DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Electrolyzers For CO_2 Conversion from BioSources

April 7, 2023
Carbon Dioxide Utilization Session

Rich Masel,
Dioxide Materials

Electrolyzer Painting Generated by Dall-E

The Team

Dioxide Materials™
The CO_2 Recycling Company™

Electrolyzer scaling
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NREL
Transforming ENERGY

Optimizing Selectivity
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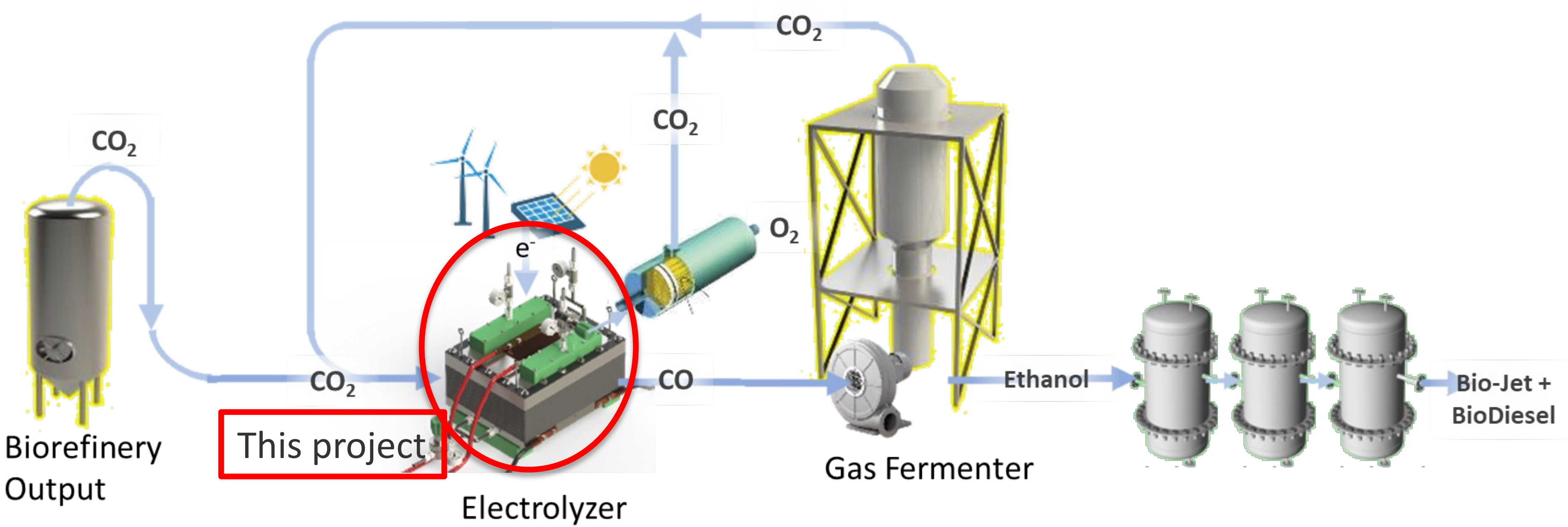
- Andrew Young

Argonne NATIONAL LABORATORY

MicroCT
- Debbie Meyers

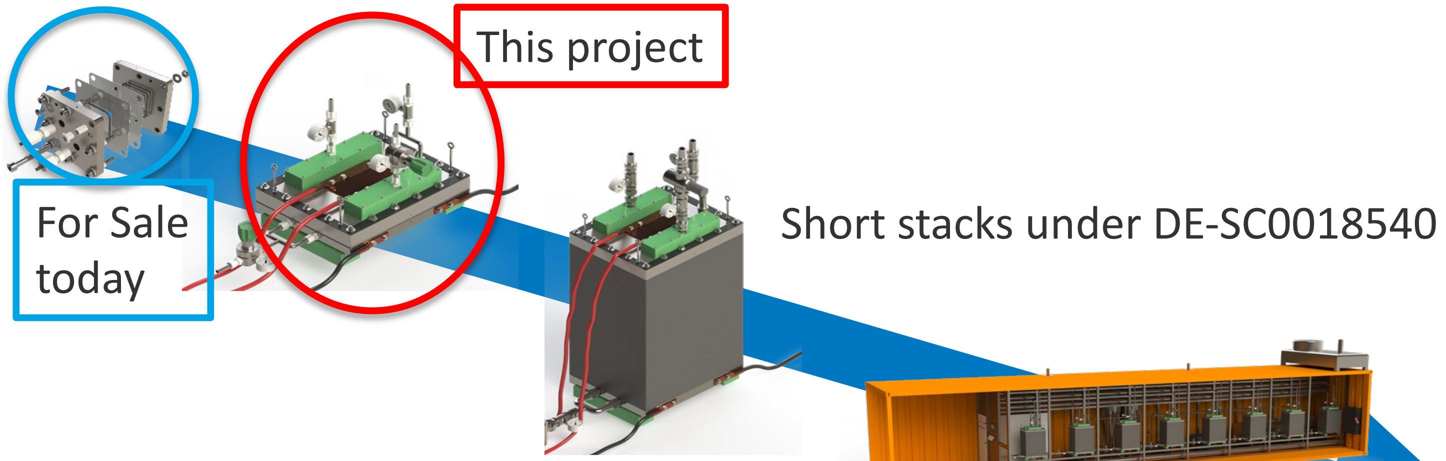
Project Overview

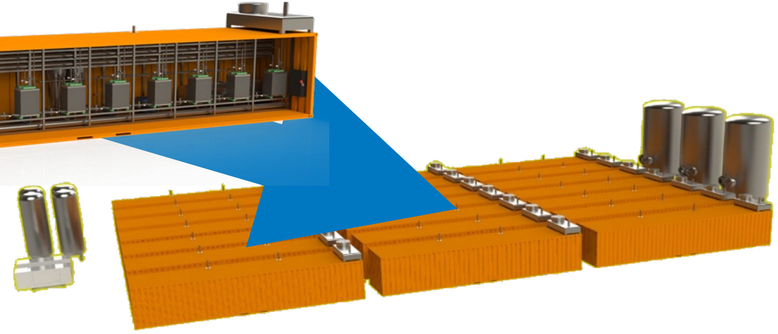
- Objective: Develop Electrolyzers That Can Be Convert CO_2 From Biorefineries To Produce Useful Products
- Save the cost of air capture



