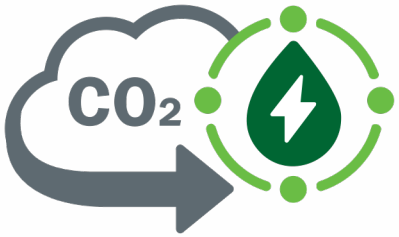


CO_2 Reduction and Upgrading for e-Fuels Consortium

U.S. DEPARTMENT OF ENERGY

DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

CO_2 Reduction and Upgrading for e-Fuels Consortium (CO_2RUe)

April 6, 2023

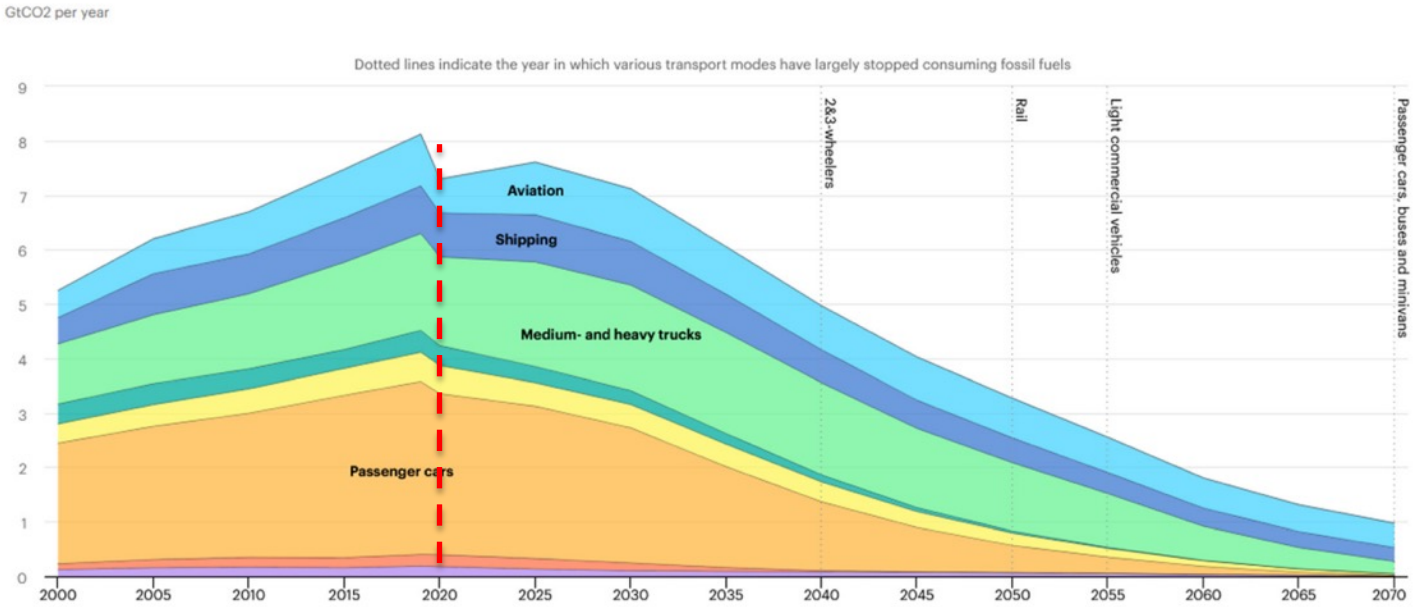
CO_2 Conversion

Michael G. Resch - Director

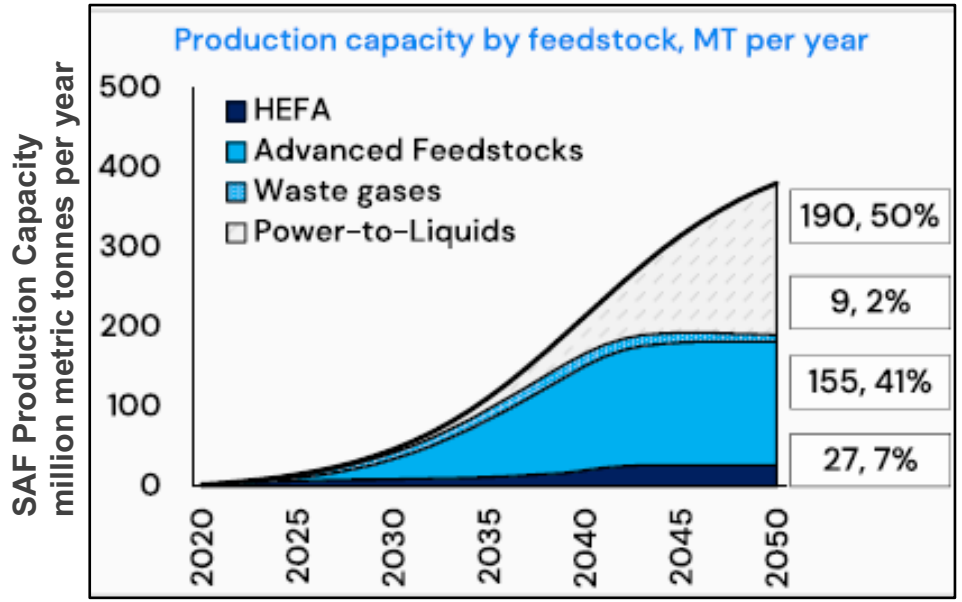
NREL

Project Overview: *A Change in Trends*

Electrification of the Transportation Sector



Increasing SAF Demand



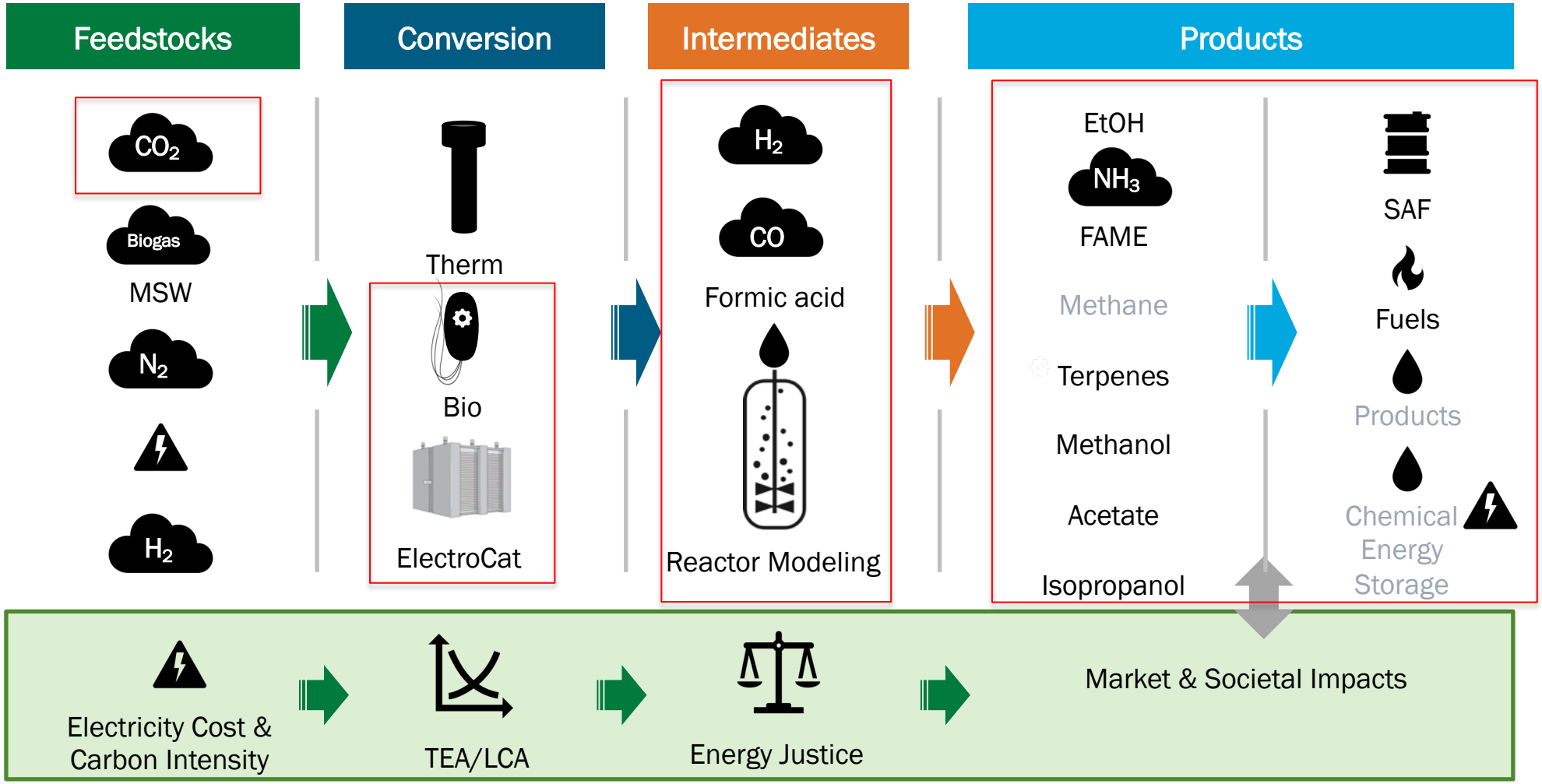
Challenge: *Commercial shipping and transportation expected to be difficult to electrify/decarbonize. Projected supply of traditional biomass feedstocks may be insufficient to fully meet global demand. CO_2 as a feedstock could help meet SAF Grand Challenge*

IEA, energy technology perspectives 2020
