Recycling carbon dioxide through PEM electrolysis

Kendra Kuhl

Co-founder & CTO

OPUS12

REVERSE COMBUSTION

ISF-2 DOE Listening Day

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ECO2R can be thought of as “reverse combustion”

Overall Reaction:

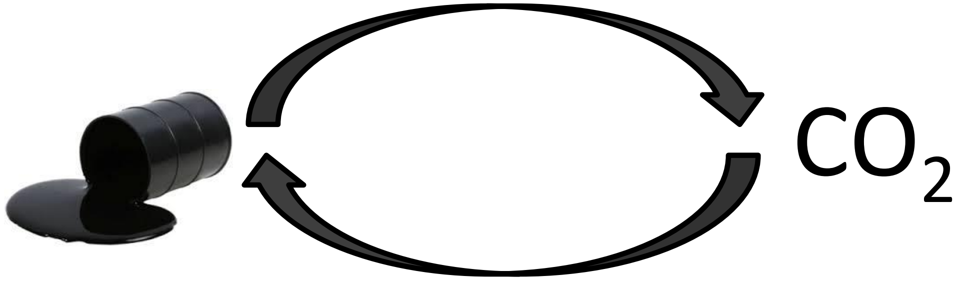
$$CO_2 + H_2O + \text{Energy} \rightarrow C_xH_yO_z + O_2$$

Split into electrochemical half reactions:

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

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

Our team: uniquely positioned to bring this product to market

NICHOLAS FLANDERS, CEO

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

KENDRA KUHL, CTO

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

ETOSHA CAVE, CSO

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

FOUNDING TEAM

SICHAO MA, SENIOR CHEMIST

PhD in Chemistry,
University of Illinois Urbana-Champaign
Research: ECO2R ethylene catalysis, reactor design

GEORGE LEONARD, SENIOR CHEMIST

BS Chemistry,
Carnegie Mellon
Work Experience: CO_2 catalysis, reactor design - Liquid Light

DANIEL DIAZ, CHEMIST

MS Material Science,
University of Michigan
Work Experience: Silicium

FIONA FOTHERBY, JUNIOR ENGINEER

BS in Chemistry,
University of

ZIYANG HUO, SENIOR CHEMIST

PhD in Chemistry,
UC Berkeley/Tsinghua University
Research: Nanoparticle catalyst synthesis

ANNIE ZENG, ENGINEER

BS Mechanical Engineering
Olin College of Engineering
Work Experience: Alteros

KEN HUA, JUNIOR ENGINEER

MS in Materials Engineering,
Northwestern

Traction: Scaling up our record-setting prototype at Lawrence Berkeley National Lab

FEDERAL GRANTS

U.S. DEPARTMENT OF ENERGY

NASA

NSF

arpa·e
Advanced Research Projects Agency • ENERGY

DOE
Small Business Vouchers Pilot
U.S. DEPARTMENT OF ENERGY

COMMERCIAL

PROTON
THE LEADER IN ON SITE GAS GENERATION.

Shell GameChanger

SoCalGas
A Sempra Energy utility

INCUBATORS & ACCELERATORS

cyclotronroad

Breakout Labs

StartX

MOLECULAR FOUNDRY

TomKatCenter
FOR SUSTAINABLE ENERGY
STANFORD UNIVERSITY

evōk
INNOVATIONS

ELEMENTAL EXCELERATOR

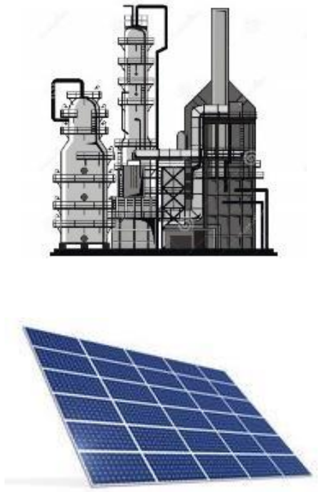
The Roddenberry Foundation

IP STRATEGY: SCHOX, PLC

Our approach: a platform technology that recycles CO_2 back into chemicals and fuels

