2023 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

Carbon Dioxide Utilization Portfolio Review

Ian Rowe
Technology Manager
April 6, 2023

Agenda: Thursday and Friday

Day 4 – THURSDAY APRIL 6, 2023				
Start Time (MT)	**End Time (MT)**	**Title**	**Organization**	**Speaker**
10:00 AM	10:10 AM	Technology Area Introduction	*BETO*	*Ian Rowe*
10:10 AM	10:30 AM	CO2 Consortium Project Management	*NREL*	*Michael Resch*
10:30 AM	11:00 AM	Feasibility Study of Utilizing Electricity to Produce Intermediates from CO2	*NREL*	*Gary Grim*
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11:30 AM	12:00 PM	Economics and Sustainability of CO2 Utilization Technologies with TEA and LCA	*ANL*	*Michael Wang*
12:00 PM	1:00 PM	*Lunch*	*All*	
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4:30 PM	5:00 PM	Multiphysics CFD for design and scale-up of gas bioreactors	NREL	Hari Sitaraman
	5:00 PM	*End of Day/Closed Door Comment Review Session*	*Reviewers*	

Day 5 – FRIDAY APRIL 7, 2023				
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8:45 AM	9:15 AM	Production Of Bioproducts from Electrochemically-Generated C1 Intermediates	Lanzatech	Jason Bromley
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Peer Review Panel

Name	Affiliation	Previous Peer Review Experience
Charles McCrory	University of Michigan	Lead Reviewer; 2021 Panelist
Antaeres Antoniuk-Pablant	Carbon Direct	New
Amishi Claros	Department of Energy	New
Cao-Thang Dinh	Queen's University	New
Mark Held	Air Protein	New
Grigorii Soloveichik	SolEXS Consulting LLC	New






Bioenergy Technologies Office

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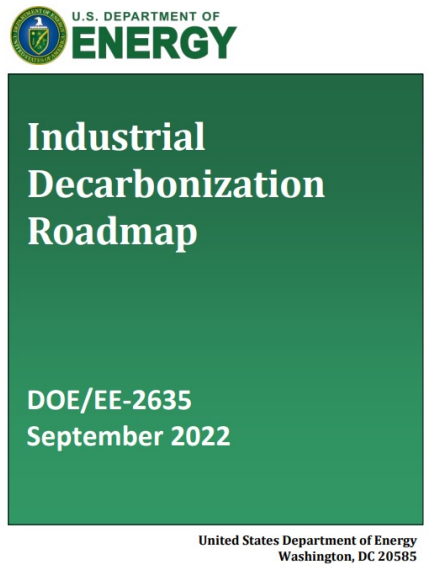
- Mission Statement: *develop and demonstrate technologies to accelerate GHG emissions reductions through the cost-effective, sustainable use of biomass and waste feedstocks across the U.S. economy.*

- Three Strategic Priorities: 1) Decarbonizing Transportation 2) Decarbonizing Industry 3) Other beneficial uses (agriculture, CDR, etc.)