ICF, Fueling Net Zero: How the aviation industry can deploy sufficient sustainable aviation fuel to meet climate demands

CO_2RUe Approach

Develop technologies to upgrade CO_2 to fuels and chemicals in order to reduce GHG emissions as well as land and water use and incentivize decarbonization.

1. Waste Gas Research Areas



1. Approach: *Emerging Opportunities Involving CO_2*

H_2-mediated Conversion Technologies

$$CO_2 + H_2 \rightarrow CO + H_2O$$
$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Fischer-Tropsch
Reverse Water-gas Shift
Catalytic Hydrogenation to Methanol
Methanol to Olefins
Methanol to Gasoline

↑Heat, ↑Pressure, ↑Scale, ↑TRL

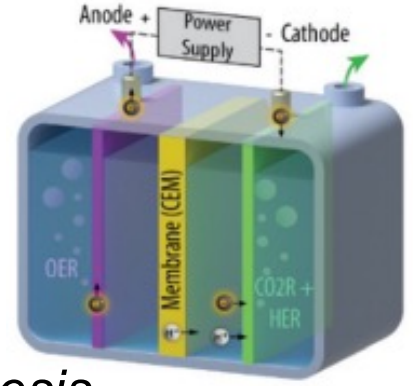
Electron-mediated Emerging Technologies

$$CO_2 + 2e^- + 2H^+ \rightarrow CO + H_2O$$
$$2CO_2 + 12e^- + 12H^+ \rightarrow C_2H_4 + 4H_2O$$

