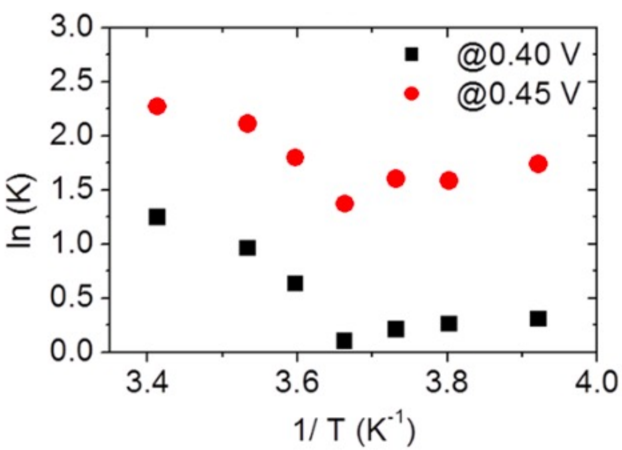
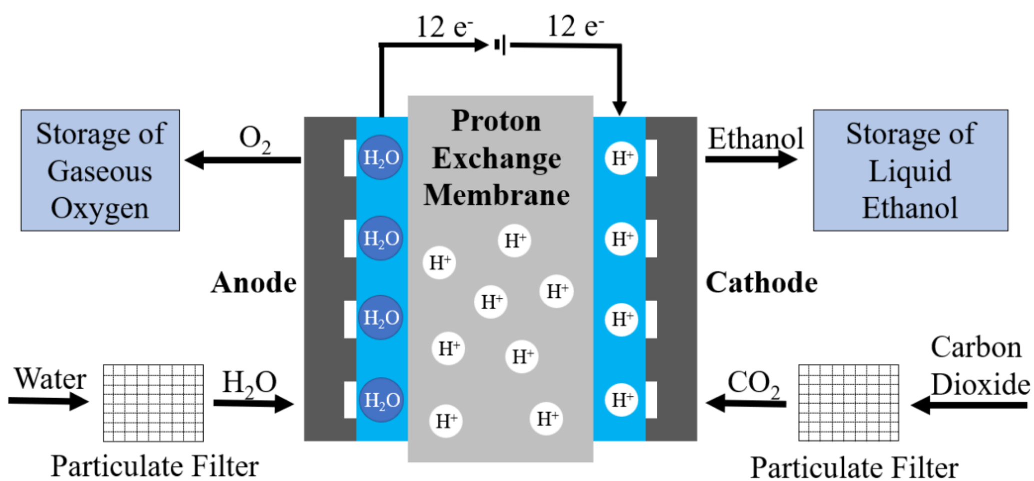
Ultra-Low Temperature Electrolysis

- **Benefits of low temperature electrolysis**
  - Ultra-Low temperature brine solutions enable Anti-Arrhenius kinetic behavior for CO_2 reduction
  - Gas-water crystalline structures can improve selectivity of CO_2 reduction reactions at electrode surfaces
  - Low temperatures and adsorbed CO suppress H_2 formation



Anti-Arrhenius kinetics of CO_2 reduction at low temperatures[3]



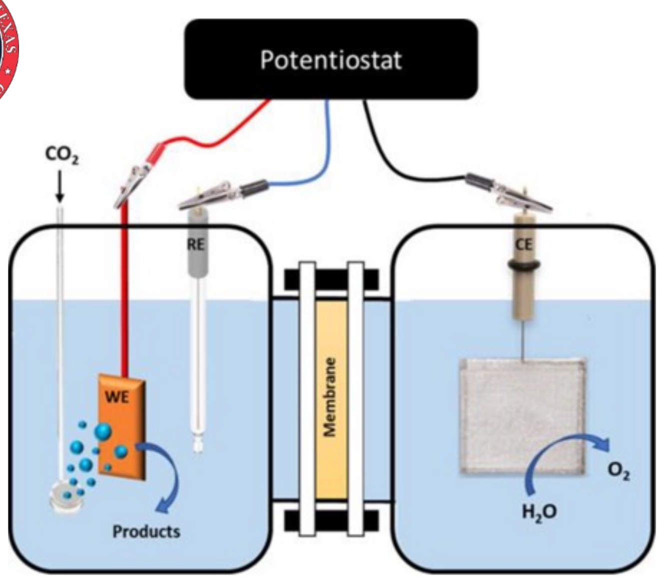
3. Sargeant, E., et al., *ACS Catal.*, 2020, 10, 14, 7464-7474