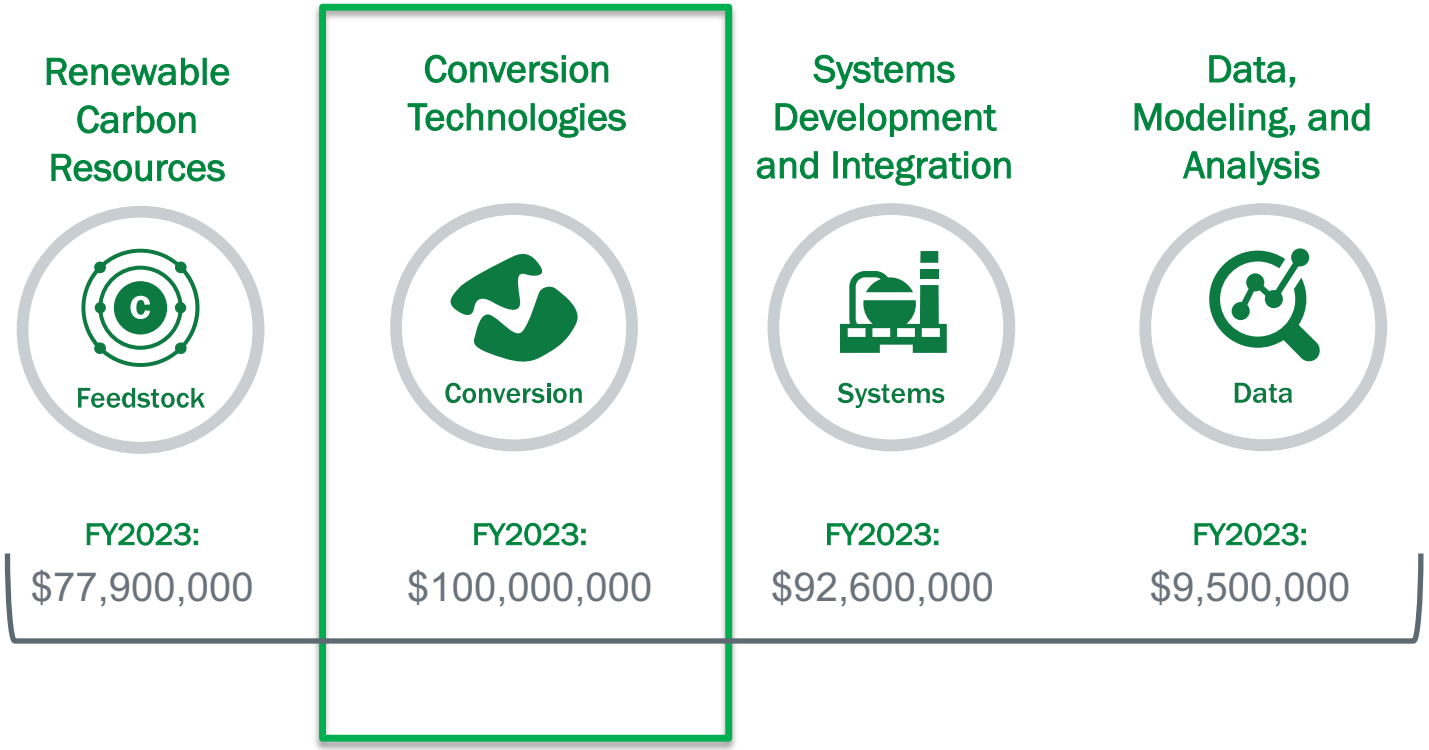
- Divided into 4 Technology Programs:
  - Renewable Carbon Resources
  - Conversion
  - Systems Development and Integration
  - Data, Modeling and Analysis

1 icon represents limited long-term opportunity 2 icons represents large long-term opportunity 3 icons represents greatest long-term opportunity	BATTERY/ELECTRIC	HYDROGEN	SUSTAINABLE LIQUID FUELS
Light Duty Vehicles (49%)*		–	TBD
Medium, Short-Haul Heavy Trucks & Buses (~14%)			
Long-Haul Heavy Trucks (~7%)			
Off-road (10%)			
Rail (2%)			
Maritime (3%)		†	
Aviation (11%)			
Pipelines (4%)		TBD	TBD