Electrolysis

Non-thermal Plasma

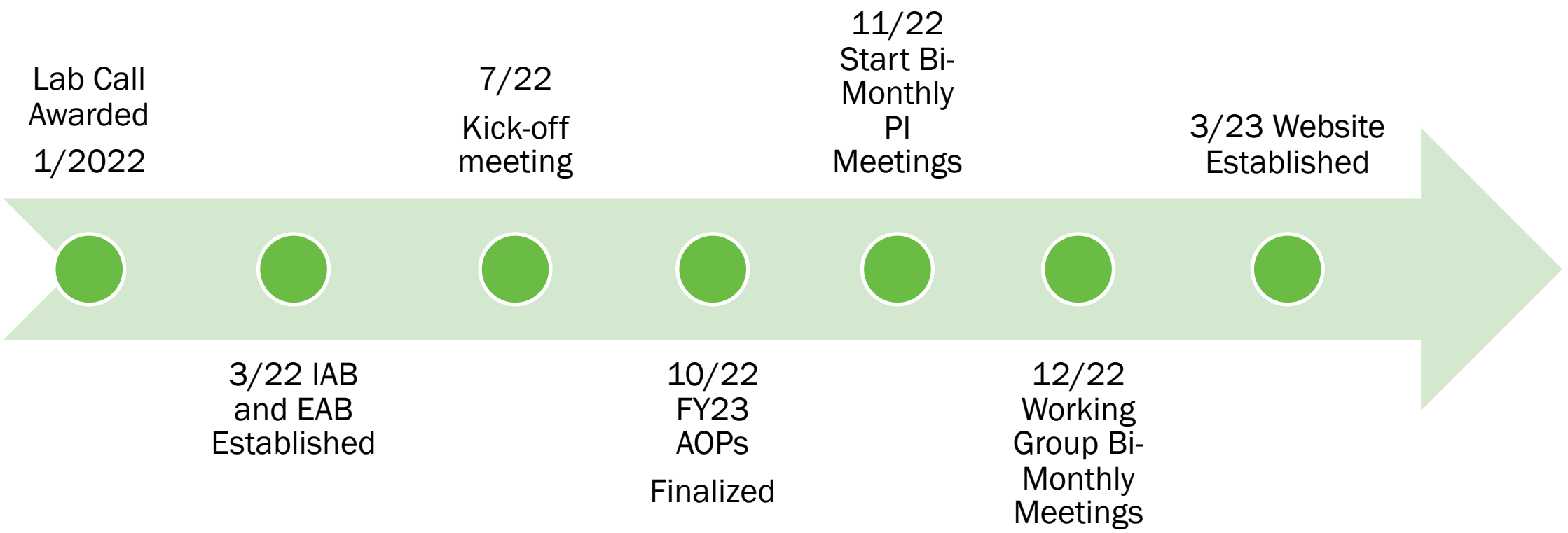
Microbial Electrosynthesis



↓Heat, ↓Pressure, ↓Scale, ↓TRL

Opportunity: *Emerging direct-electrification pathways show promising attributes, but low in TRL and in need of more R&D*

1. Lifetime of the CRUE Consortium



1. How We Work Together

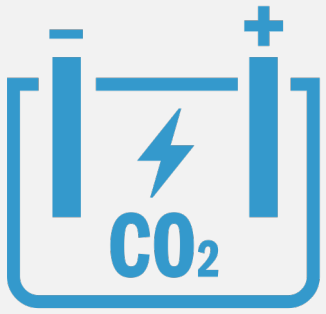
U.S. Department of Energy
TM: Ian Rowe
PM: Sophia Becker

External Advisory Board (EAB)

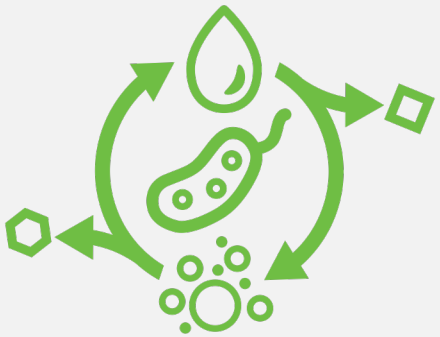
Consortium Lead
Director: Michael Resch
PM: Kimmy Mazza

Internal Advisory Board (IAB)

CO_2 Electrolysis
(E-COWG)



Biological Upgrading
(B-COWG)



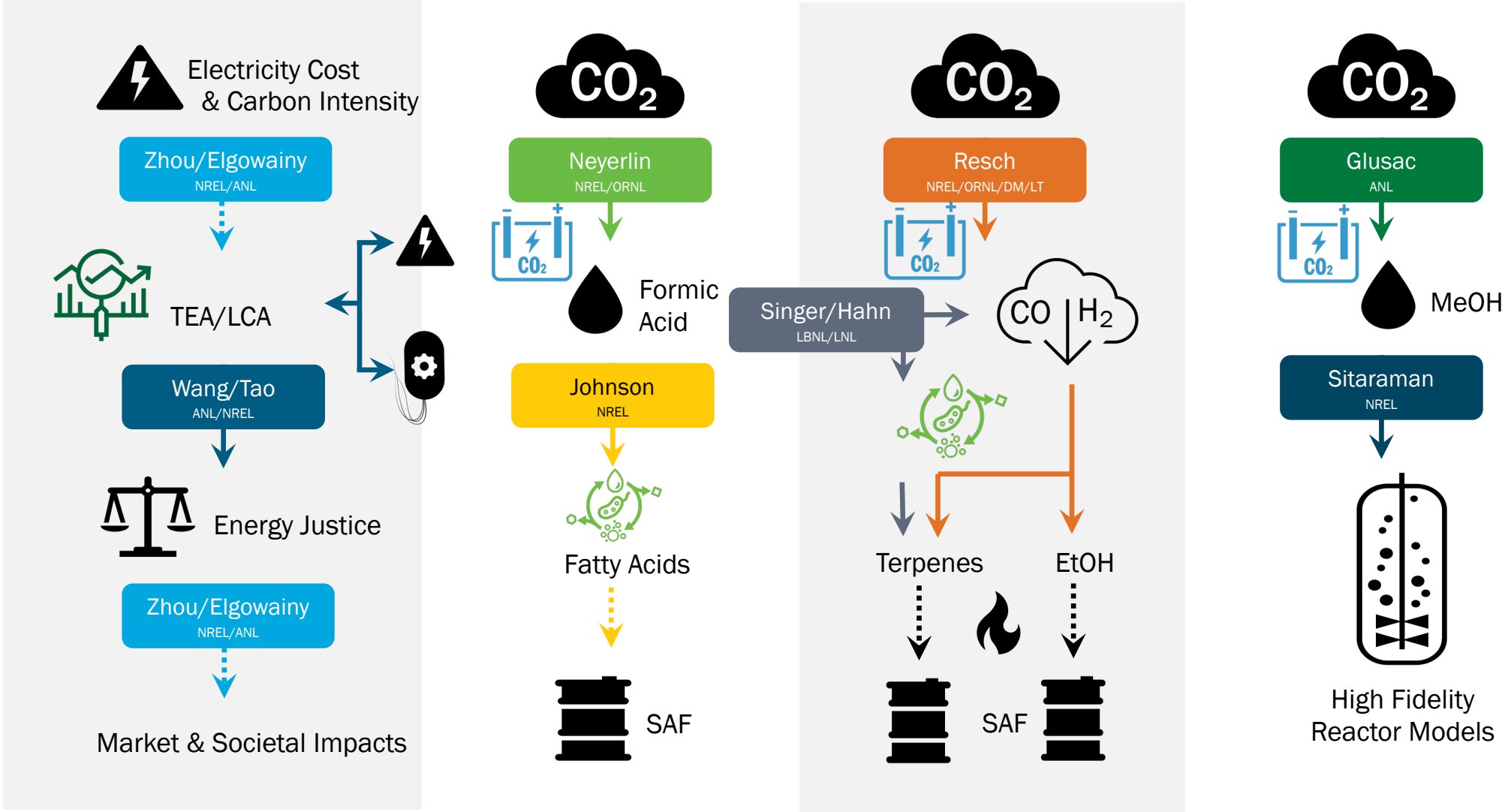
Analysis and Modeling
(A-COWG)

