Electrochemical conversion of coal-derived CO_2 into fuels and chemicals using a modified PEM electrolyzer

DE-FE0031712

Kendra Kuhl

opus 12

U.S. Department of Energy

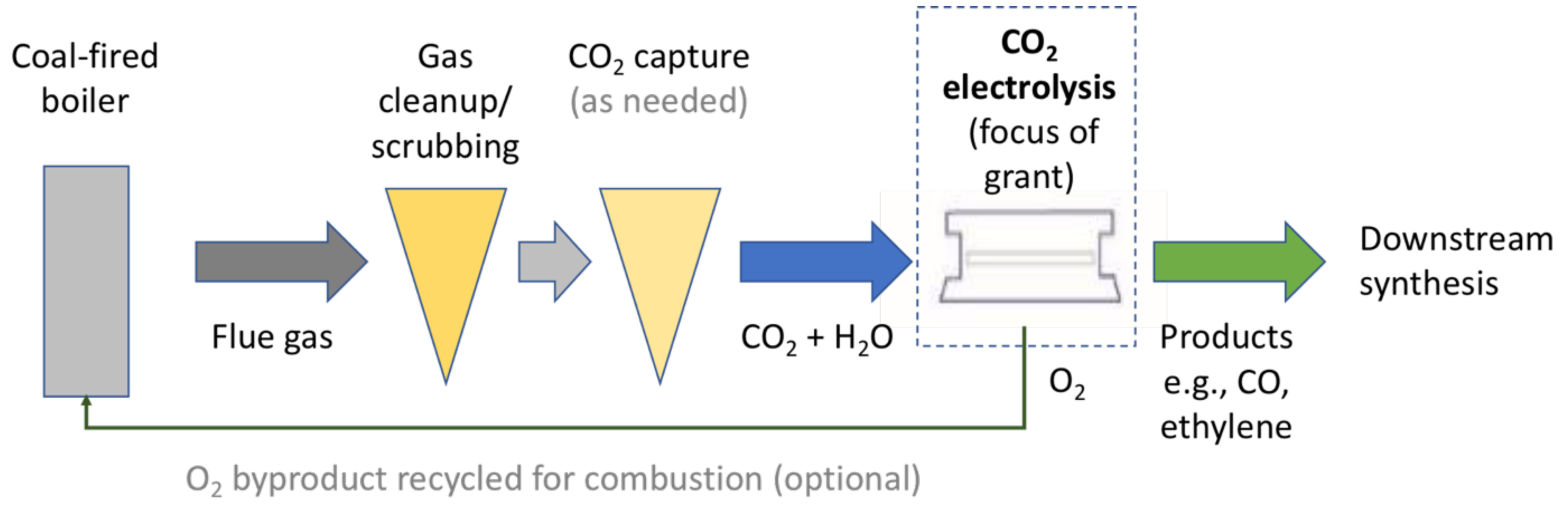
National Energy Technology Laboratory

2020 Annual Review Meeting

Contact: kendra@opus-12.com

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_2 electrolysis performance.



Outline

- Opus 12 Background
- Technology Description
- Project Overview
- Future Plans & Commercial Traction

Founding Team: world leaders in CO_2 electrochemistry

Stanford, Lawrence Berkeley National Lab

Dr. Kendra Kuhl
CTO

PhD in Chemistry, Stanford, Post doc, SLAC
Research: Transition metal catalyzed CO_2 electroreduction, reactor design

Stanford INNOVATORS UNDER 35

Dr. Etosha Cave
CSO

PhD in Mechanical Eng, Stanford
Research: Modified gold catalysts for CO_2 electroreduction, reactor design

Stanford Rolling Stone

Nicholas Flanders
CEO

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

Stanford Forbes 30 UNDER 30

U.S. DEPARTMENT OF ENERGY NASA NSF cyclotronroad DCVC

Shell GameChanger DAIMLER U.S. AIR FORCE equinor SoCalGas Sempra Energy

Current Status & Key partnerships

Current Status	**38 employees & 10,000 sq ft facility in Berkeley, CA**
Key customers and commercial partners	Mercedes-Benz; U.S. AIR FORCE; SoCalGas; Sempra Energy
Federal & State Grants and Contracts	U.S. DEPARTMENT OF ENERGY; NASA; NSF; arpa·e; STATE OF CALIFORNIA ENERGY COMMISSION
Incubators & Accelerators	techstars; cyclotronroad; MOLECULAR FOUNDRY; StartX