BETO Program Areas

FY2023 Budget Authority = $280M



BETO Applied R&D

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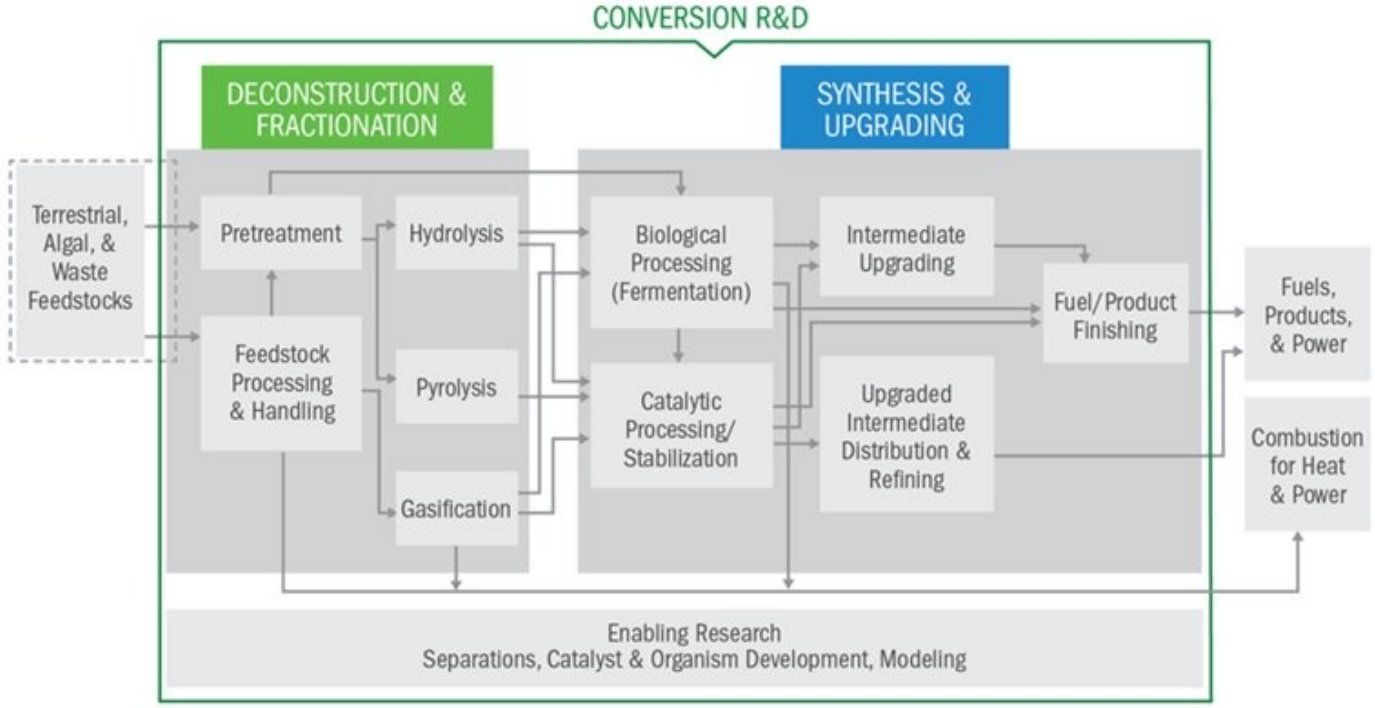
- TRL 1: Basic principles observed and reported
- TRL 2: Technology concept and/or application formulated
- TRL 3: Analytical and experimental critical function and/or characteristic proof of concept
- TRL 4: Component and/or breadboard validation in a laboratory environment
- TRL 5: Component and/or breadboard validation in a relevant environment
- TRL 6: System/subsystem model or prototype demonstration in a relevant environment
- TRL 7: System prototype demonstration in an operational environment
- TRL 8: Actual system completed and qualified through test and demonstrated
- TRL 9: Actual system proven through successful mission operations

Applied R&D support in BETO: Technology Readiness level ~2-5

Pathways and unit operations focused R&D



Conversion R&D

Strategic Goal: *decarbonize the U.S. economy by developing efficient and economical biological and chemical technologies to convert renewable carbon resources into bioenergy and renewable chemicals and materials.*

CO_2 Utilization R&D Portfolio

Strategies:

- Develop gaseous platforms
- Develop sugar and lignin platforms
- Develop oil platforms
- Develop targeted chemical production platforms
- Develop bioplastic design and plastic recycling platforms
- Develop waste management and environmental remediation strategies