(COWG) CO2 Working Group

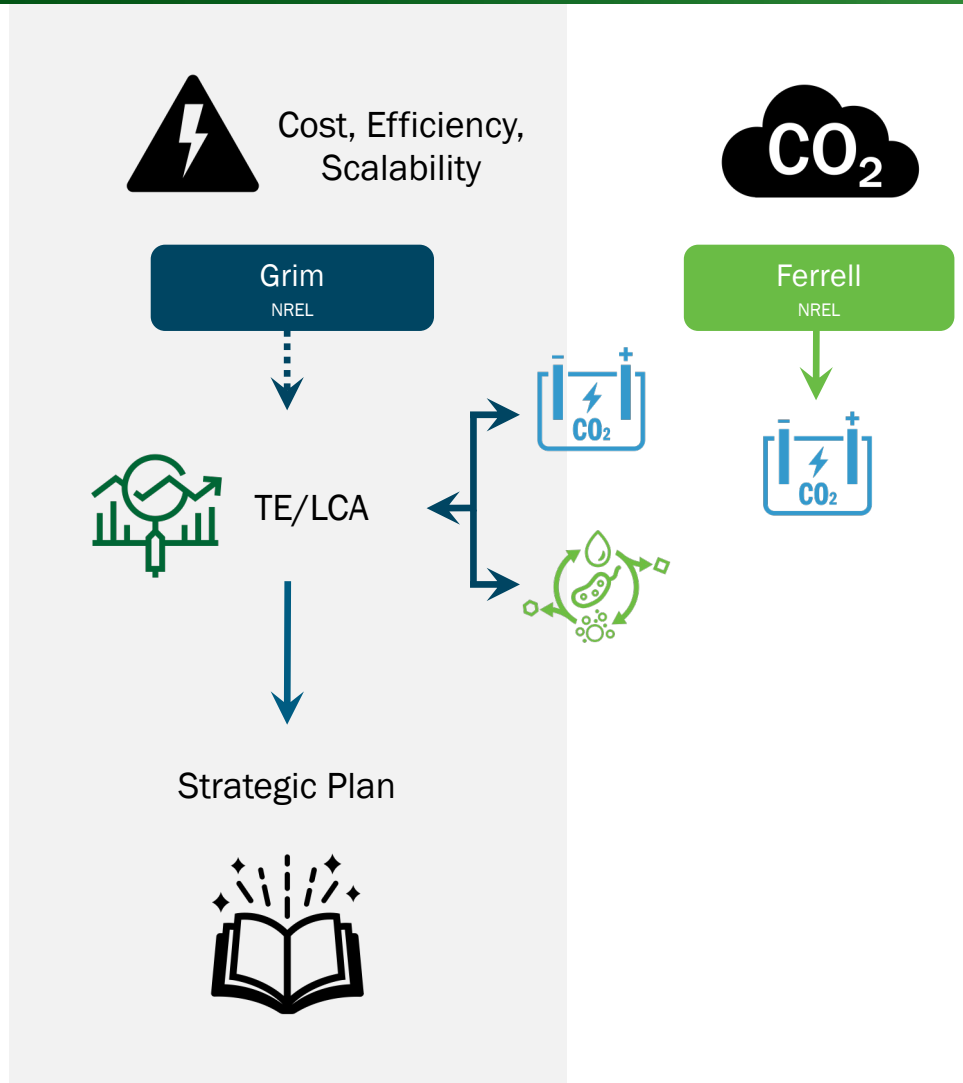
1. Challenges and Risk Mitigation

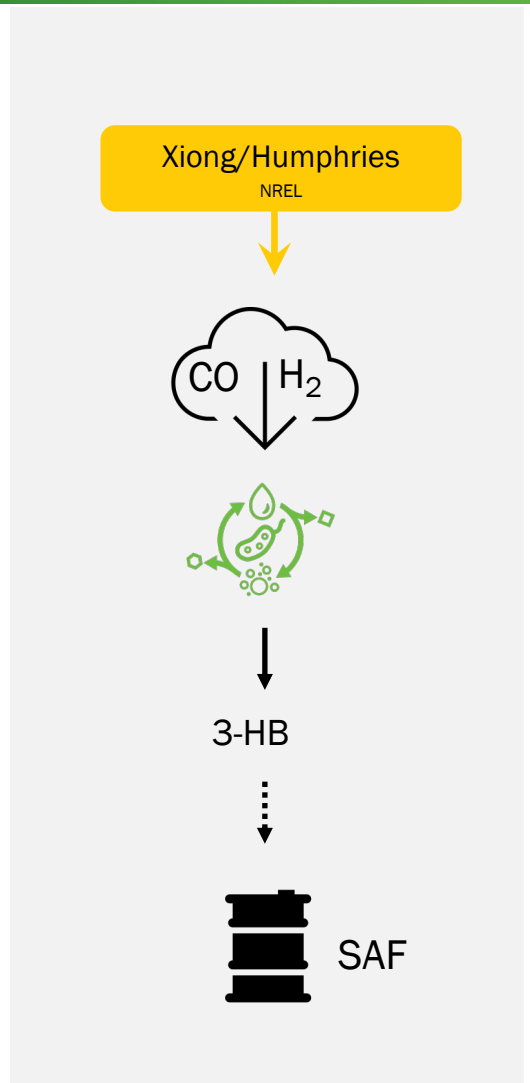
CO_2RUe Risk Factors	Risk Mitigation
Early-Stage Research difficult to de-risk and demonstrate	Outreach to EAB, industry, stateholders and research to address barriers
Siloed Projects	Working group communication, collaborative milestones
Electricity and CO_2 feedstock supply expensive and limited	Leverage BETO analysis models on location, cost and availability 2030 & 2050
Large uncertainties of incentives	Establish technologies with the potential for cost parity with conventional SAF