1

INPUTS: CO_2, WATER, ELECTRICITY



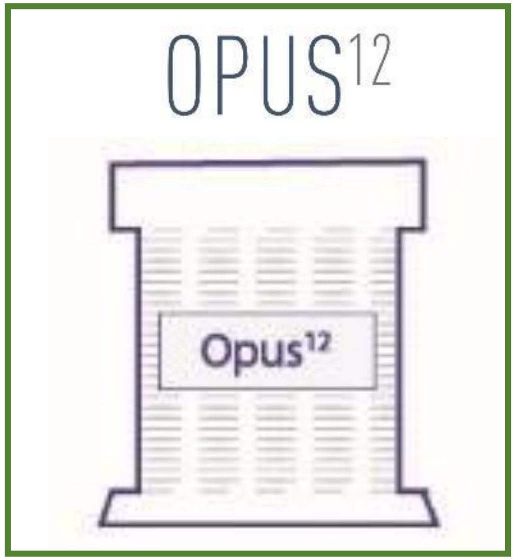
CO_2

H_2O

ELECTRICITY

2

ELECTROCHEMICAL REDUCTION OF CO_2



PEM Electrolyzer

3

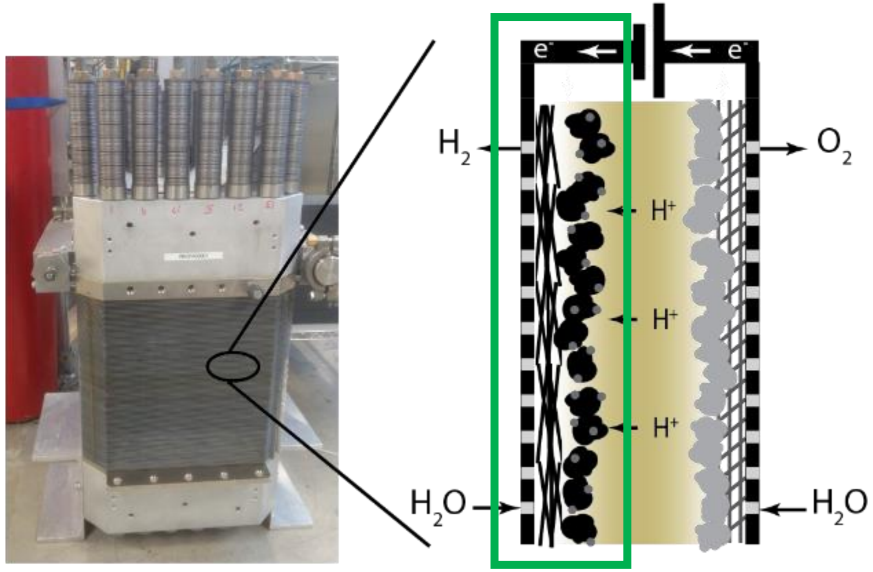
OUTPUTS: PRODUCTS THAT DROP INTO EXISTING SUPPLY CHAINS

CHEMICALS & FUELS

PURE O_2

We are converting a commercial-scale water electrolyzer into a CO_2 electrolyzer.

COMMERCIAL PEM WATER ELECTROLYZER



OPUS 12 PEM CO_2 ELECTROLYZER

Innovations in Opus 12's new catalyst layer:

- Metal nanoparticle catalysts
- Novel polymer materials
- Anode unchanged

Opus 12 has developed a breakthrough drop-in solution that enables us to use existing PEM architecture. This significantly reduces scale-up risk and capital costs.

PEM electrolyzers

By integrating into a PEM electrolyzer, we capture all of the benefits of an existing industrial reactor design, while significantly reducing scale-up risk