Why CO_2? US Renewable carbon needs

- 36B gallons of SAF = 600M tons of biomass
- ~9B gallons of marine fuel (EIA 2019) = 150M tons of biomass
- ~5B gal of diesel (~10% of today's use) = 80M tons of biomass
- 100M tons of chemicals (~50% of today's market) = 400M tons of biomass
- ~ 500M tons of carbon removal via BECCS or BiCRS = 500M tons of biomass (assumes roughly half of CDR uses biomass)

TOTAL = 1.8B tons of biomass

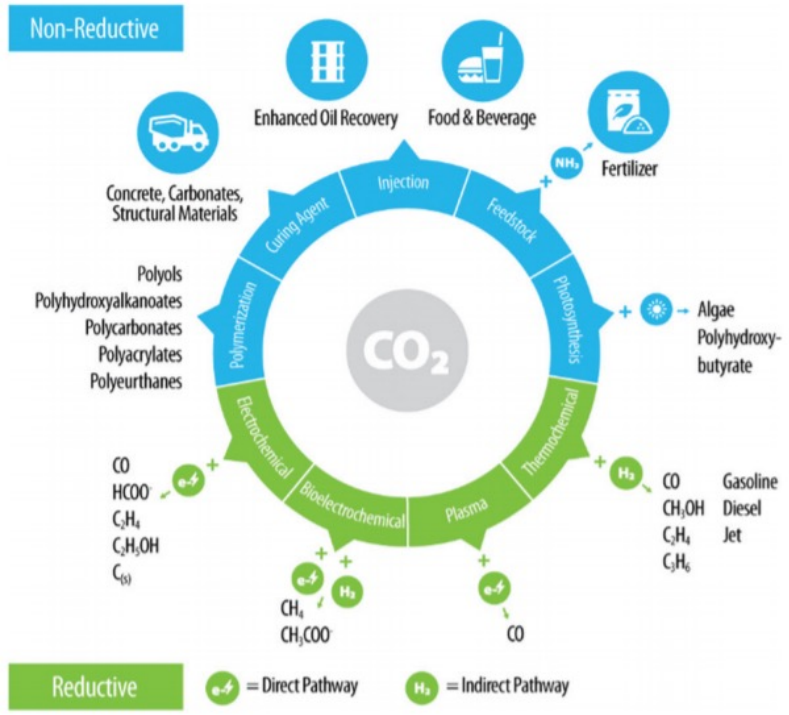
- **To meet the needs of our hard-to-electrify sectors, we will need a lot of renewable carbon.**
- **Biomass is likely limited and cannot meet the entirety of that demand**
- **CO_2 offers an additional vast supply of carbon**

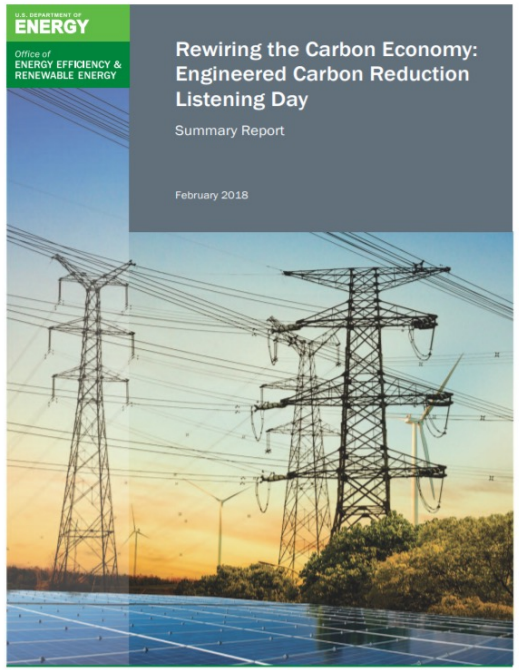
CO_2 Utilization

- **Started investigating CO_2U in 2017 with a workshop and some initial seed projects**
- **Closely examined past and current R&D occurring at other DOE Offices (FECM, ARPAe, SC)**
- **Identified the state of technology, R&D gaps, and the rightsized approach for BETO expertise**