2. Progress – FY21 Lab Call Selected Projects

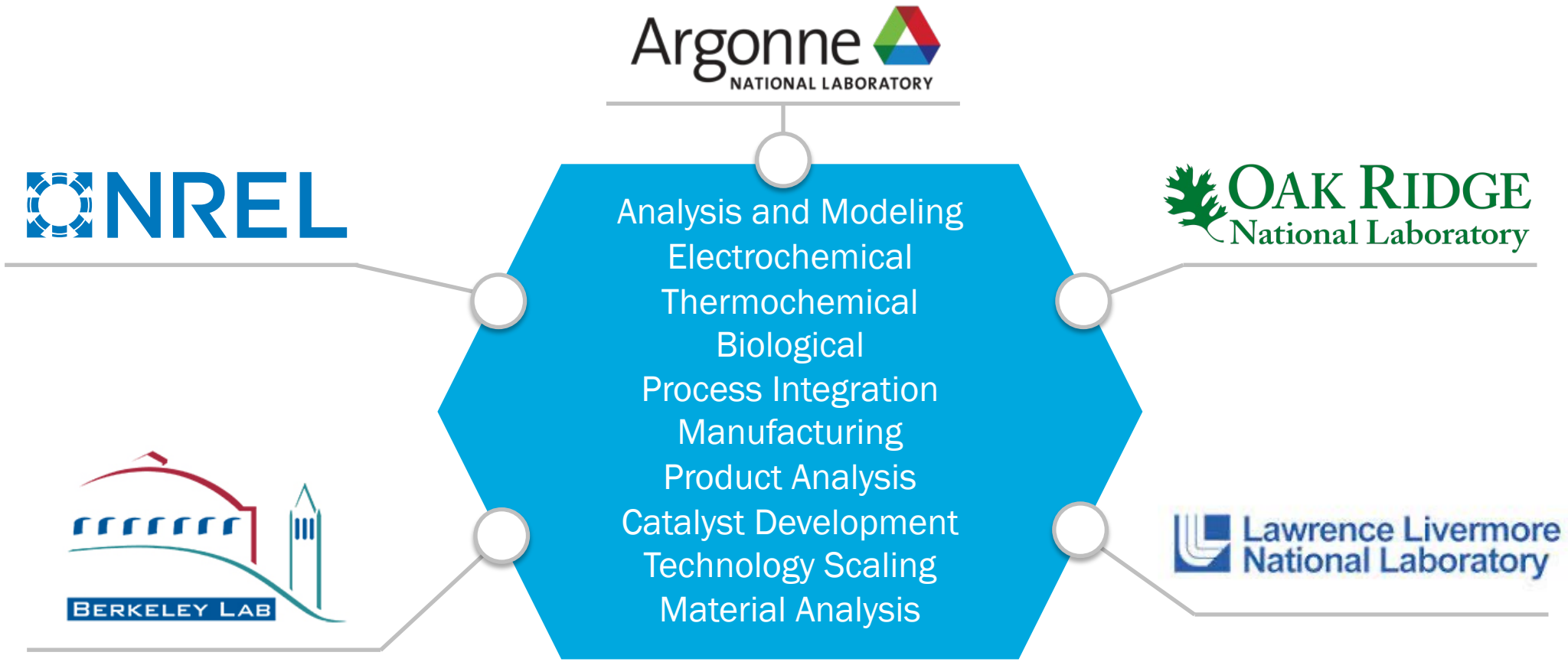


2. Progress – Existing CO_2 Projects

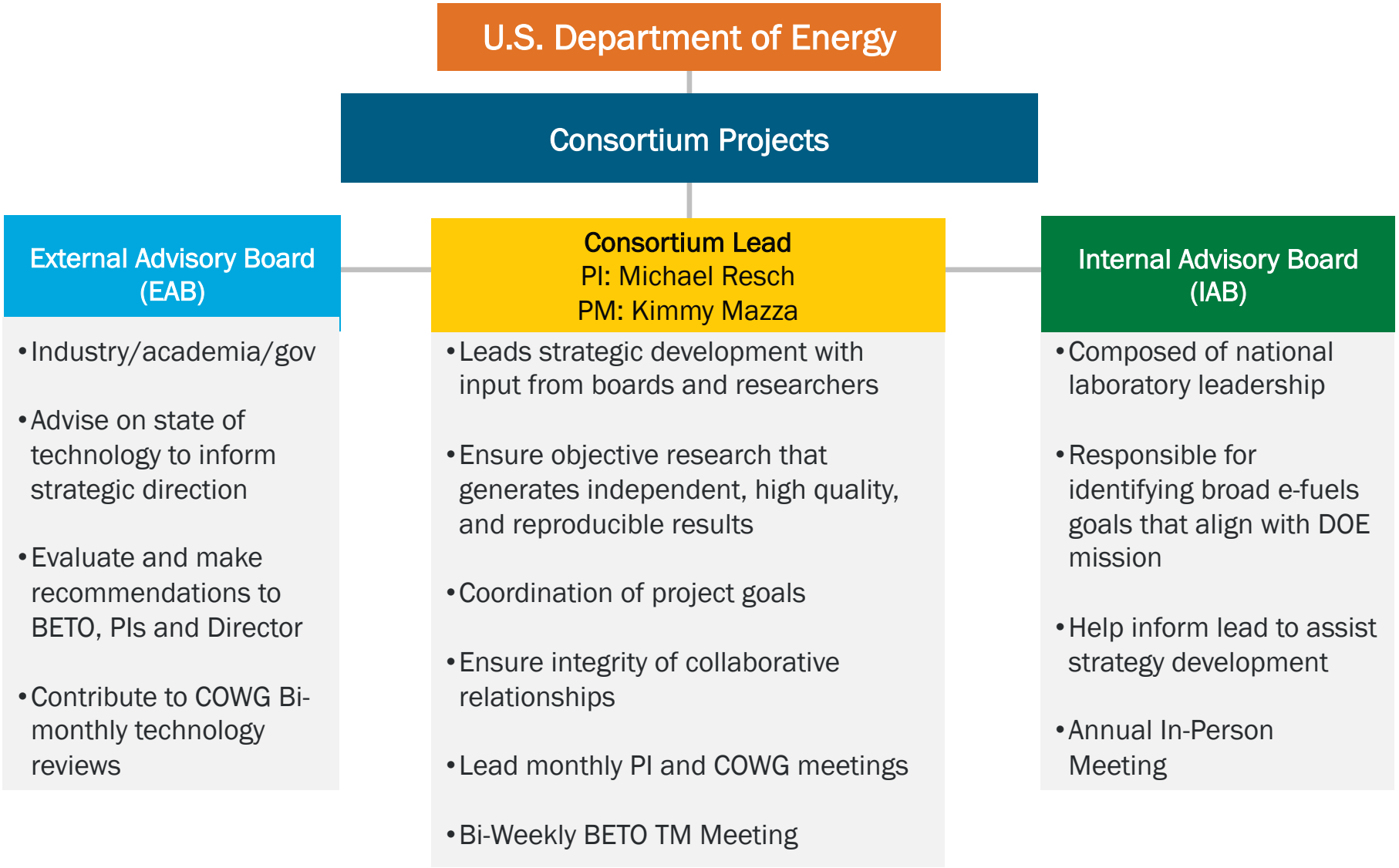




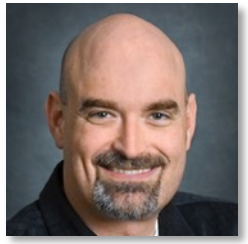
2. Lab Capabilities



2. CO_2RUe Consortium Structure



2. Internal Advisory Board (IAB)



LBNL – **Blake Simmons**, Division Director, Biological Systems & Engineering

NREL – **Adam Bratis**, Associate Lab Director

LLNL – **Roger Aines**, Energy Program Chief Scientist in E Program

ANL – **Seth Darling**, Chief Science & Technology Officer in Advanced Energy Technologies Directorate

ORNL - **David Scholl**, Director Transformational Decarbonization Initiative

2. External Advisory Board (EAB)