Advantages

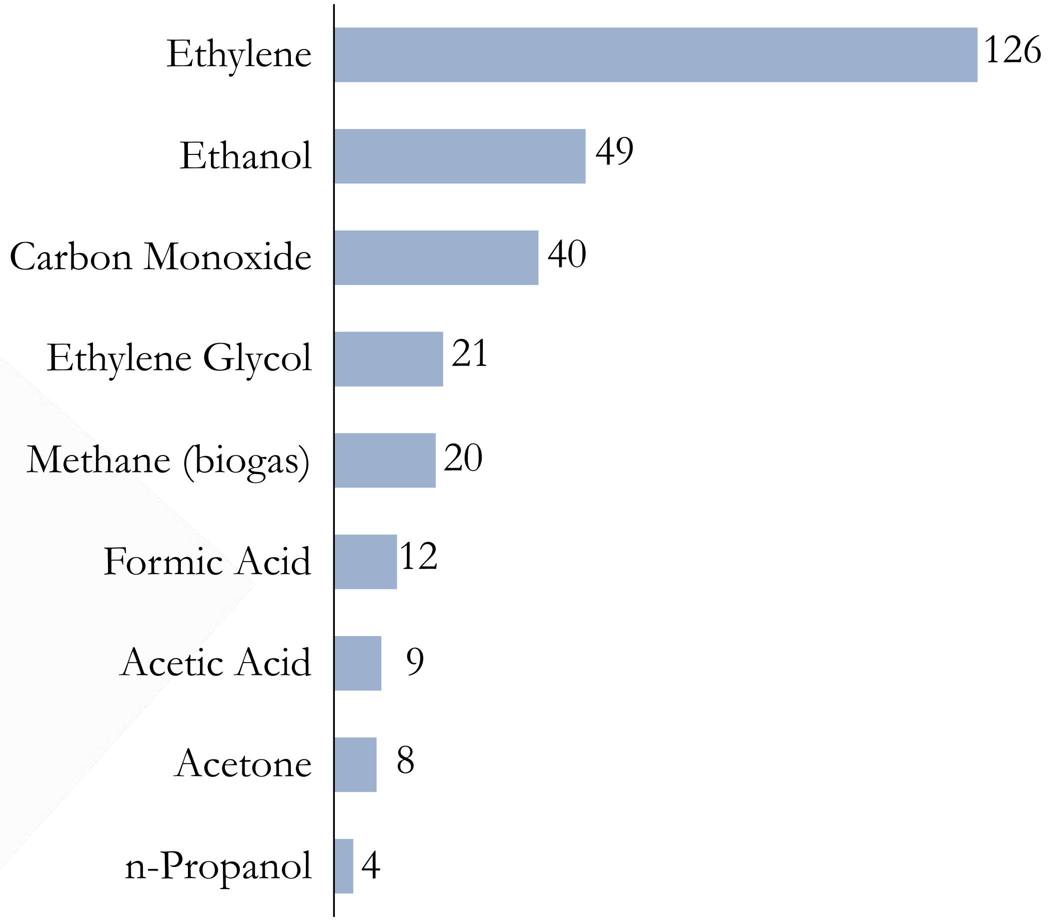
- **Commercial readiness** – deployed around the world for decades
- **Fast ramp times** – enables use of intermittent low-cost electricity (modern systems can integrate directly with a wind turbine)
- **Low capex** – thanks to years of commercial development and mild operating conditions
- **Modularity and scalability** – allows for integration with CO_2 sources of diverse volumes
- **High current density**, leading to a small footprint
- **Operational simplicity** – no need for specialized operators on site

Electrochemical CO_2 conversion (ECO2R): a $300 billion global market

The global market for our technology is huge and diversified: nearly $300 billion and growing at over 4% per year.