Transforming the carbon economy: challenges and opportunities in the convergence of low-cost electricity and reductive CO_2 utilization†

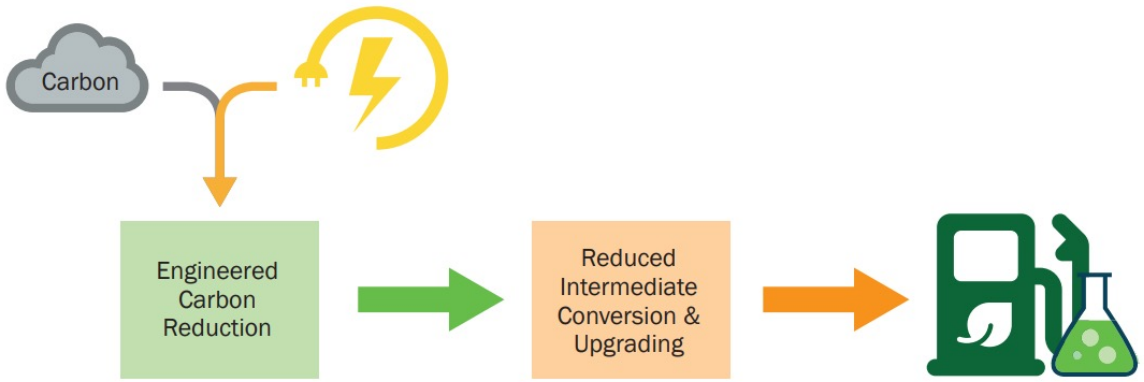
R. Gary Grim, Zhe Huang, Michael T. Guarnieri, Jack R. Ferrell III, Ling Tao * and Joshua A. Schaidle *





CO_2 Utilization

- CO_2 represents a potential alternative renewable carbon feedstock for fuels and chemicals which need to be decarbonized
  - PRO: abundant resource with potential for very low carbon footprint
  - CON: no energy, early TRL stage in comparison to other renewable feedstocks and relies heavily on the availability of renewable electricity



Two-part strategy:

<u>CO_2 reduction to C1 intermediates</u>
- Catalyst development
- Electrochemical cell design and scale-up
- TEA/LCA

<u>Intermediate upgrading to fuels and chemicals</u>
- Microbial engineering for C1 fermentation
- Reactor design
- Process integration
- TEA/LCA

Thursday April 6th – National Lab Projects (AOPs)

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CO_2 Reduction and Upgrading for e-Fuels Consortium
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- **Twelve projects, all part of the new *CO_2 Reduction and Upgrading for e-fuels Consortium***
- **Approximately $10M annually**
- **Began late Q1 2022**
- **A combination of a few existing projects and several new starts resulting from FY21 lab call**

Friday April 7th – Funding Opportunity Awards

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- **Six projects from two different FOAs**
  - *FY18 Rewiring Carbon Utilization ($1.5M each)*
  - *FY20 Scalable CO_2 Electrocatalysis ($2.5M each)*
- **Approximately $13M total**
- **Industry and Academia leads**

Questions?

CO_2 Reduction and Upgrading for Efuels Consortium

CO_2 reduction to intermediates

- An efficient and scalable process for the electrochemical reduction of CO2 to formate (NREL)
- Electrode and Membrane Materials for CO2 Electrolyzers: Methanol (ANL)
- Bioconversion of Syngas from Electrochemical CO2 Reduction (LBNL)

CO_2 Intermediate upgrading

- Multiphysics CFD for design and scale-up of gas bioreactors that utilize CO2 (NREL)
- Integration of CO2 Electrolysis with Microbial Syngas Upgrading (NREL)
- Biological conversion of formic acid (NREL)
- Bioconversion of Syngas from Electrochemical CO2 Reduction (LBNL)

Enabling analyses

- Markets, Resources, and Environmental and Energy Justice of CO2-to-Fuels Technologies (NREL)
- Economics and Sustainability of CO2 Utilization Technologies with TEA and LCA (ANL/NREL)