Program Overview

Goal: validate ability to electrochemically produce ethanol from atmospheric CO_2

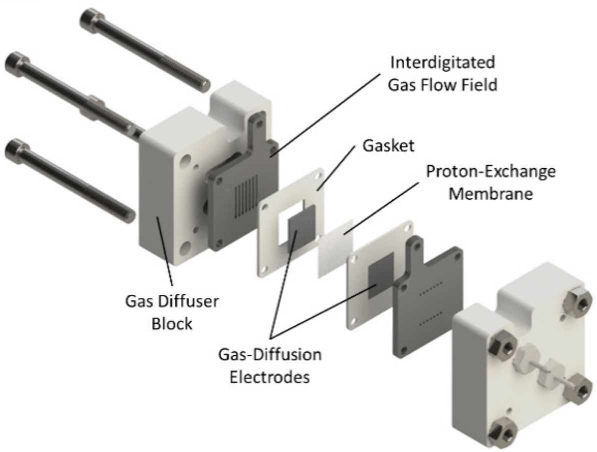
Parallel development to achieve overall goal:

1: Synthetic development of CO_2 reduction catalyst



Electrochemical H-cell for catalyst development[4]

2: Testing of electrochemical cell for ethanol production

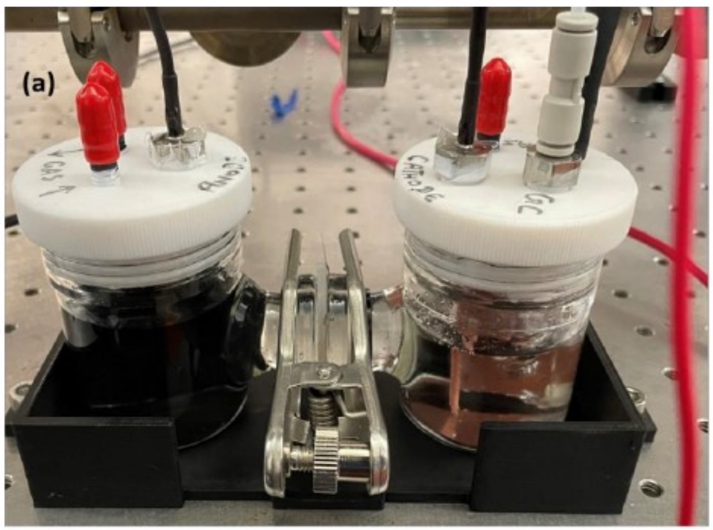


Gas diffusion cell for electrochemical production of ethanol