Project Objectives

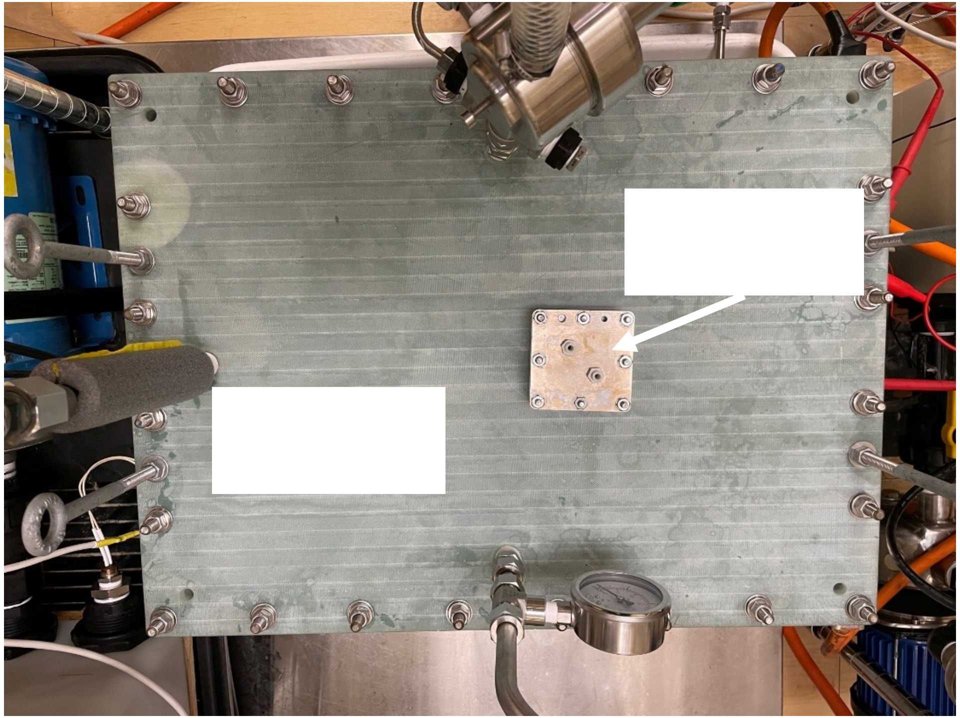
- Move down the product development pathway





- Test with CO_2 from fermenter
- Understand how dilute/recycled CO_2 will affect performance

Size Comparison



1. Approach: Electrolyzer Scaling

- Design and build electrolyzer cells with 1000 cm^2 active area (The same size as in the proposed stacks)
    - Use CFD – one phase flow -to estimate flow distribution
        - Ignores 2 phase effects
    - Build the cells & run
    - Identify failure modes and repeat
- Milestones
    - Mid-project verification (100 hours @ 200 mA/cm^2 with 90% selectivity) (Met)
    - Project end (1000 hours @ 200 mA/cm^2 with 90% selectivity)

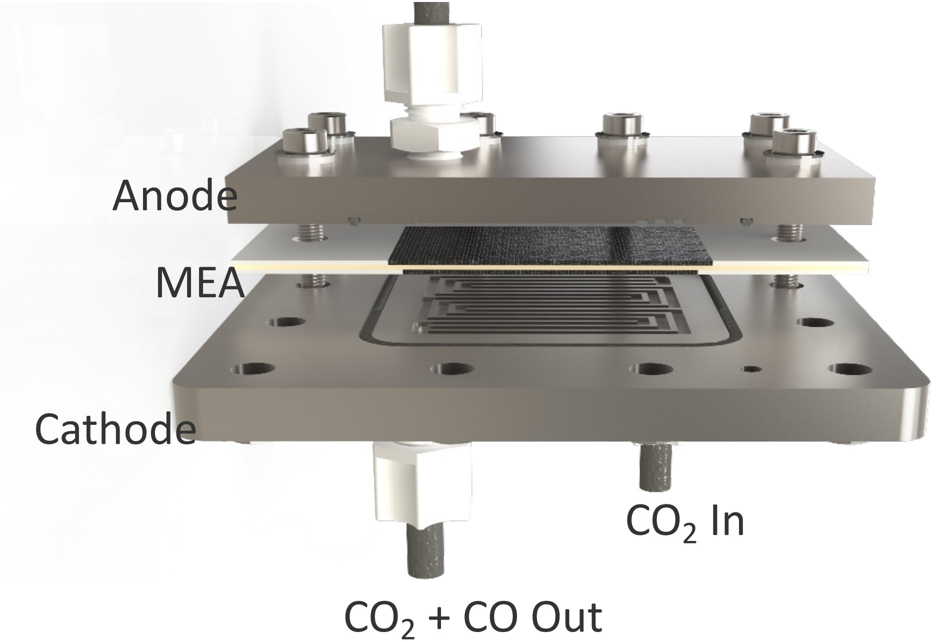
1. Approach: Electrolyzer Scaling

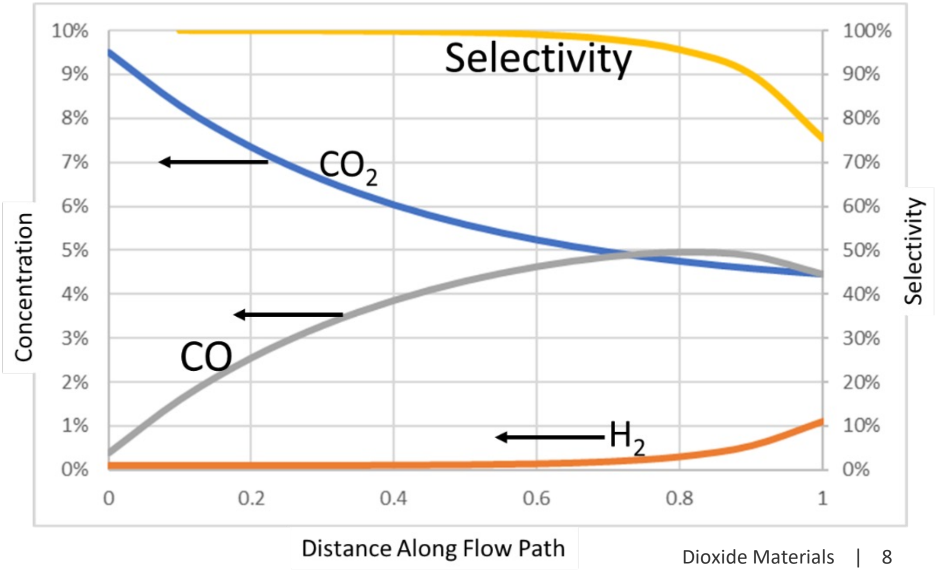
- Deconstructive Tests (suggested by verification team)
  - Load components from failed cells into small electrolyzer
  - Test modifications in small cells (e.g. stronger membranes) before moving to 1000 cm^2 cells

	Wet impact Strength, J, ASTM D3420
Standard membrane	0.056
Improved membrane	0.164
Grocery bag	0.1-0.15