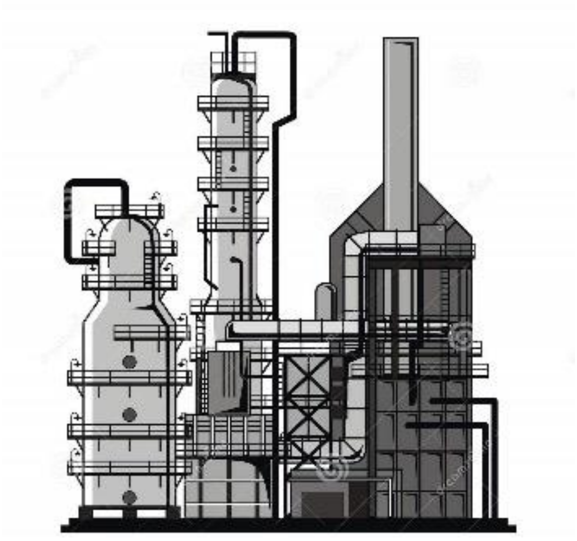

Transforming global CO_2 emissions
…into a multi billion dollar opportunity

— opus 12

A platform technology that recycles CO_2 back into chemicals and fuels

1

INPUTS: CO_2, WATER, ELECTRICITY



CO_2

H_2O

Electricity

2

ELECTROCHEMICAL REDUCTION OF CO_2

Fuels & Chemicals

O_2

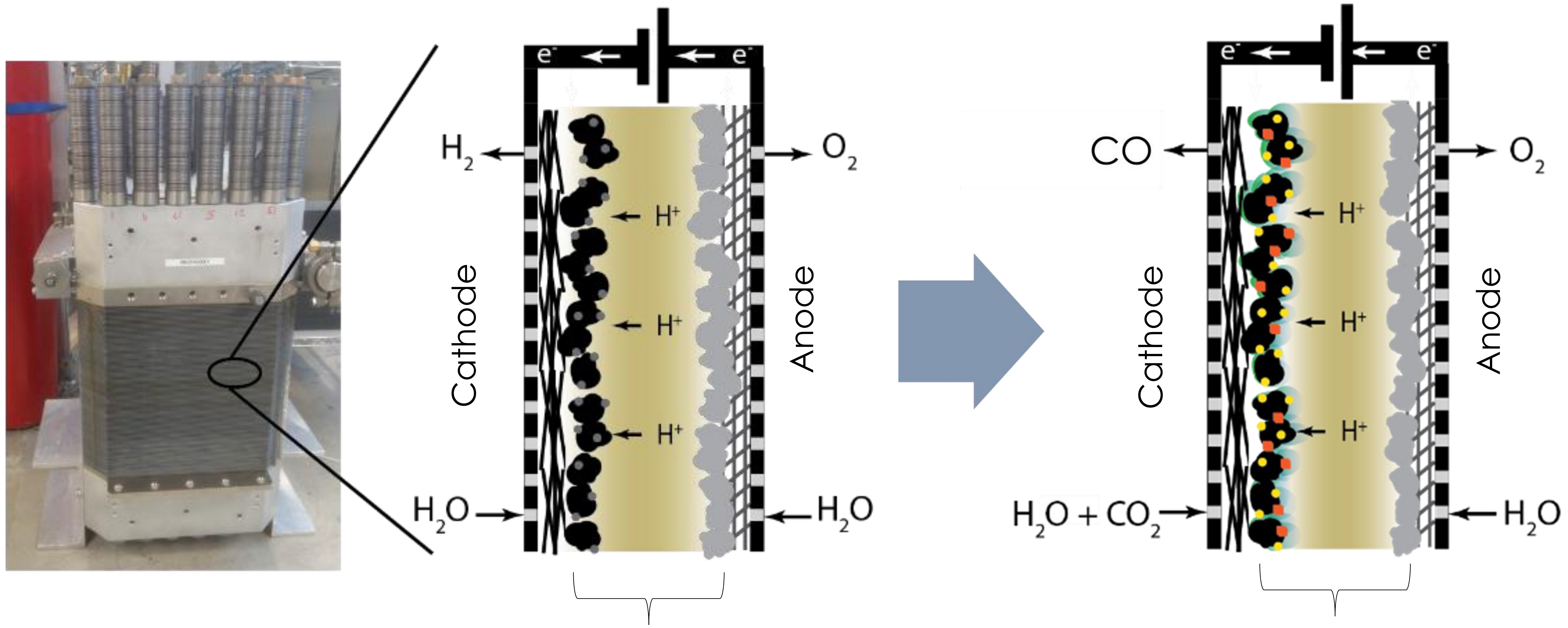
3

OUTPUTS: PRODUCTS THAT DROP INTO EXISTING SUPPLY CHAINS

We are converting a commercial water electrolyzer to a CO_2 electrolyzer

COMMERCIAL PEM WATER ELECTROLYZER

OPUS 12 PEM CO_2 ELECTROLYZER



Membrane electrode assembly (MEA)