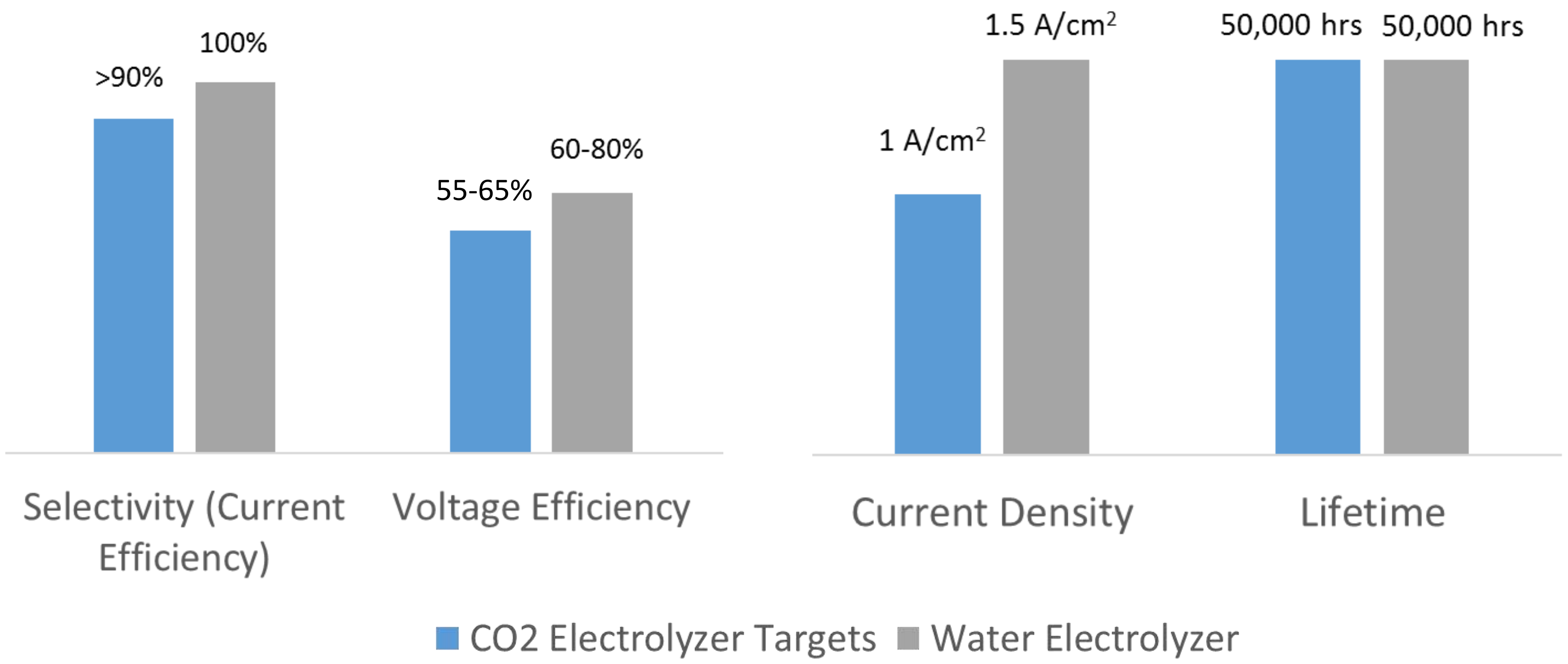
Our team has demonstrated the electrochemical conversion of CO_2 into 16 different products; the top nine by market value are illustrated here

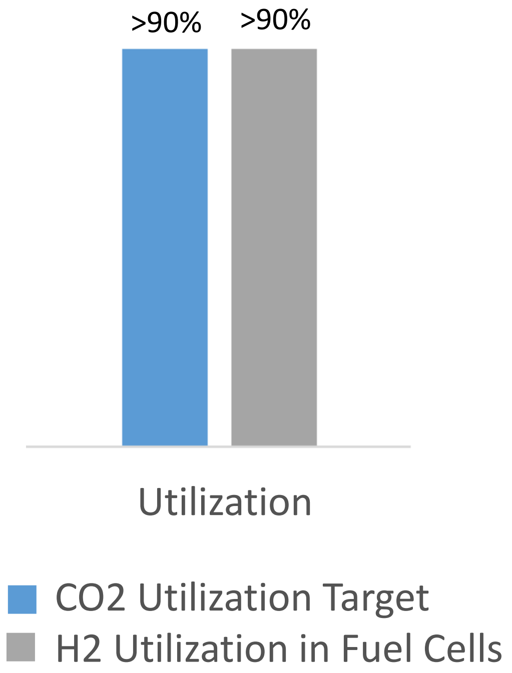
PRODUCT $BILLION, GLOBAL SALES



TOTAL PRODUCTS: $300 BILLION

Performance Targets





ECO2R Enables Emerging Markets

- Complimentary to biological processes
  - CO_2 produced from fermentation/anaerobic digestion could be converted into additional product

- Feedstock for biological processes
  - Products of ECO2R can be fed to microbes as an energy & carbon source

Carbon-neutral, zero land use feedstock for biological processes

CO_2

H_2O

ELECTRICITY

CO

PRODUCTS

Fuel

Food

Materials

Chemicals

Bioreactor image from:
Steel Times International
April 2013

OPUS 12

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Etosha Cave

George Leonard

Daniel Diaz

Sichao Ma

Annie Zheng

Fiona Fotherby

Kenneth Hua

Ziyang Huo

Scientific Advice:

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Tom Jaramillo, Stanford

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Mike Tucker, LBNL

John Newman, UC Berkeley

Adam Weber, LBNL

Nate Lynd, UT Austin

Mark Warner, Warner Advisors

Ilan Gur, Cyclotron Road

Nem Danilovic, LBNL

cyclotronroad

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ENERGY TECHNOLOGIES AREA (ETA)

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TomKatCenter FOR SUSTAINABLE ENERGY
STANFORD UNIVERSITY

The Roddenberry Foundation

SoCalGas
A Sempra Energy utility

arpa·e
Advanced Research Projects Agency • ENERGY

Thank you for your attention