1. Approach: Optimize Selectivity

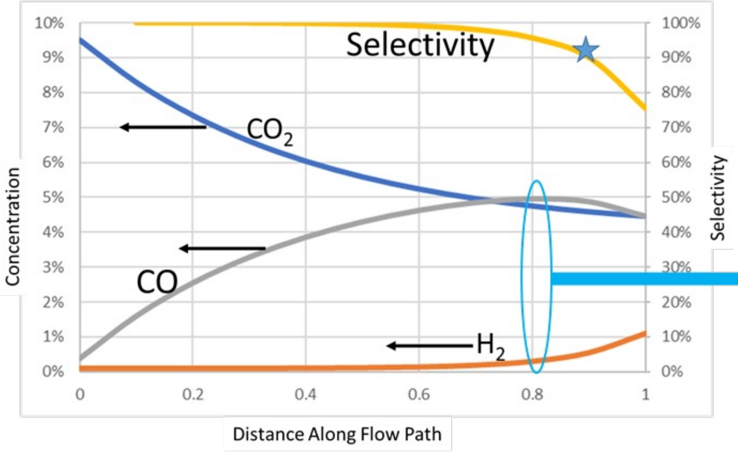
- Concentrations drop as CO_2 and water are consumed
  - Cathode reaction: $CO_2 + H_2O + 2e^- \rightarrow CO + 2\ OH^-$
- What factors are limiting selectivity?

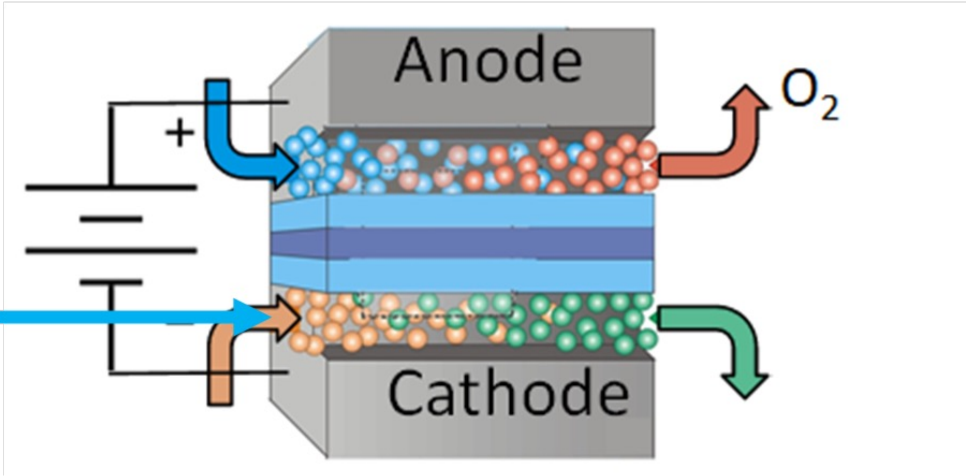




1. Approach: What Limits selectivity

Feed gas mixture with a concentration at each point on the curve
Flow rate high enough so concentration constant throughout the cell
Measure rate and selectivity as a function of concentration/humidity





Milestone: Paper describing the limiting factors

1 Approach: Use Results to Improve Performance

- BP2 work showed the catalyst layer structure has a significant effect on the selectivity
  - Originally proposed:
    - CT tomography to characterize the structure
    - Vary the preparation procedure to improve structure
  - New task
    - Capacitance measurements to characterize catalyst utilization
- BP3 – Milestone structure improvements to obtain 10, 20, 30, 40% increase in selectivity at reduced humidity

Approach: Testing On Fermenter Gas

- Original Plan: test 250 cm^2 cell on fermenter gas from Poet or ICM.
    - Requires huge volume of gas
    - Compression would change composition
- Revised plan: test large cell at the NREL process development unit (PDU)

TEA/LCA

- Develop low level TEA/LCA internally (Electrolyzer not system)

- Provide data to the NREL/ANL TEA/LCA team for more sophisticated results & system integration

Summary of The Approach

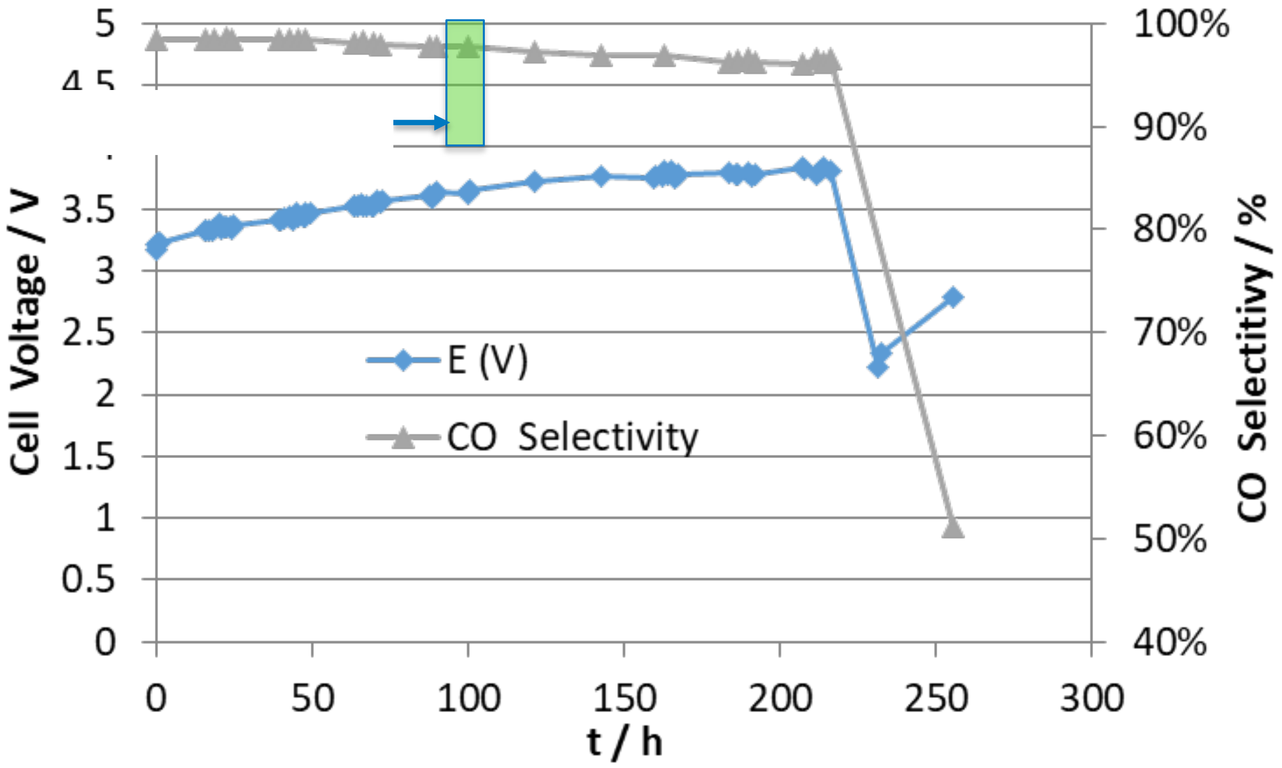
- Run a 1000 cm2 cell, determine the failure modes and correct
- Learn the critical parameters that determine selectivity
- Provide data to NREL/ANL TEA/LCA team