Innovations in Opus 12’s new cathode catalyst layer:

- Metal nanoparticle catalysts
- Novel polymer materials
- Anode unchanged

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

Electrolyzer stack photo credit: Nel Hydrogen

Reverse Combustion

opus 12

Overall Reaction:

$$CO_2 + H_2O + \text{Energy} \rightarrow C_xH_yO_z + O_2 \qquad \text{(ECO2R)}$$

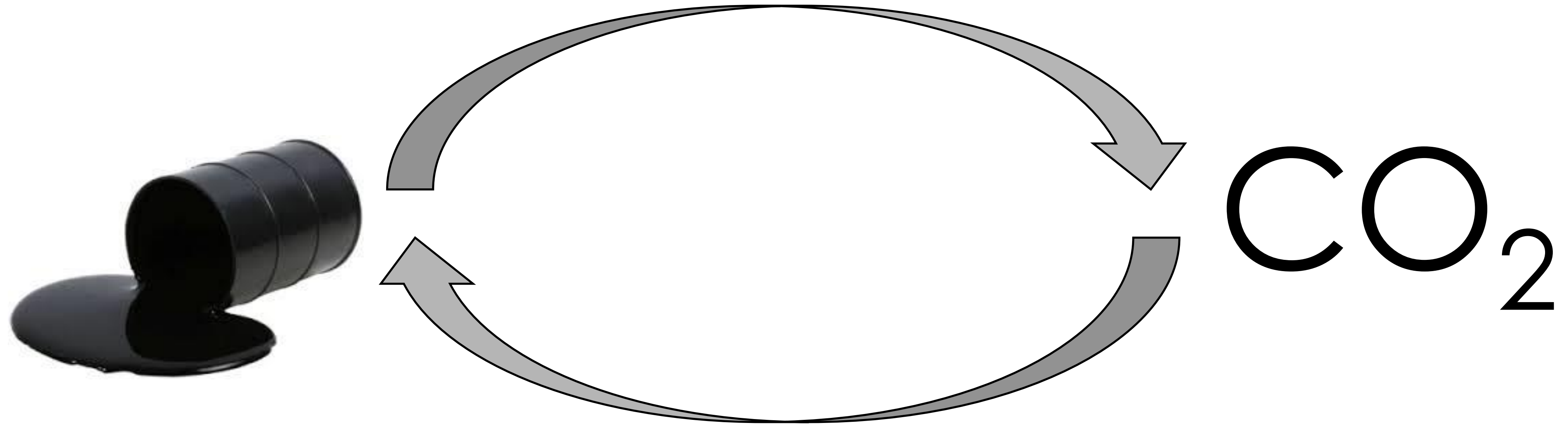
Split into electrochemical half reactions:

	E^o
Water Oxidation (Anode)	
$2H_2O \rightarrow O_2 + 4(H^+ + e^-)$	1.23 V
CO_2 Reduction (Cathode)	
$CO_2 + m(H^+ + e^-) \rightarrow \underset{\uparrow}{C_xH_yO_z} + nH_2O$	~0 V

Fuels & Chemicals

Determines minimum energy required for ECO2R 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

Project Goal

Evaluate new polymer-electrolytes to increase voltage efficiency and demonstrate durability of CO_2 electrolysis performance.