4. Hernandez-Aldave, S., Andreoli, E., *Catalysts*, **2020**, 10(6), 713

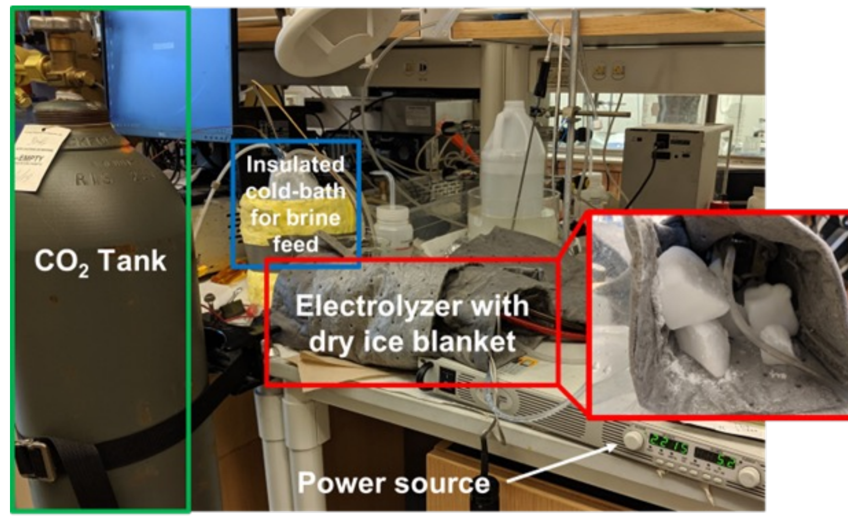
Cathode Development

Bench-top scale development of CO_2 reduction catalyst



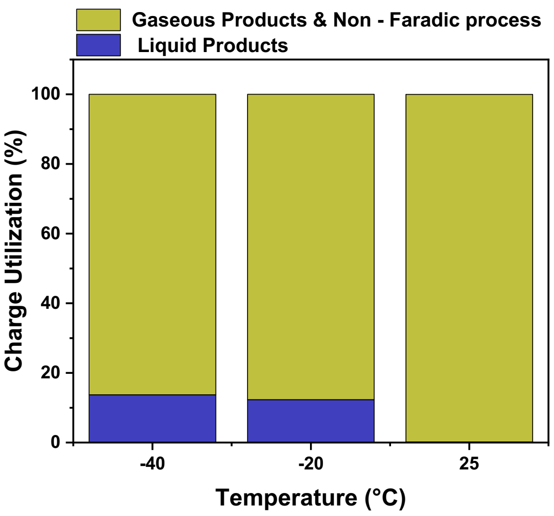
Bench-top scale H-cell for catalyst development

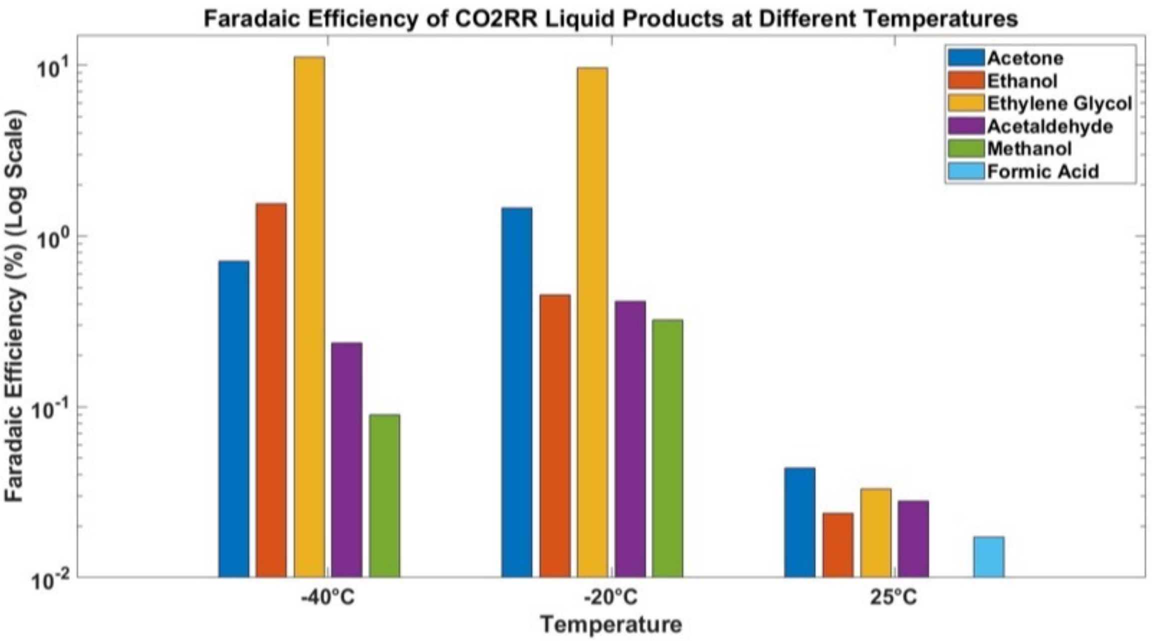
Demonstration of catalyst performance under ambient Martian conditions