Next Progress and Outcomes

2. Progress and Outcomes

- Eight cell designs simulated, three built
- Met go/no-go milestone of >200 mA/cm^2 for 100 hours with >90% selectivity

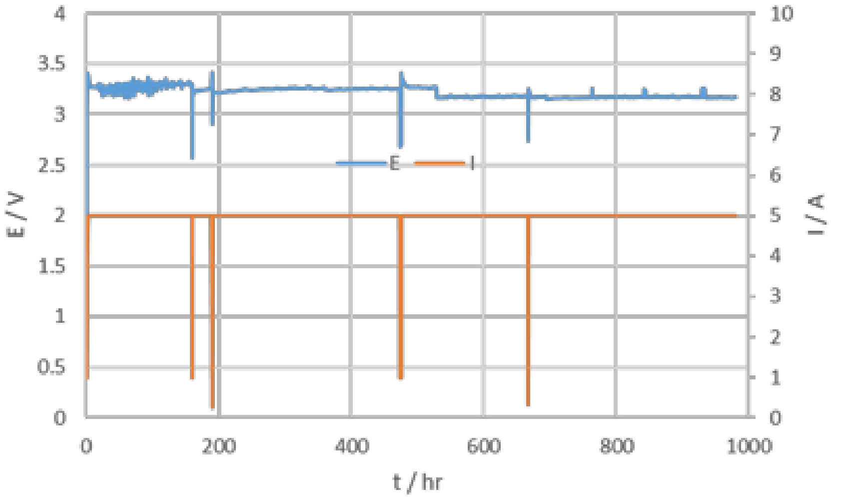
Run Meeting Go/No-Go Milestone

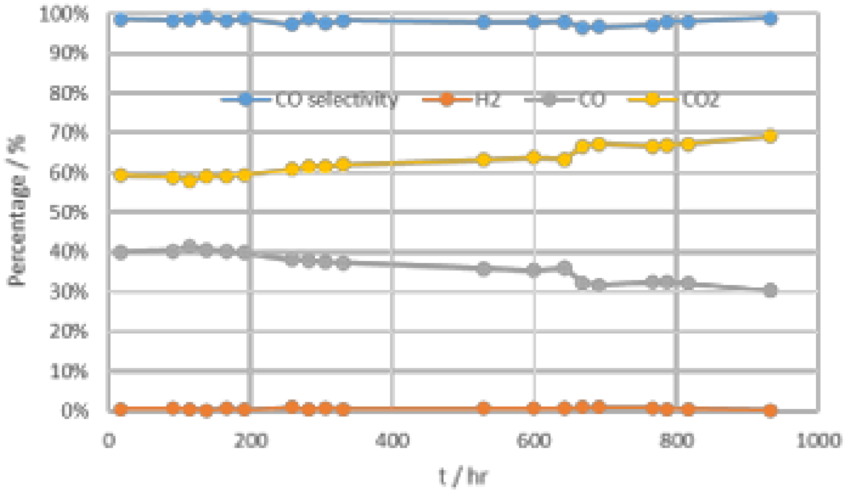


Meets go/no-go milestone: 100 hour performance, >90% selectivity

Test of MEA removed From Cell With Cracked GDL

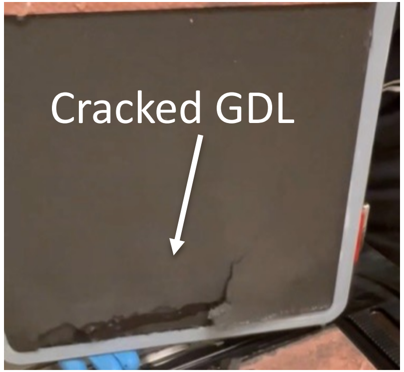
- Cut out section of membrane from cell that had failed
- Mount in 25 cm^2 cell for testing – new GDL's





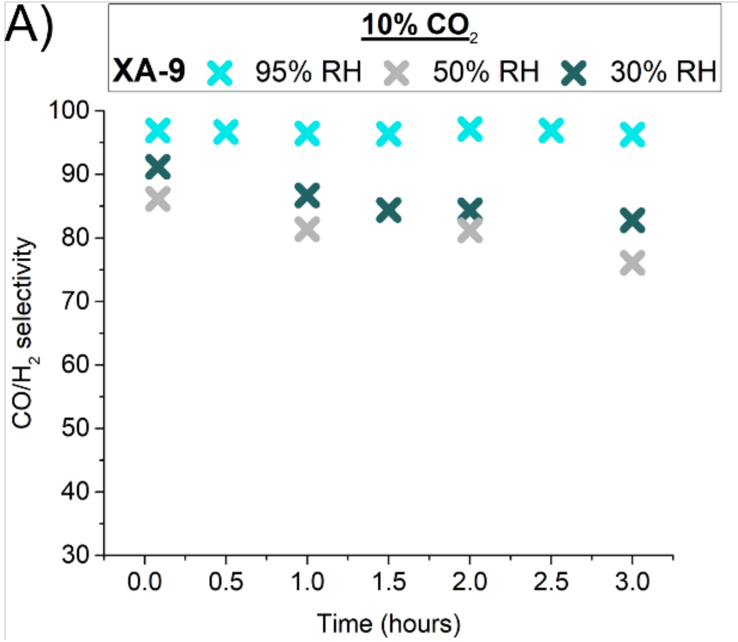
2. Main Failure Modes Due To Increased Size Identified

Failure Mode	Risk Mitigation
Thermal: Hot spots	• Design anode flow field so analyte carries away heat ✓
Mechanical: Cathode GDL cracking & pushing through membrane	• Testing carbon cloth ✓ • Use conventional flow fields to better support the GDL ✓ • Strengthening the membranes ✓
Manufacturing defects: ●Dust particle in membrane leading to failure ●Conventional flowfield not Flat	• Manufacturing membrane in a clean environment ✓ • Membrane redesign ✓ • Identify high spots & polish
Supply Issues: Protruding fiber in GDL producing pinhole	
BOP: Power supply & pump failures	