Task 2

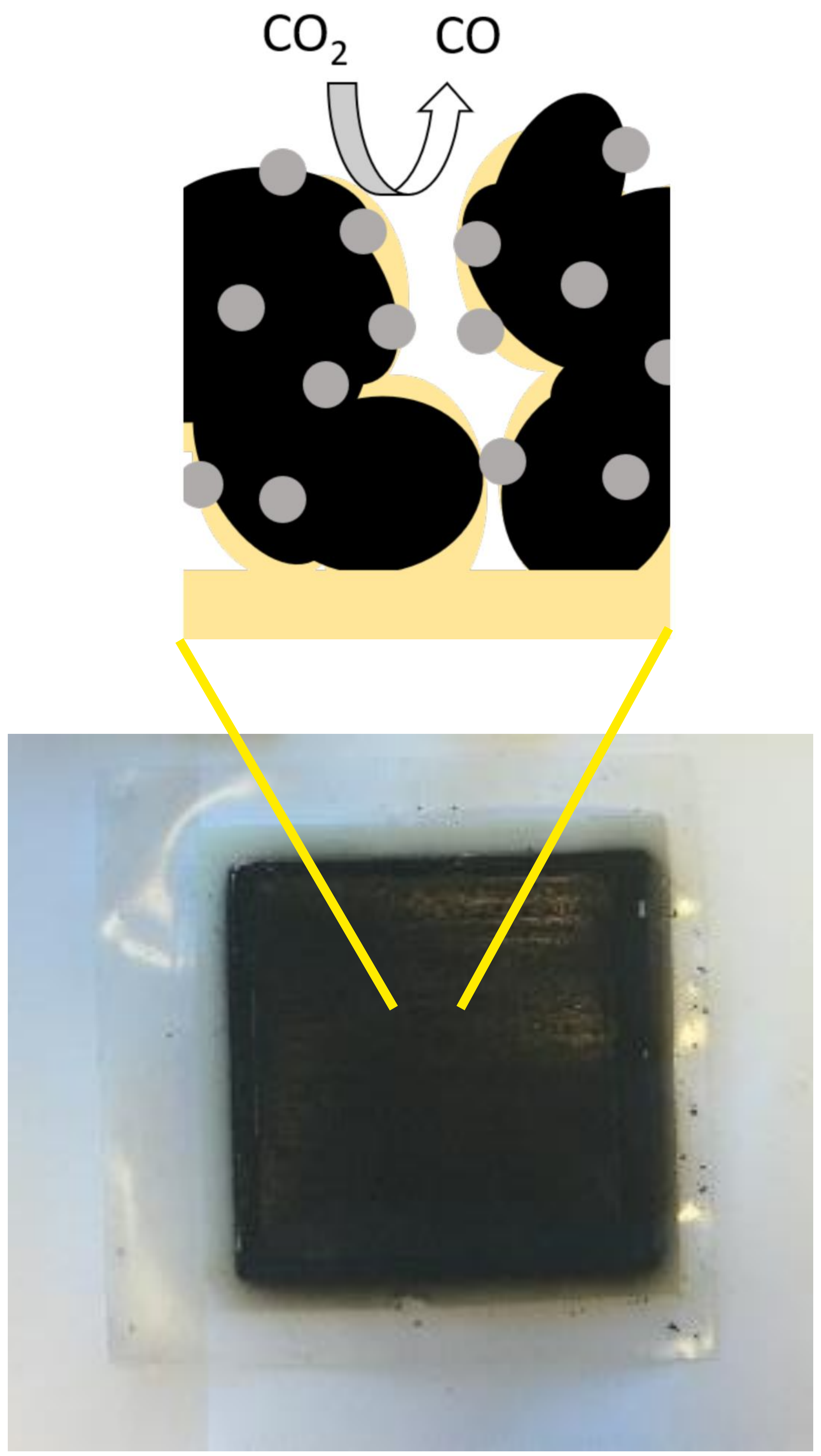
- Identified commercially available polymer-electrolytes
- Down selected to top 3 based on properties

Name	Property 1	Property 2	Property 3
Polymer 1	n/a	>60	≥0.06
Polymer 2	1.9-2.3	>120 at 80 C	n/a
Polymer 3	2.2-2.7	112 at 80 C	n/a
Polymer 4	TBD	TBD	TBD
Polymer 5	0.67 ± 0.1	22	n/a
Polymer 7	2.1-2.5	>80	n/a
Polymer 8	2.1-2.5	>80	n/a
Polymer 9	TBD	TBD	TBD
Polymer 10	1.1	n/a	0.045
Polymer 11	1.7-1.9	n/a	2.8
Polymer 12	1.2-1.4	4.5-6.5	1.2-2.0
Polymer 13	1.1-1.4	4.0-8.0	1.8-4.0
Baseline	1.9-2.1	4.0-5.0	1.8-4.0
Polymer 14	0.6-0.8	60-70	0.2-0.3

