Electrochemical conversion of coal-derived CO₂ into fuels and chemicals using a modified PEM electrolyzer

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U.S. Department of Energy
National Energy Technology Laboratory
2020 Annual Review Meeting

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COAL Project Overview

1/25/19-1/24/21, Federal: $800k, Cost Share: $200k
Evaluate new polymer-electrolytes to increase voltage efficiency and demonstrate durability of CO\textsubscript{2} electrolysis performance.
Outline

• Opus 12 Background
• Technology Description
• Project Overview
• Future Plans & Commercial Traction
Founding Team: world leaders in CO₂ electrochemistry

Stanford, Lawrence Berkeley National Lab

Dr. Kendra Kuhl
CTO
PhD in Chemistry, Stanford, Post doc, SLAC
Research: Transition metal catalyzed CO₂ electroreduction, reactor design

Dr. Etosha Cave
CSO
PhD in Mechanical Eng, Stanford
Research: Modified gold catalysts for CO₂ electroreduction, reactor design

Nicholas Flanders
CEO
MBA, MS E-IPER, Stanford
Work Experience: COO/CFO Levo, McKinsey CleanTech practice

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## Current Status & Key partnerships

<table>
<thead>
<tr>
<th>Current Status</th>
<th>38 employees &amp; 10,000 sq ft facility in Berkeley, CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key customers and commercial partners</td>
<td><img src="logos1.png" alt="Logos" /></td>
</tr>
<tr>
<td>Federal &amp; State Grants and Contracts</td>
<td><img src="logos2.png" alt="Logos" /></td>
</tr>
<tr>
<td>Incubators &amp; Accelerators</td>
<td><img src="logos3.png" alt="Logos" /></td>
</tr>
</tbody>
</table>
Transforming global CO$_2$ emissions

...into a multi billion dollar opportunity
A platform technology that recycles CO$_2$ back into chemicals and fuels

**Inputs:** CO$_2$, WATER, ELECTRICITY

**Electrochemical Reduction of CO$_2$**

**Outputs:** Products that drop into existing supply chains

Fuel & Chemicals

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We are converting a commercial water electrolyzer to a CO$_2$ electrolyzer

Polymer-electrolytes make up the membrane and are incorporated into the anode and cathode
Overall Reaction:

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{Energy} \rightarrow \text{C}_x\text{H}_y\text{O}_z + \text{O}_2 \]  
(EOO2R)

Split into electrochemical half reactions:

<table>
<thead>
<tr>
<th>Water Oxidation (Anode)</th>
<th>( \text{E}^0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4(\text{H}^+ + \text{e}^-) )</td>
<td>1.23 V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \text{CO}_2 ) Reduction (Cathode)</th>
<th>( \text{E}^0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{CO}_2 + m(\text{H}^+ + \text{e}^-) \rightarrow \text{C}_x\text{H}_y\text{O}_z + n\text{H}_2\text{O} )</td>
<td>(~0 ) V</td>
</tr>
</tbody>
</table>

Determines minimum energy required for EOO2R to various products

Burning hydrocarbons releases energy and carbon dioxide

To convert carbon dioxide into chemicals and fuels, must add energy back into the system

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Project Goal

Evaluate new polymer-electrolytes to increase voltage efficiency and demonstrate durability of CO$_2$ electrolysis performance.
Task 2

- Identified commercially available polymer-electrolytes
- Down selected to top 3 based on properties
Task 3-5

Ink formulation  
Catalyst layer deposition  
Short-term Performance testing

Target voltage efficiency achieved while maintaining high current efficiency and current density.

Membrane-electrode assembly
Current focus of the project is demonstrating durability. We have already made significant advances in lifetime, continuing our technical progress in this area.
Task 7: TEA/LCA

10x reduction in $/ton CO cost compared to project baseline

Based on $0.08/kWh electricity cost, $120/ton CO₂, and 1 MW scale
Scale-up Pathway
Integration into existing electrolyzer designs

We partner with electrolyzer producers to build CO₂ conversion systems

1. 2 kW
   5 kg/ day CO₂
2. 50 kW
   350 kg/ day
3. 1 MW
   7 tons per day
4. 20-100+ MW
   150 - 1,000+ tons per day
Convert waste CO₂ into chemicals

Modular units require no changes to customers’ core operations and products are identical to existing fossil fuel derivatives.
February, 13 2020: we unveiled the world’s first car part made from CO₂ with Mercedes-Benz in Stuttgart, Germany

Carbon-Neutral PC
a. 2 tons of CO₂ offset per ton of CO
b. 10-15% Opus 12 CO by weight
Case Study

Jet Fuel

Carbon-Neutral Jet Fuel

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<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>2.5 kg CO₂/L</td>
</tr>
<tr>
<td>e.jet</td>
<td>&lt;0.4 kg CO₂/L with solar (85-100% reduction)</td>
</tr>
</tbody>
</table>

Opus 12’s technology converts CO₂ to CO, which is upgraded to jet fuel

Application development funding:

Shell GameChanger

LanzaTech Successful test, summer 2020

$1.5 million contract signed for Opus 12 e-jet delivery in 2021
Summary

Completed all project milestones to date

Current focus: Durability demonstration, TEA, and LCA

Clear path to scale and commercialize innovations
• All work carried out by Opus 12: www.opus-12.com

We are electrochemists, material scientists, and engineers with cutting-edge expertise in the field of CO₂ electrocatalysis and electrochemical reactor design, scouted from the best programs in the world. Our team has partnered with industry leaders in electrolysis and plant design to implement our technology at scale.
# Gantt Chart

<table>
<thead>
<tr>
<th>Task</th>
<th>Task Title</th>
<th>Start</th>
<th>End Date</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project Management and Planning</td>
<td>1/25/2019</td>
<td>1/24/2021</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>2</td>
<td>New polymer-electrolyte identification and selection</td>
<td>1/25/2019</td>
<td>4/25/2019</td>
<td>Q3</td>
<td>Q4</td>
</tr>
<tr>
<td>3</td>
<td>Ink formulation</td>
<td>4/26/2019</td>
<td>10/25/2019</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>4</td>
<td>MEA Fabrication</td>
<td>10/26/2019</td>
<td>1/25/2020</td>
<td>Q3</td>
<td>Q4</td>
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<tr>
<td>6</td>
<td>Durability Testing</td>
<td>4/26/2020</td>
<td>10/25/2020</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>Technoeconomic &amp; Life Cycle Analysis</td>
<td>1/25/2020</td>
<td>1/24/2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total Project</strong></td>
<td><strong>1/25/2019</strong></td>
<td><strong>1/24/2021</strong></td>
<td></td>
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</tr>
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