Ultra-low temperature set-up at UTSA for CO_2 reduction

Product Optimization

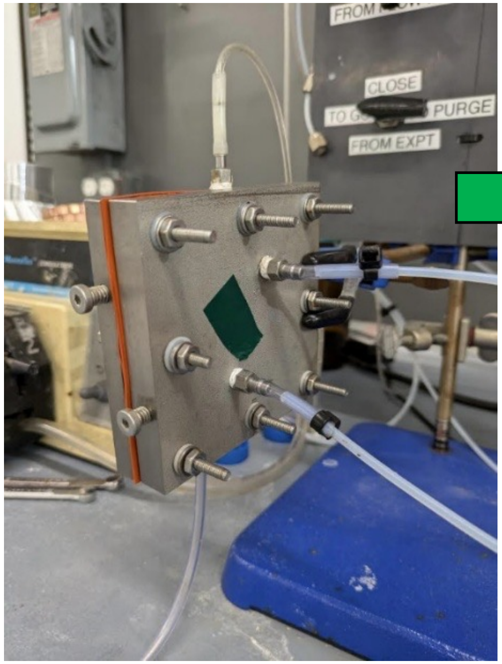




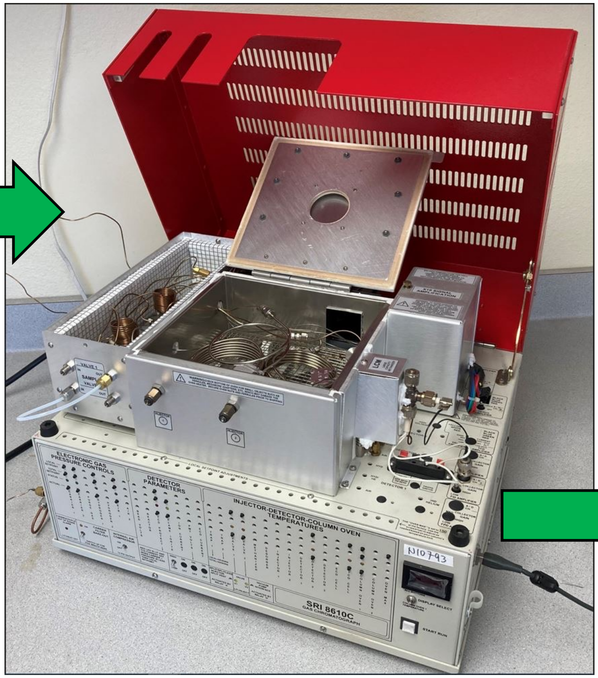
- Ratio of liquid product found to increase with decreasing temperature
- Faradaic efficiency for ethanol and other C_2 products increases with decreasing temperature