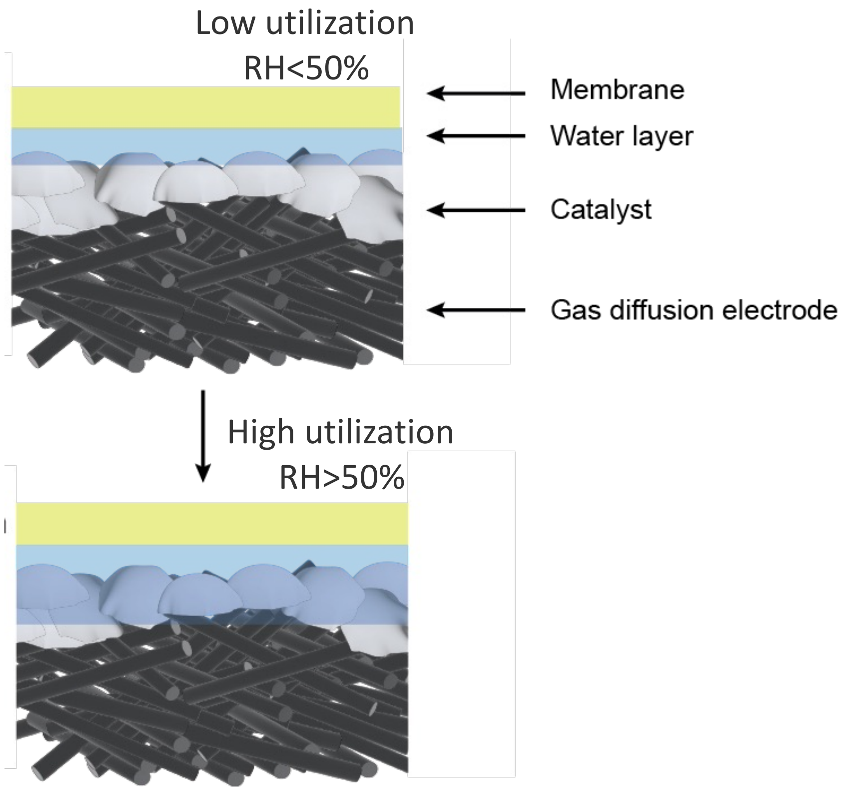


2. Progress and Outcomes: Selectivity Optimization

- Determined key parameters limiting selectivity
  - Humidity – can maintain selectivity above 90% down to 10% CO_2 if we keep humidity ~95% in cathode
    - Cathode reaction: $CO_2 + H_2O + 2e^- \rightarrow CO + 2\ OH^-$
  - Catalyst layer structure: Need the full catalyst layer to be utilized
- Paper in preparation: Understanding the limits of Electrochemical conversion at low CO2 concentrations



2. Progress and Outcomes: Selectivity Optimization

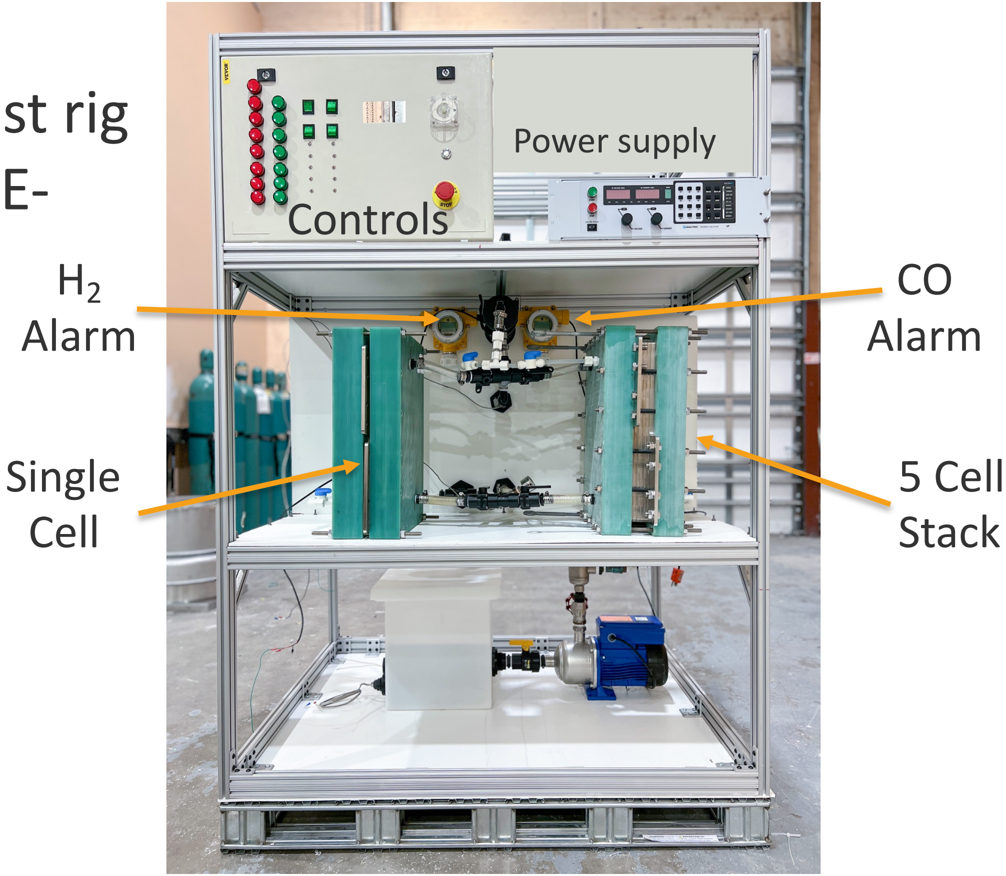


2. Progress and Outcomes: Selectivity Optimization

Selectivity Loss Mechanism	Risk Mitigation
Loss of humidity as H_2O is used up	• Improve water transport in membrane • Dual cells with intermediate humidification ✓
Catalyst structure limits catalyst utilization	• Modify layer preparation to improve structure

2. Progress and Outcomes Planning For PDU

- Continued developing test rig started under an SBIR (DE-SC0018540)