Task 3-5

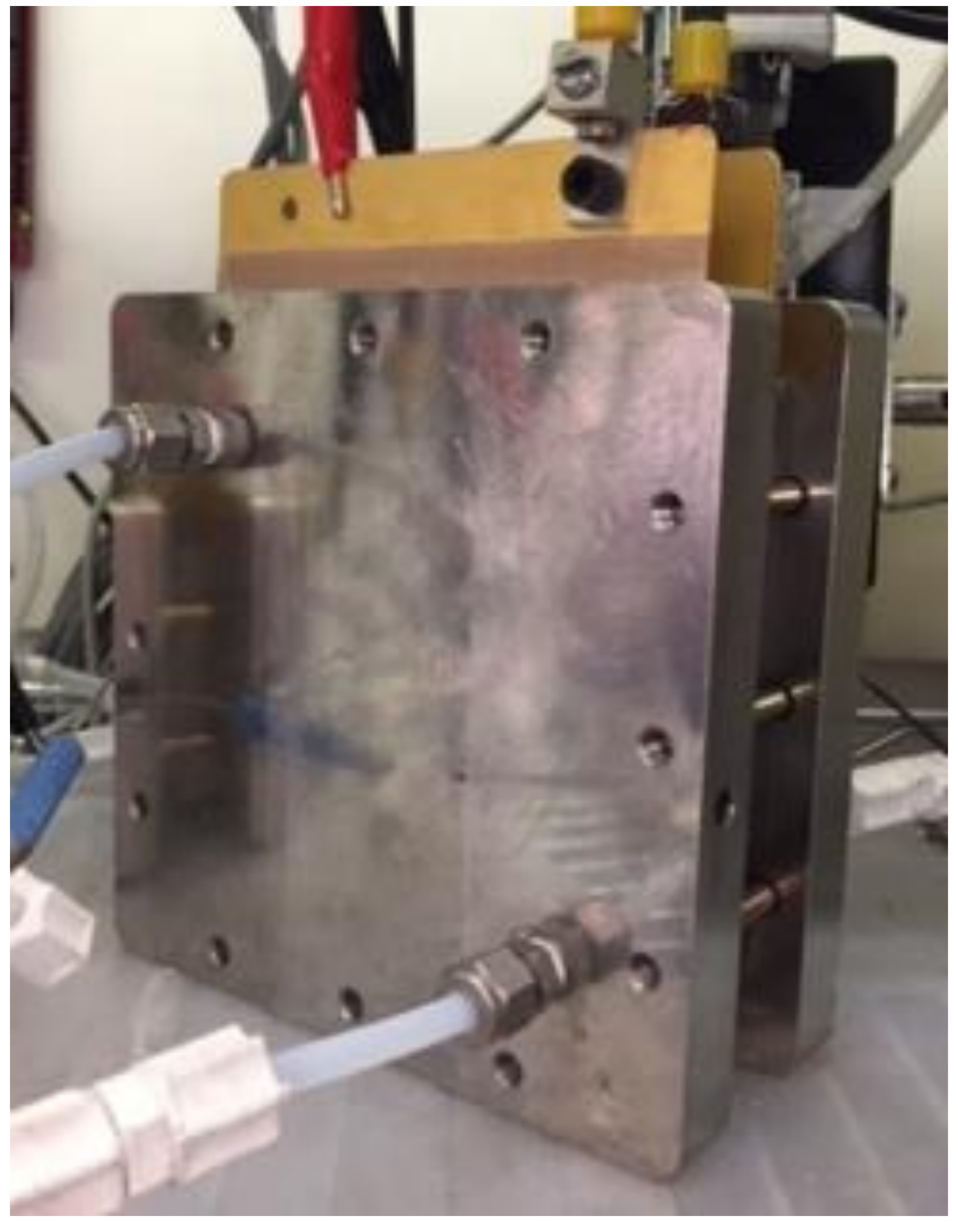
Ink formulation

Catalyst layer deposition



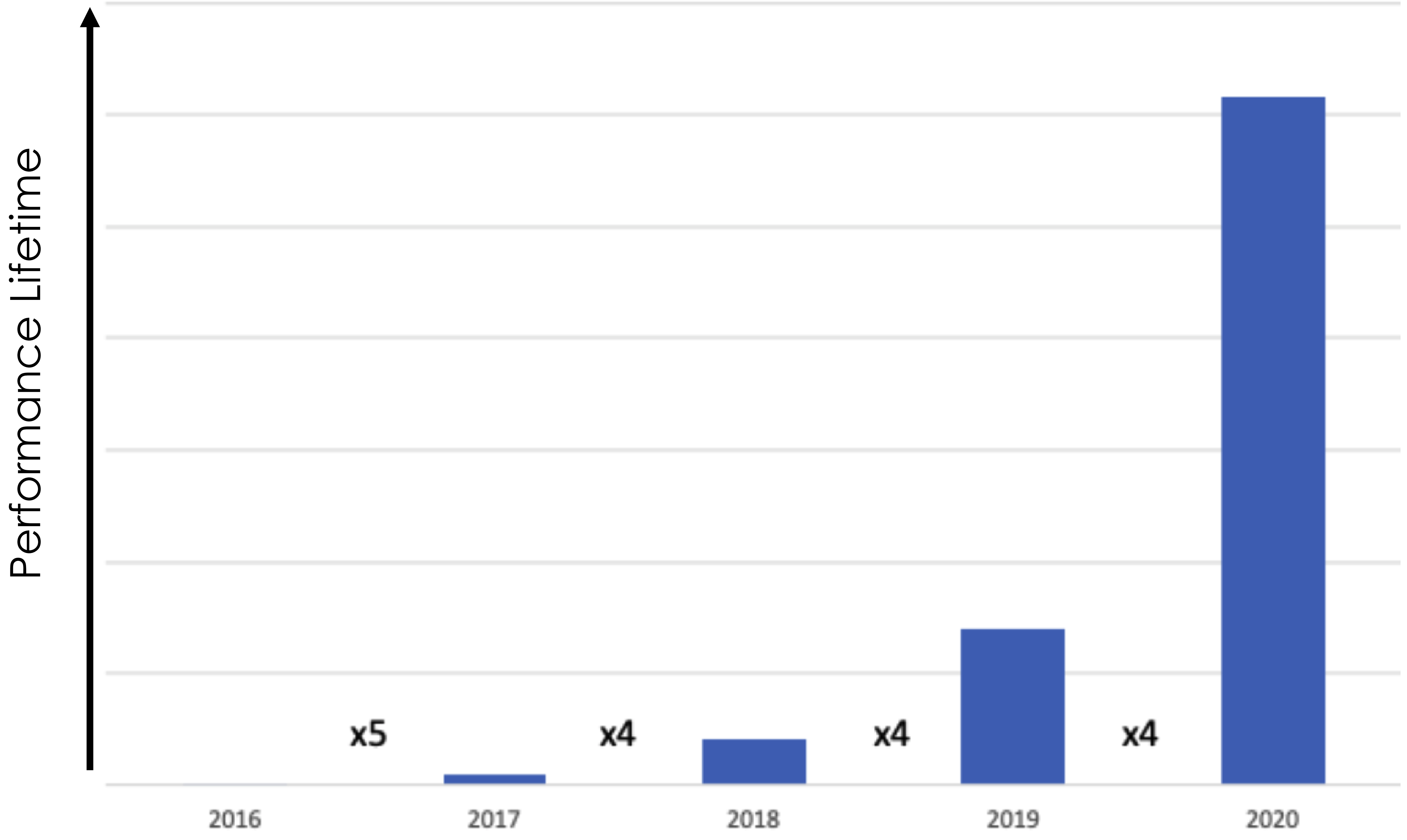
Membrane-electrode assembly

Short-term Performance testing



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

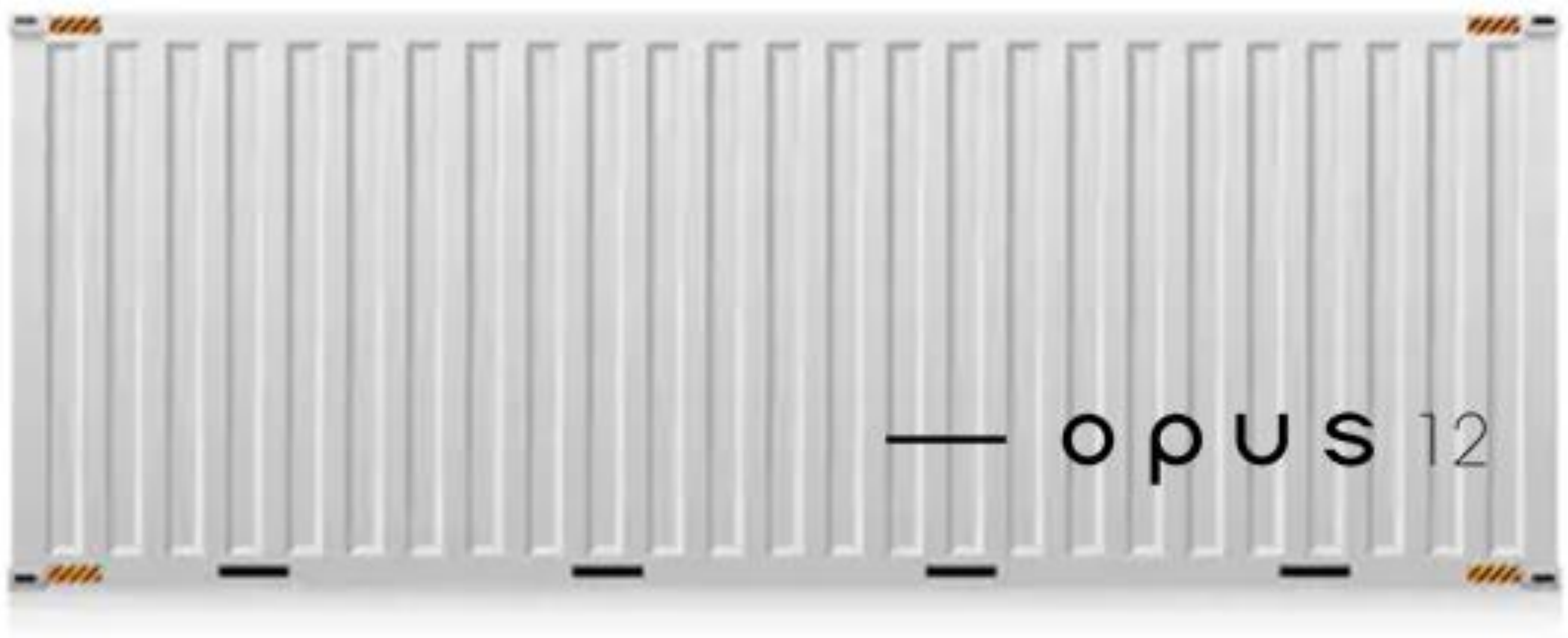
Task 6



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 CO_2, and 1 MW scale

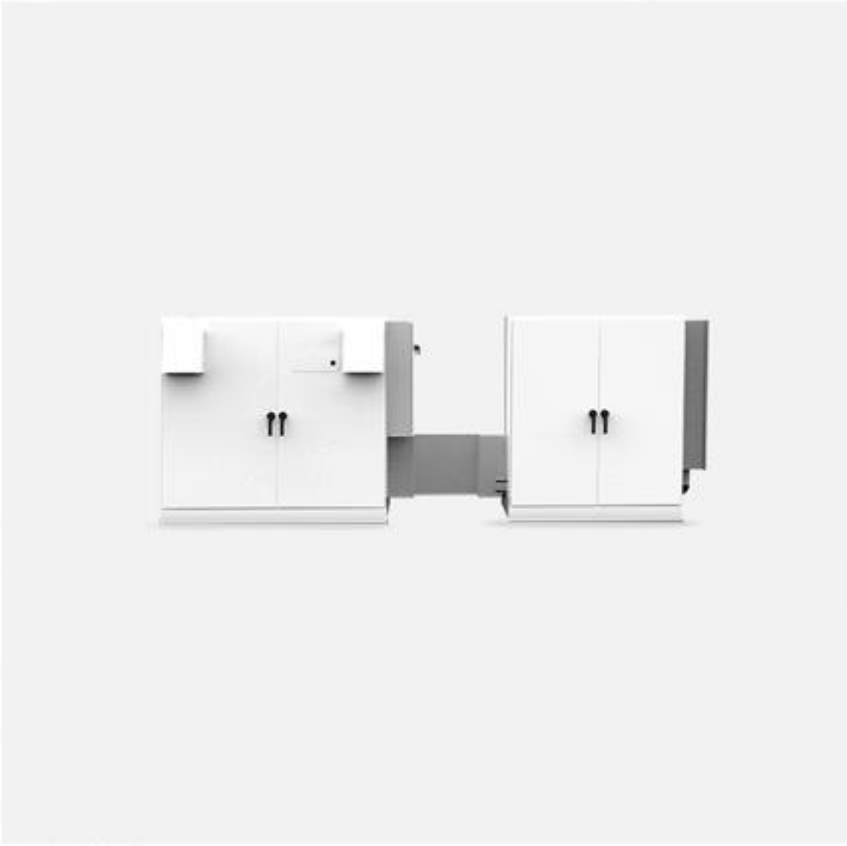
Scale-up Pathway

Integration into existing electrolyzer designs

1

2 kW

5 kg/ day CO_2



2

50 kW

350 kg/ day

3

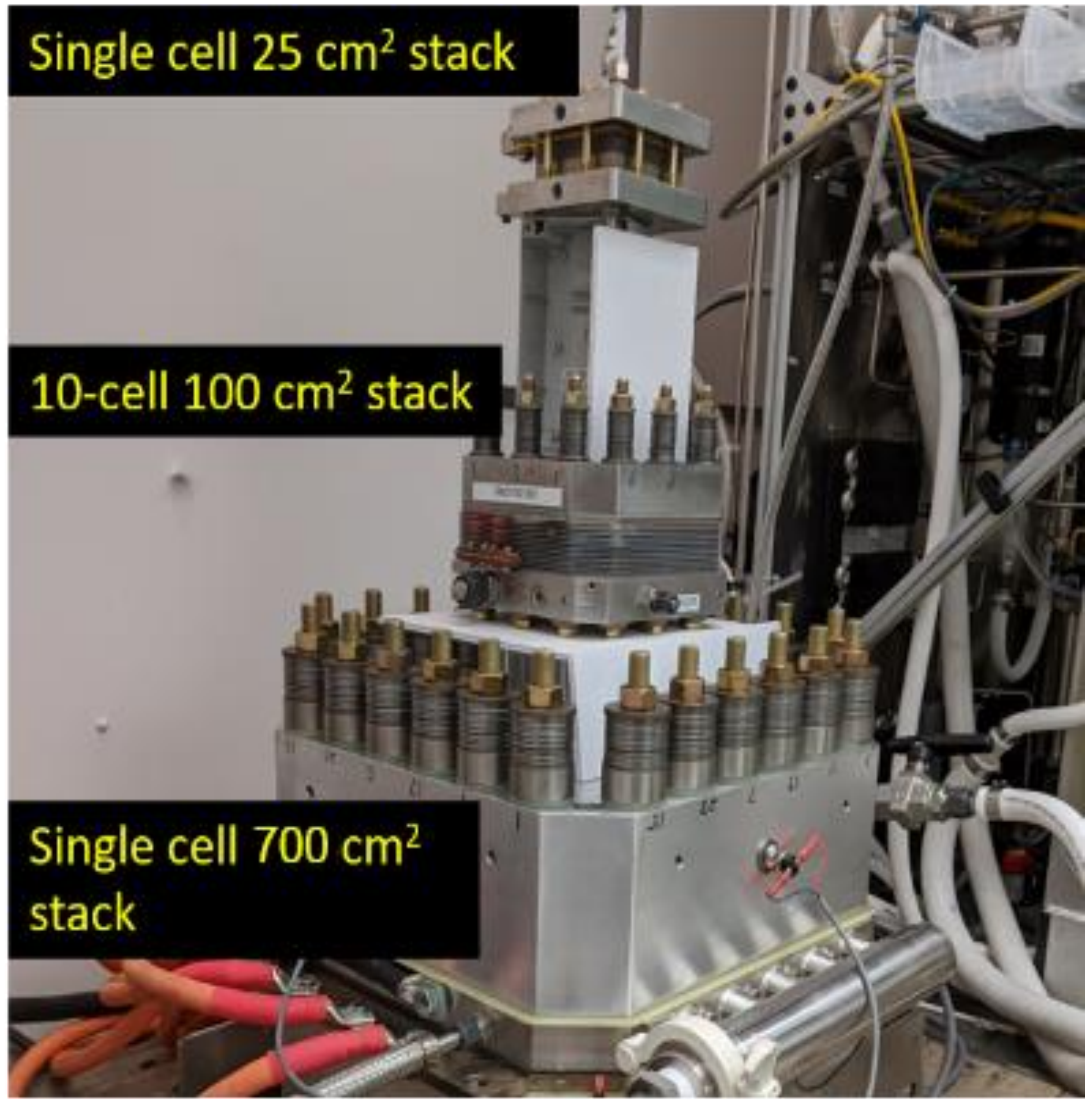
1 MW