Feedstocks/CO_2 producers
Eric Hittinger – RIT
Dave Carlson – POET

Electrochemical
Tyler Petek – Lubrizol
Matt Kanan – Stanford
Kathy Ayers – Nel

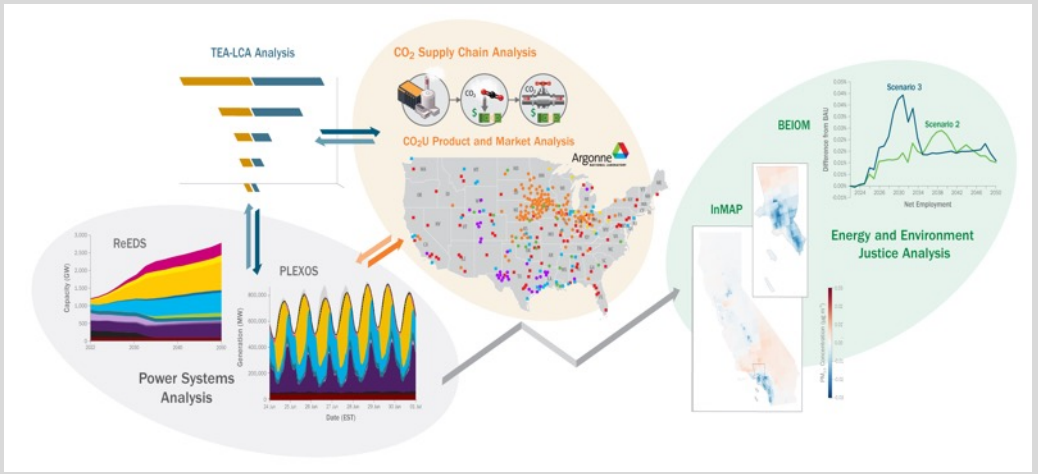
Biological
Jan Westpheling – University of GA
Mich Hein – Electrochaea

Thermochemistry/Fuels
Clare Behrens – Leidos
Aalo Gupta – Phillips 66

2. Near term activities

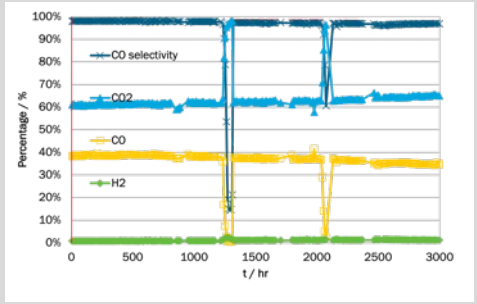
- ✓ **Regular meetings with PIs and Advisory Board**
- ✓ **CO_2 to fuels Strategic Plan report and publication**
- ✓ **Establish pathway technical targets**
- ✓ **Develop Consortium website and communication**
- **Learning Materials**
  - DEIA directed opportunities for students and teachers