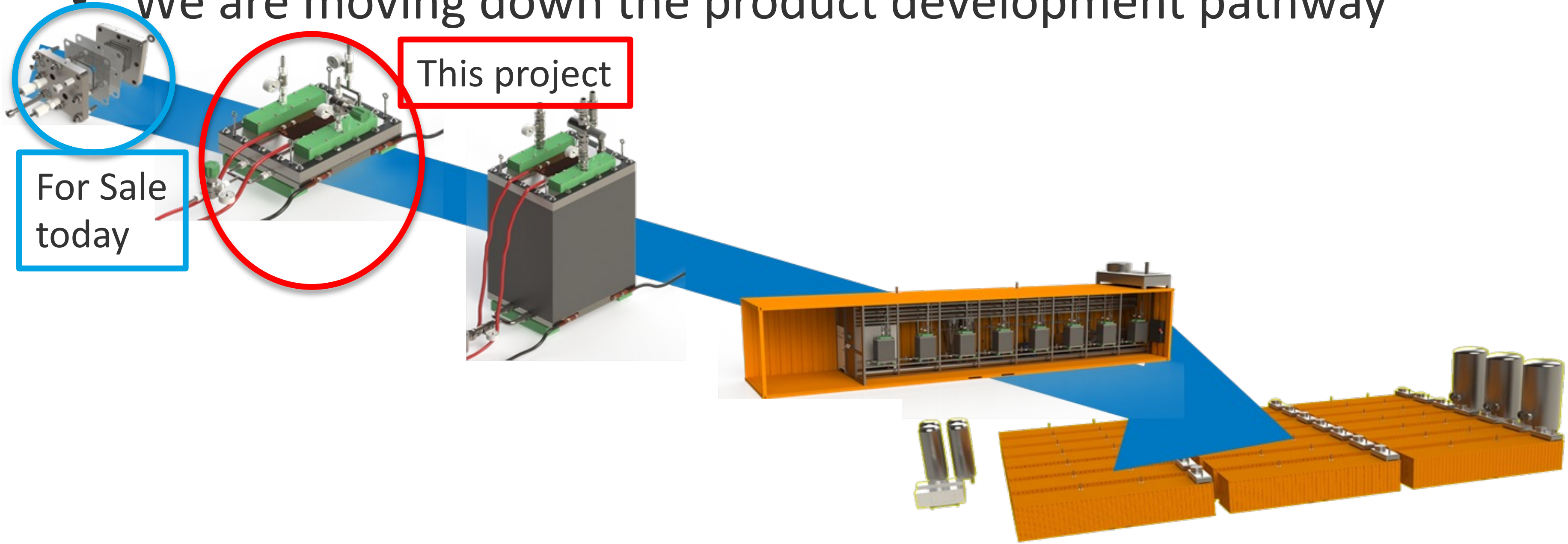


2. Progress and Outcomes: Preliminary TEA/LCA

- Need 3+ year lifetime before MEA replacement
- Need inexpensive electricity to make process economic
  - <$0.03/kW in the US
  - <$0.04/kW in the EU
  - <$0.07/kW in China
- Need to power renewable/nuclear energy to reduce overall CO_2 emissions
  - Commercial scale plant needs 100+ MW electricity
- May need battery storage
  - Electrolyzer turns down easily if temperature maintained but downstream process cannot load follow

3: Impact

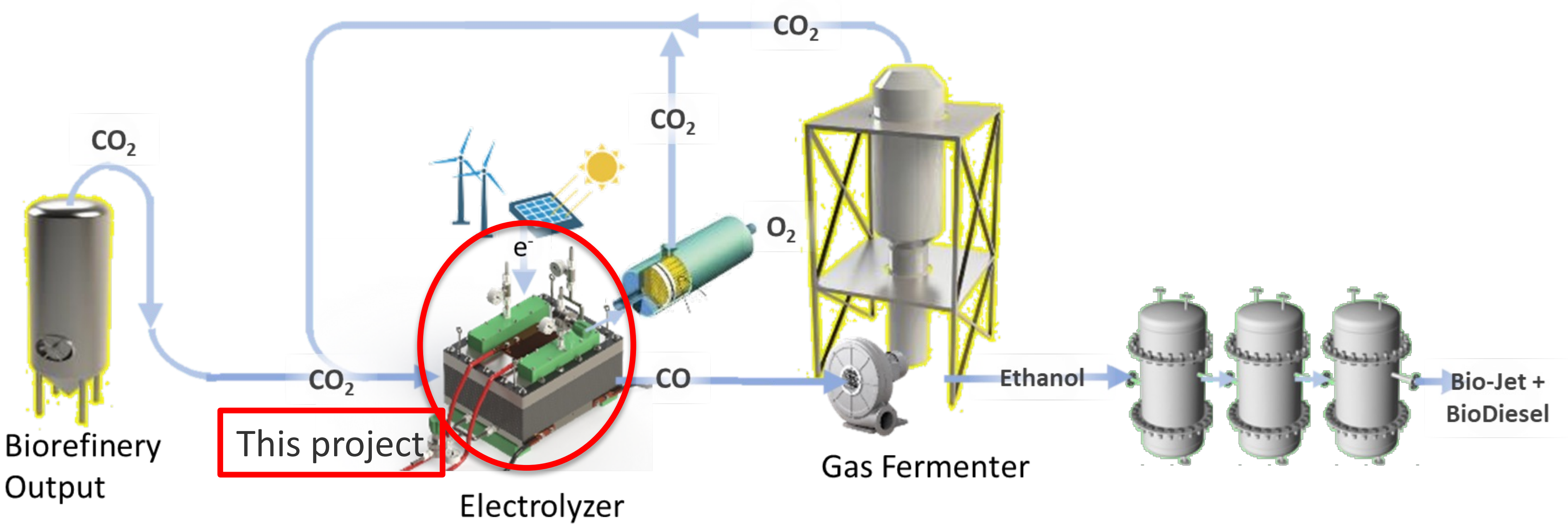
- We are moving down the product development pathway



performance and suggesting improvements

3. Impact (Cont).

- Enabling a process to convert CO_2 from a biorefinery into SAF
- Save the cost of air capture
- Improving biorefinery carbon efficiency



Summary

- Cells with an active area of 1000 cm^2 feasible
- Lifetime limited by
  - Carbon paper defects
  - Dust
- Selectivity limited by
  - Catalyst layer structure
  - Water management
- 100 hours >90% selectivity demonstrated in 1000 cm^2 cell – project goal 1000 hours >90% selectivity

Quad Chart Overview

	FY22 Costed	Total Award
DOE Funding		
Project Cost Share*		

TRL at Project Start: 2 for 1000 cm^2 cell
TRL at Project End: 5

Project Goal

Scale Dioxide Materials electrolyzers to 1000 cm^2 size.

Improve selectivity

End of Project Milestone

Electrolyzer cell with an active area above 750 cm^2 operating for 1000 hours with a selectivity above 90%

Funding Mechanism

FY2020 DE-FOA-0002203

Project Partners*

- NREL ($600,000)
- ANL ($75,000)