CO_2 Electrolysis

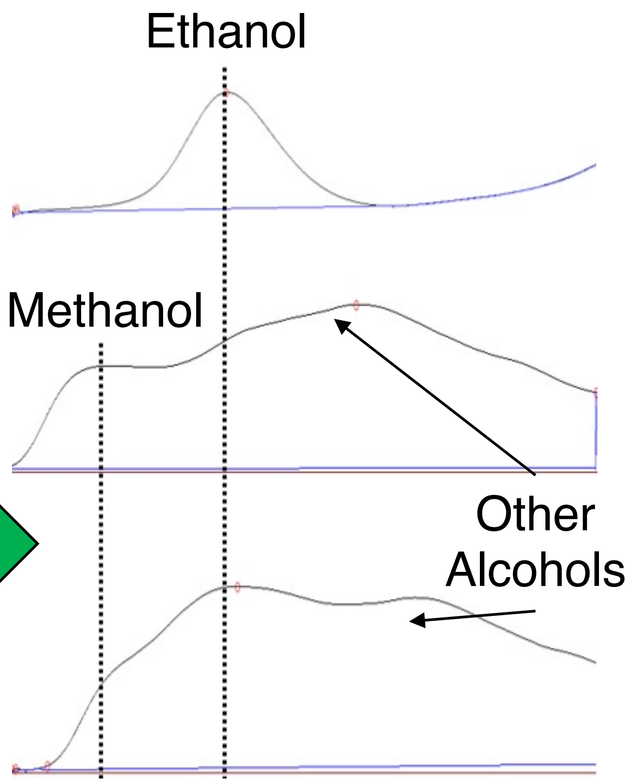
- Large scale testing of CO_2 conversion to ethanol at Faraday
- Achieved production rate of up to 2.2 grams of ethanol per hour; FE up to 87%
- Energy efficiency of 0.321 g EtOH per Whr



Electrochemical flow cell for CO_2 reduction.



Gas Chromatograph



Product Analysis at Faraday

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Testing under Simulated Martian Conditions

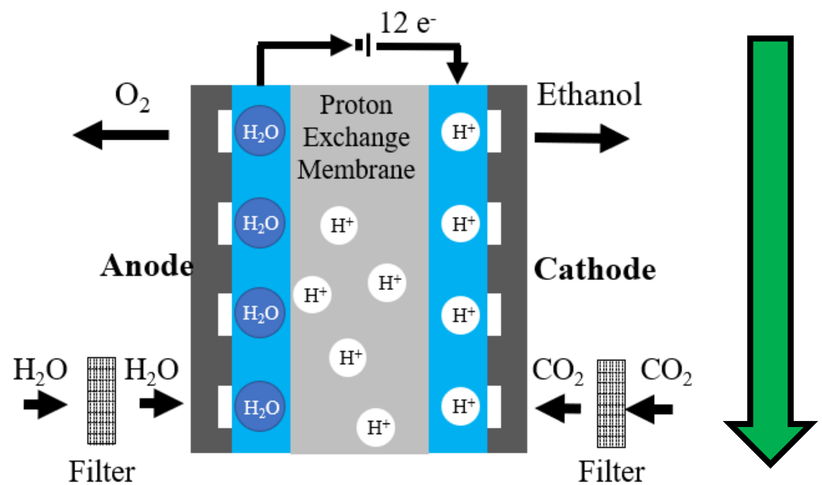
Validate cell performance at ultra-low temperatures

Experimental parameters:

- Current density
- Electrolyte flow rate
- Pressure of CO_2
- Pulsed vs DC currents

Metric	Phase II Target
Production Rate	20 g EtOH per hr
Faradaic Efficiency	80%
Energy efficiency	0.5 g EtOH per Whr