7 tons per day

4

20-100+ MW

150 - 1,000+ tons per day



We partner with electrolyzer producers to build CO_2 conversion systems

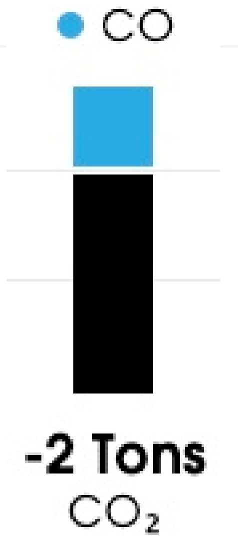
Convert waste CO_2 into chemicals

Modular units require no changes to customers' core operations and products are identical to existing fossil fuel derivatives

Case Study

Automotive

February, 13 2020: we unveiled the world's first car part made from CO_2 with Mercedes-Benz in Stuttgart, Germany



Carbon-Neutral PC

a. 2 tons of CO_2 offset per ton of CO

b. 10-15% Opus 12 CO by weight

Case Study

Jet Fuel

Carbon-Neutral Jet Fuel

Regular	▬	2.5 kg CO_2/L
e.jet	▪	<.4 kg CO_2/L with solar (85-100% reduction)

Opus 12's technology converts CO_2 to CO, which is upgraded to jet fuel

Application development funding:

Shell GameChanger

LanzaTech Successful test, summer 2020

U.S. AIR FORCE **$1.5 million contract signed for Opus 12 e-jet delivery in 2021**

e.jet

by — opus 12

Summary

Completed all project milestones to date

Current focus: Durability demonstration, TEA, and LCA

Clear path to scale and commercialize innovations

Organization Chart

- 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 CO_2 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

				Year 1				Year 2			
Task	Task Title	Start	End Date	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Project Management and Planning	1/25/2019	1/24/2021								
2	selection	1/25/2019	4/25/2019								
3	Ink formulation	4/26/2019	10/25/2019								
4	MEA Fabrication	10/26/2019	1/25/2020								
5	Energy Efficiency Testing	1/26/2020	4/25/2020								
6	Durability Testing	4/26/2020	10/25/2020								
7	Technoeconomic & Life Cycle Analysis	1/25/2020	1/24/2021								
	Total Project	**1/25/2019**	**1/24/2021**								