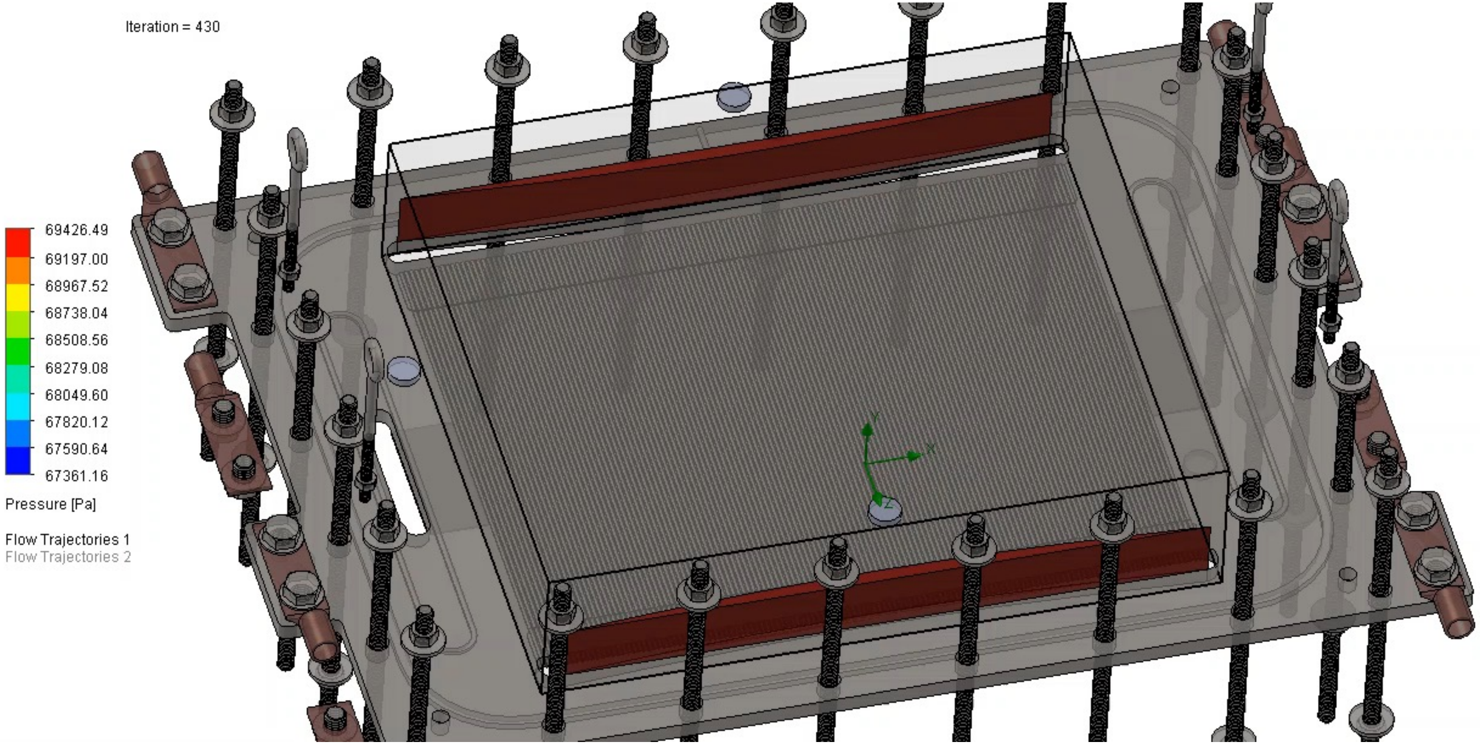
Dioxide Materials™
The CO_2 Recycling Company™

dioxidematerials.com

This work was supported by the Department of Energy under contract DE-EE0009286.