Testing against various gravitational vectors



Testing against various orientations with respect to gravity

Ensure production rate/efficiency do not vary in different orientations

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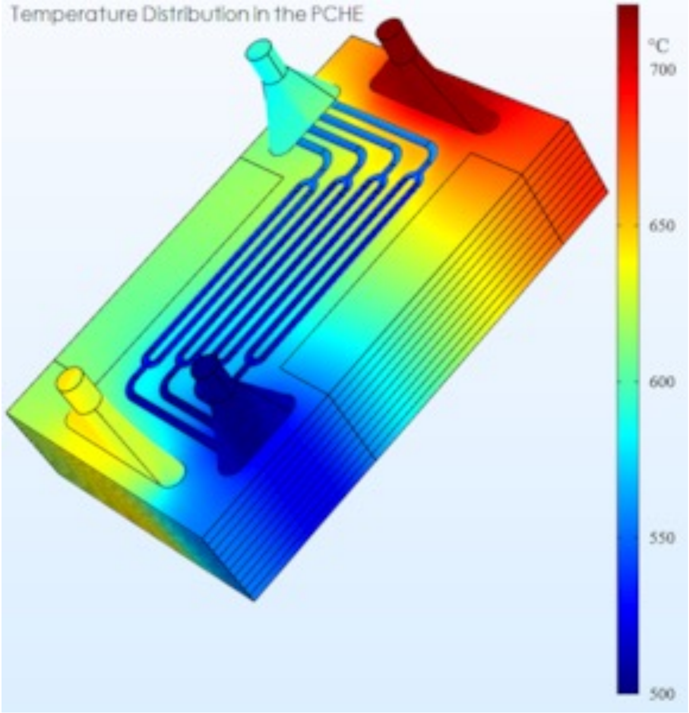
Improved Cell Design

Model flow of CO_2 and current through electrochemical cell using COMSOL software

Modeling software will be used for analyzing:

- Primary current distribution
  - Resistance between anode and each point on the cathode
- Secondary current distribution
  - Impact of non-linear electrochemical kinetics
- Tertiary current distribution
  - Mass transport of electroactive species at the boundary layer

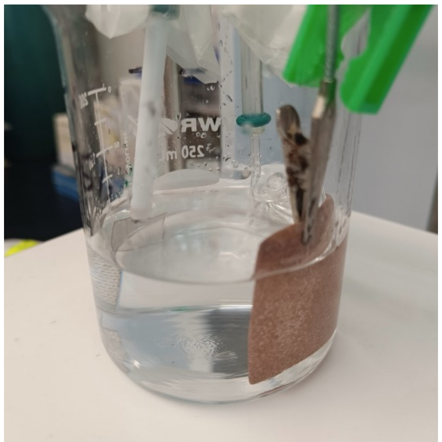
Results will be used to optimize design of future prototypes of cell