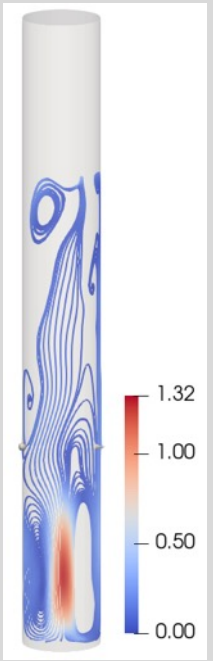
2. Technical Accomplishments



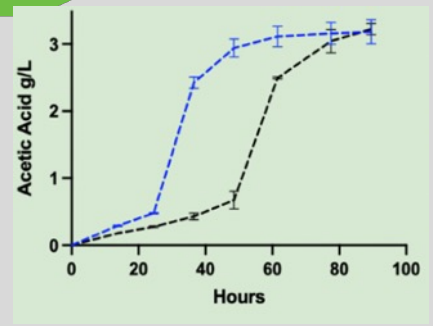
Identifying economic and environmental Drivers

Electrolyzer design

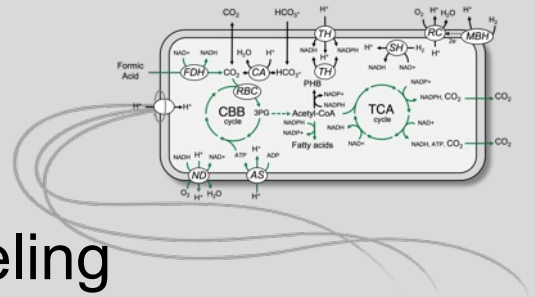




Reactor modeling



Metabolic engineering

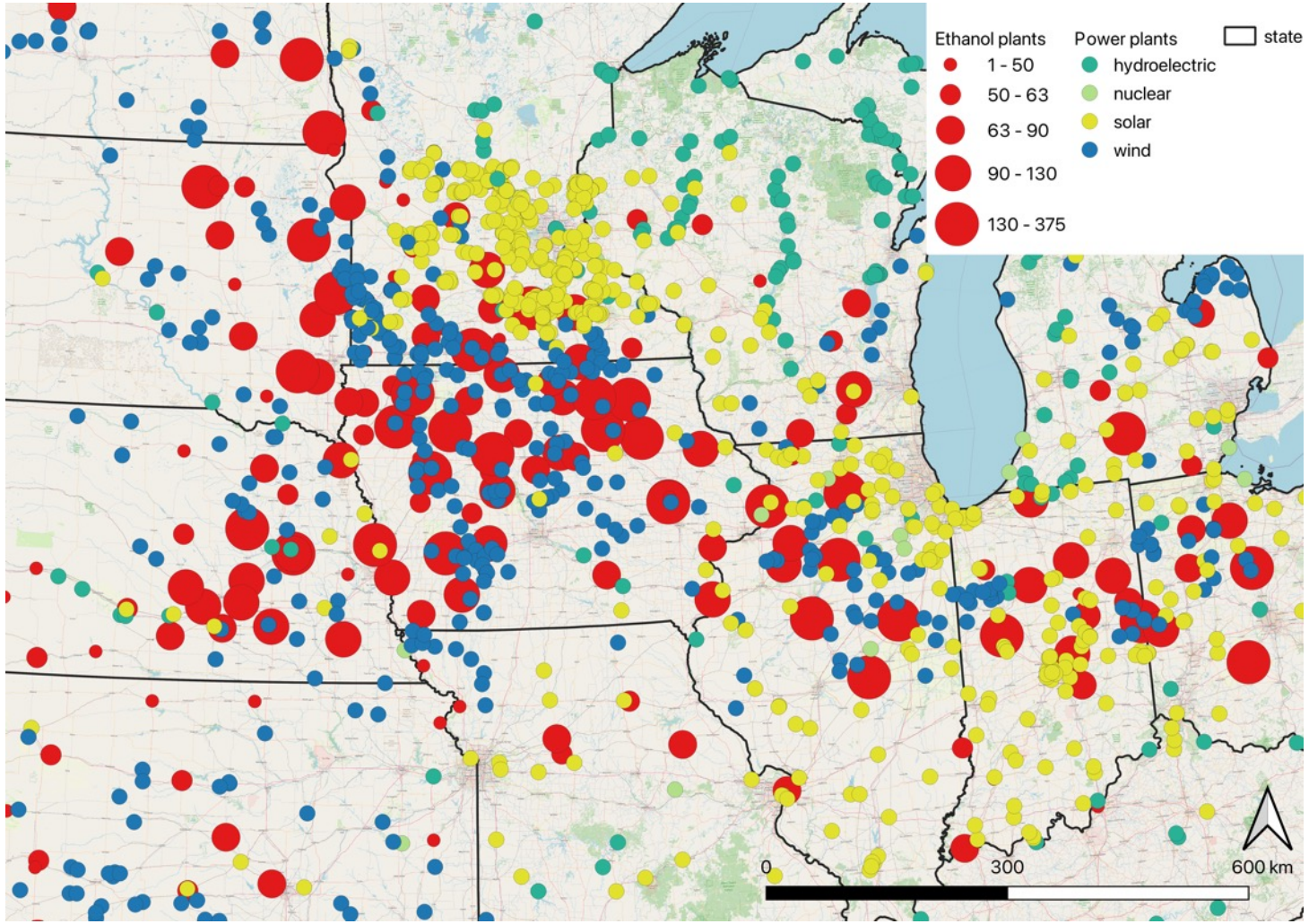


3. Impact

- Understand how much CO_2 derived fuels could contribute towards **SAF Grand Challenge** of 3 B gallons SAF by 2030, 35 B gallons by 2050
- Focus on products with a **50% reduction in GHG emissions**
- Engage industry in **partnerships to** Identify opportunities
- High impact journal publications, conference presentations and webinars
- Cross lab **collaborations**
- **Partnering** with other CO_2 Consortia
- **Integration** of projects and pathways
- Incentivize waste CO_2 utilization
- **Derisk technologies** toward commercialization and deployment