Additional Slides

Movie of Simulation To Understand Dead spots

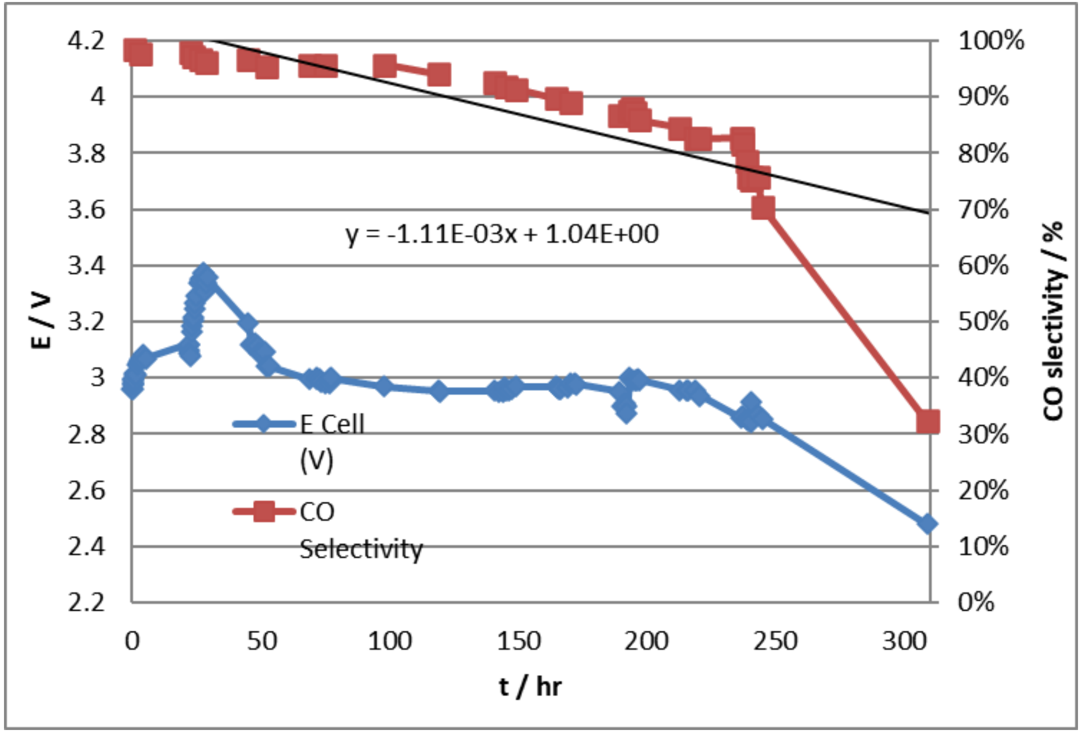


Many dead zones

First test of new flowfields to support GDL

Membrane with dust particles. Dust was from remodeling at new facility

- No issues with GDL

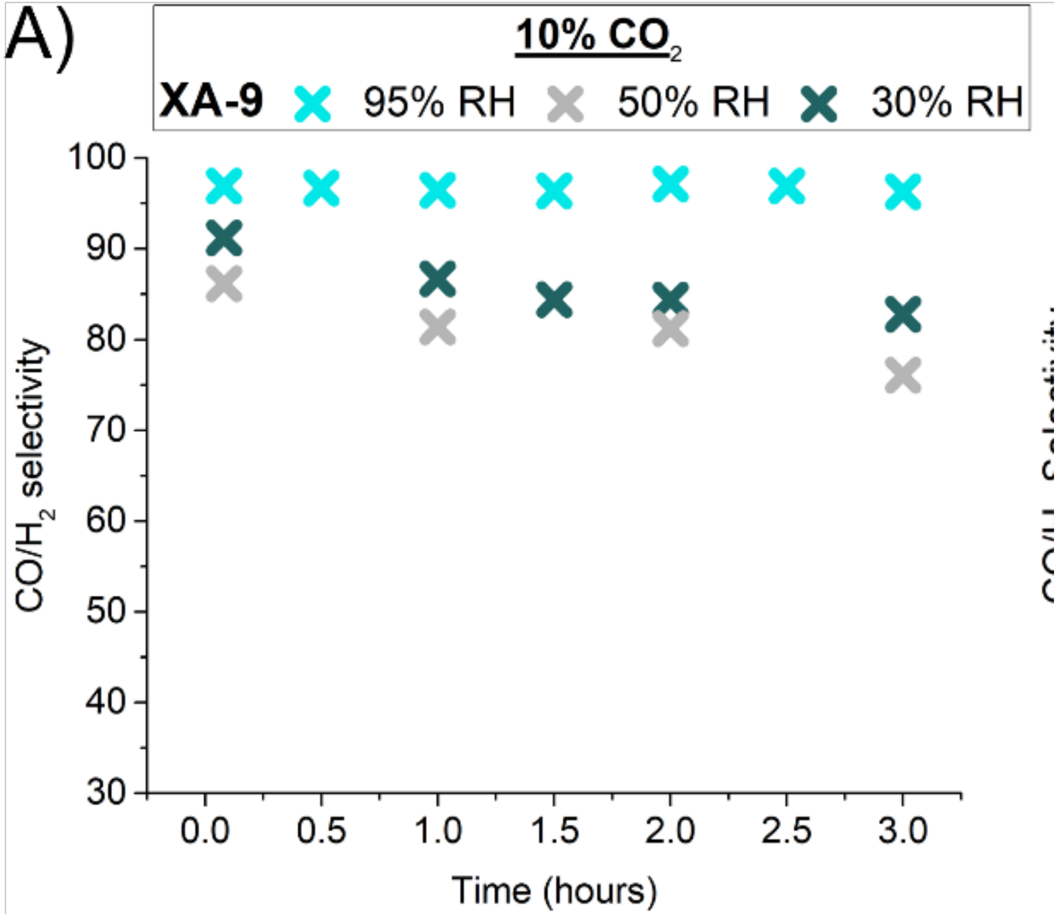


Membrane Impact Strength Improvement

	Impact Strength, J, ASTM D3420
Standard membrane	0.056
Improved membrane	0.164
Grocery bag	0.1-0.15

Device measures energy needed to punch a hole in the membrane

Selectivity Data



BP1 Milestones

	2.1 Create 30 cm membranes	25-Nov-21
2.1.ML.1	Membranes that are 28+ cm wide and at 40+ cm long	25-Nov-21
	2.2 Anode Flowfields	28-Oct-21
2.2.ML.1	Simulations indicate equal flows	28-Oct-21
	2.3 Assemble with balance of plant	17-Mar-22
2.3.ML.1	Temperature controlled	17-Mar-22
	2.4 Electrolyzer operation	18-Oct-22
2.4.ML.1	200 mA/cm^2 achieved in a cell with an active area of at least 750 cm^2 for ≥24 continuous hours	22-Apr-22
2.4.ML.2	200 mA/cm^2 achieved in a cell with an active area of at least 750 cm^2 for ≥100 continuous hours	20-Jun-22
2.4.ML.3	200 mA/cm^2 at ≥ 80% selectivity to CO achieved in a cell with an active area of at least 750 cm^2 for ≥100 continuous hours	19-Aug-22
2.4.ML.4	200 mA/cm^2@ > 90% selectivity, active area ≥750 cm^2 for ≥100 continuous hours	18-Oct-22
	3 3 Test alternate ionomers/catalysts	25-Jan-23
3.1.1	base case	24-Nov-21
3.1.ML.1	Determine lowest CO concentration where 90% selectivity can be obtained as a function of Temperature and humidity	24-Nov-21
3.1.2	gold catalyst	17-Feb-22
3.1.ML.2	Determine lowest CO concentration where 90% selectivity can be obtained as a function of Temperature and humidity	18-Feb-22
3.1.3	Alternate ionomer 1	13-May-21
3.1.ML.3	Determine lowest CO concentration where 90% selectivity can be obtained as a function of Temperature and humidity	16-May-22
3.1.4	alternate ionomer 2	4-Aug-22
3.1.ML.4	Determine lowest CO concentration where 90% selectivity can be obtained as a function of Temperature and humidity	5-Aug-22
	4 4 Papers and conference meetings	6-Apr-23
4.ML.1	Paper presented at BETO AMR	6-Apr-23

BP2 Milestones

5.1	250 hour tests	19-Jan-23
5.1.ML.1	200 mA/cm²@ > 90% selectivity, active area ≥750 cm² for ≥250 continuous hours	19-Apr-23
5.2	500 hr tests	20-Aug-23
5,2.ML1	200 mA/cm²@ > 90% selectivity, active area ≥750 cm² for ≥500 continuous hours	20-Aug-23
5.3	1000 hr tests	29-Jan-24
5.3.ML.1	Milestone: 200 ma/cm²@ > 90% sel, 1000 hr	29-Jan-24
66	ionomer optimization	14-Nov-23
6.1	Tests of alternate ionomers	7-Feb-23
6.1.ML.1	Milestone: 10% improvement compared to task 3	7-Feb-23
6.1.ML.2	Milestone: 20% improvement compared to task 3	30-May-23
6.2	Tests in commercial cells	25-Jul-23
6.2.ML.1	Milestone: 20% improvement compared to task 3	25-Jul-23
6.3	Nano-Computed Tomography	12-Dec-23
6.3.ML.1	Nano-Computed Tomography on catalyst from task 3	17-Feb-23
6.3.ML.2	Nano-Computed Tomography on catalyst from 6.1.1	25-Jul-23
6.3.ML.3	Nano-Computed Tomography on catalyst from 6.1.2	12-Dec-23
77	structural improvements	18-Jan-24
7.1	Tests of alternate structures	18-Jan-24
7.1.ML.1	Milestone: 10% improvement compared to task 6	22-Aug-23
7.1.ML.2	Milestone: 20% improvement compared to task 6	14-Nov-23
7.2	Tests in commercial cells	18-Jan-24
7.2.ML.1	Milestone: 20% improvement compared to task 6	18-Jan-24
88	Integration with Fermenter	17-Jan-24
8.1	Integration with fermenter	19-Dec-23
8.1.ML.1	20% CO converted to ethanol	30-Nov-23
8.1.ML.2	40% CO converted to ethanol	19-Dec-23
8.2	Operation of gas from a biorefinery	19-Dec-23
8.2.ML.1	Milestone: ethanol produced	19-Dec-23

Publications, Patents, Presentations, Awards, and Commercialization

Publications

1. Henckel, D.A., Rajana, S., Liu, Z., Resch, M., Masel, R. I., Neyerlin, K.C., Enabling high selectivity for CO_2 to CO conversion at low CO_2 partial pressures (In Preparation)

Commercialization

- Dioxide Materials is planning to offer new stronger membranes shortly
  - Now developing SOP for commercial production
- Dioxide Materials has been selling small electrolyzers since 2018
  - Will incorporate stronger membranes shortly