Example of COMSOL analysis Faraday has previously performed

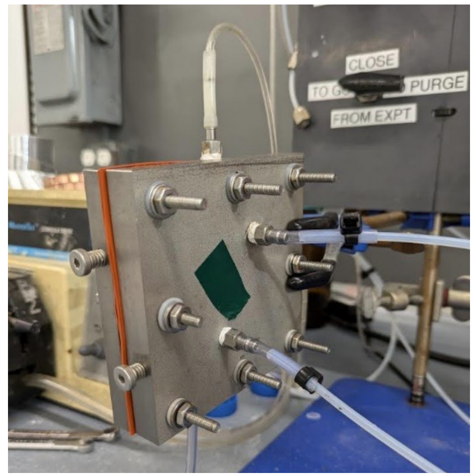
Scaling Electrochemical Cell

Undivided Electrochemical Cell



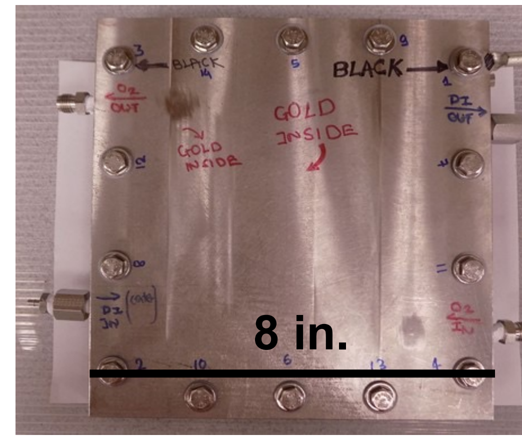
9 cm^2 Active Area

Phase I Flow Cell



9 cm^2 Active Area

Sub-Scale Flow Cell



82 cm^2 Active Area

Increased active area for larger ethanol production rate

Next steps: increase scale of cell for larger production rate of EtOH

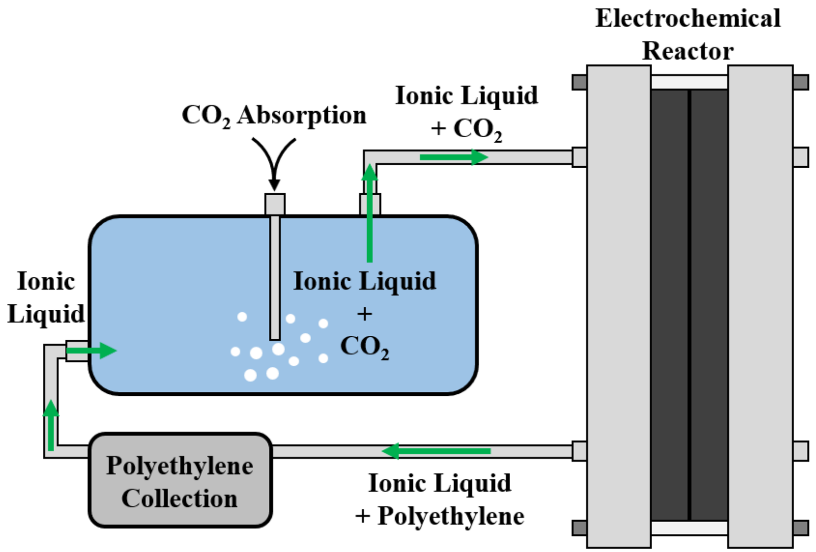
Test stacked cells for ethanol production

Further Possibilities for CO_2 Valorization

Expand possible high-value product able to be produced from Martian atmosphere

Ongoing work:

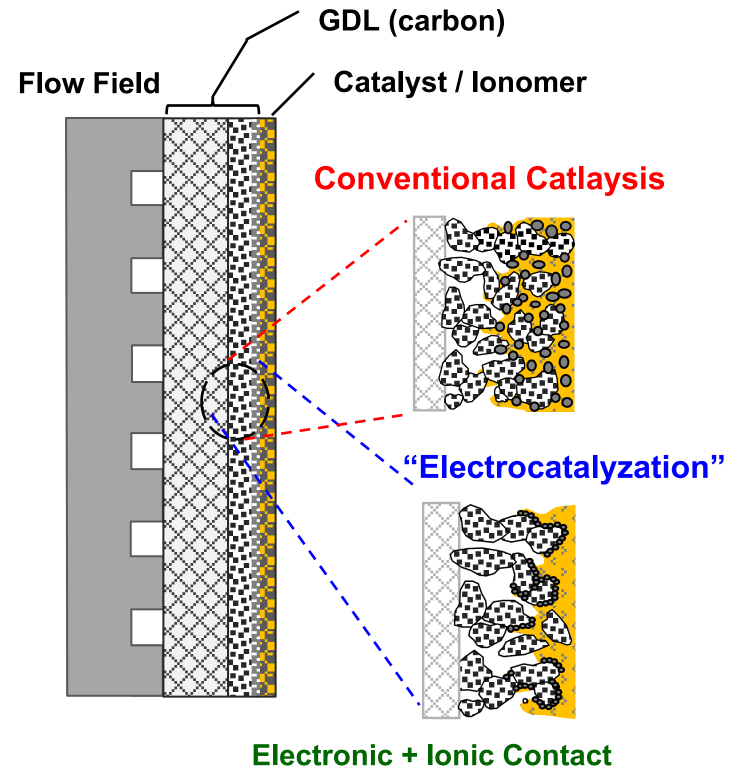
CO_2 to Polyethylene



Preliminary testing found ability to convert CO_2 directly to polyethylene

Previous work:

CO_2 to Formate



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Acknowledgements

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- **Collaborators:**

University of Texas at San Antonio

Professor Shrihari Sankarasubramanian

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Thank you for your attention!

Questions?

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