3. Setting Near Term Technical Targets

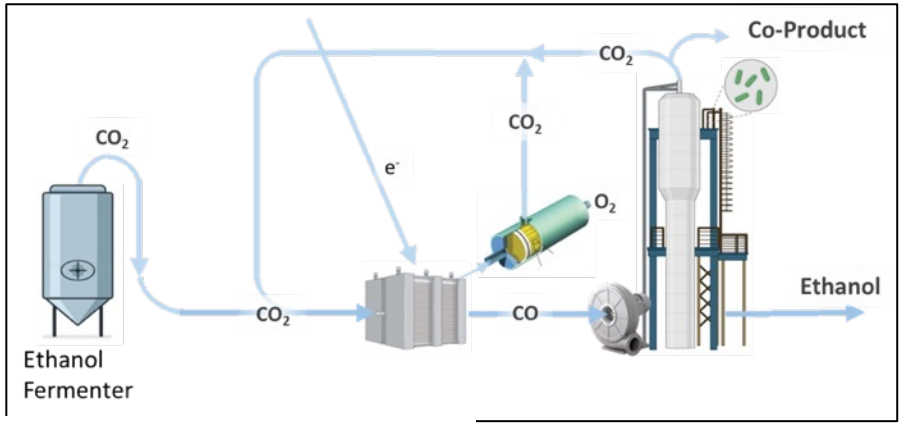
- **Feedstocks (siting, availability, cost)**
  - Low Carbon Electricity
  - CO_2
- **Electrochemcial**
  - Carbon efficiency
  - e^- efficiency
  - Scalability
  - Robustness
- **Fermentation**
  - T-R-Y
  - Carbon efficiency
  - Reactor design



3. Impact of the Integration of Renewable Electricity with Ethanol Refineries to Valorize Biogenic CO_2 Emissions

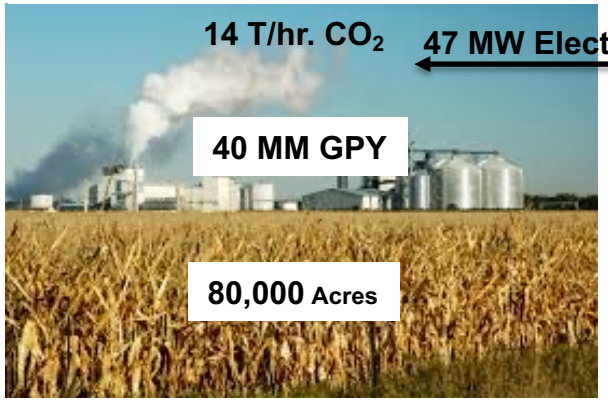
3. What If We Could Convert Biogenic CO_2 From a Gen. 1 Ethanol Refinery into Additional Product?

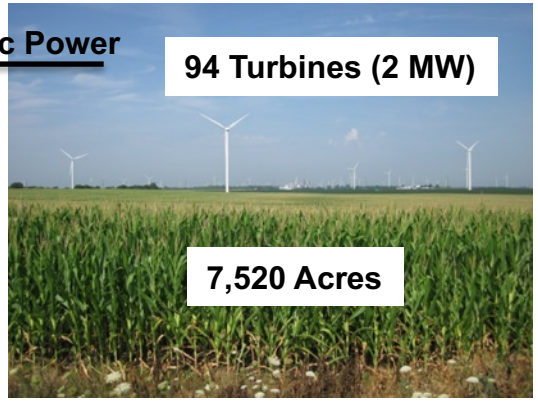
- 40 MM Gal/yr. biorefinery produces 14 T CO_2/hr.
- converted this CO2 could increase production capacity from 40 MGY to 58 MGY.
- This would require 5,600 m^2 (2.5kg/hr./m^2) of electrolyzer membranes and about 47 MW of renewable power
- Assume (for 47 MW):
  - 2 MW Wind Turbine
  - Capacity factor: 25%
  - Acres per turbine: 80
  - Turbines needed: 94



40 MM GPY Refinery Will Need 80,000 Acres of Corn Field

94 Turbines (2 MW) Can Produce 47 MW at 25% Capacity Factor





There is enough space available in corn fields to install wind turbines to produce power to convert all of the biogenic CO_2 from fermentation

Quad Chart Overview

Timeline

- Project start date: October 2023
- Project end date: September 2025

	FY22 Costed	Total Award
DOE Funding	0$	$1,950k ($650k/yr.)

Funding Mechanism

CO_2 Lab Call

Project Goal

This project will directly support BETO's CO_2 utilization goals under "Decarbonizing energy-intensive industries" by ensuring BETO has a robust plan and well-run consortium to develop technologies to upgrade CO_2 to fuels and chemicals in order to reduce GHG emissions, decrease land and water use, and incentivize decarbonization. This project directly supports diversity, equity, and inclusion by making resources available on the website for students and teachers to learn about BETO technologies in a free and accessible environment.

End of Project Milestone

Write a white paper highlighting all of the technical advances of the consortium in the previous three-year cycle. The document will be used for BETO as a marketing tool and it will be posted on the consortium website. (FY25 Q4)

Thank You

DOE – Kevin Craig
Ian Rowe
Robert Natelson

ANL - Michael Wang
Amgad Elgowainy
Ksenija Glusac

LLNL - Chris Hahn

LBNL - Steve Singer
Eric Sundstrom

NREL - Ella Zhou
Hariswaran Sitaraman
Wei Xiong
Jack Ferrell
Gary Grim
Ling Tao
K.C. Neyerlin
Chris Johnson
Kimmy Mazza
Amie Sluiter

Q&A

Michael.resch@nrel.gov

NREL/PR-5100-85325

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