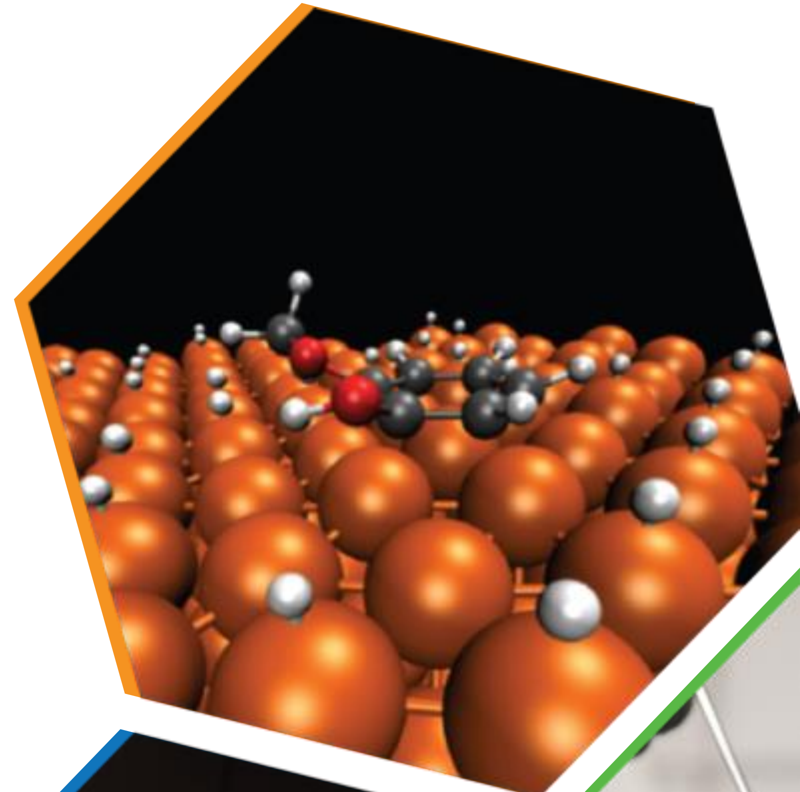
ChemCatBio
Chemical Catalysis for Bioenergy

ChemCatBio DFA
Catalyst Development for Selective Electrochemical Reduction of CO_2 to High-value Chemical Precursors with Opus 12

WBS # 2.5.4.707
U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)
2019 Project Peer Review

Frederick Baddour – NREL



U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
BIOENERGY TECHNOLOGIES OFFICE

Quad Chart Overview

Timeline

- Project Start: January 1, 2018
- Project End: January 1, 2020
- Percent Complete: 50%

	Total Costs Pre FY17	FY17 Costs	FY18 Costs	Total Planned Funding (FY19–FY21)
DOE Funded	$0	$0	$87k	$163k
Project Cost Share	N/A	N/A	$40k	$67k

Partners (FY19–FY20):

NREL: $250k

Opus 12: $107k (30%)

Barriers addressed

Ot-B. *Converting CO_2 waste streams (expenses) into desirable products (revenue)*

Ct-G. *Decreasing the Time and cost to developing novel industrially relevant catalysts*

Objective

The goal of this project is to gain a fundamental understanding of the impact of metal nanoparticle and carbon support physical properties on electrochemical CO_2 reduction performance. This insight will enable the development of customizable reactors that can convert CO_2 with high selectivity to CO, CH_4, or C_{2+} products for the specific needs of customer segments within the biofuels and bio-products industry.

End of Project Goal

The end of project goal is to *demonstrate a 20% reduction in overpotential and 20% higher partial current* to carbon-containing products compared to baseline MEAs with commercially available catalysts.

ChemCatBio Foundation

Integrated and collaborative portfolio of catalytic technologies and enabling capabilities

Catalytic Technologies

- **Catalytic Upgrading of Biochemical Intermediates** (NREL, PNNL, ORNL, LANL, NREL*)
- **Catalytic Upgrading of Indirect Liquefaction Intermediates** (NREL, PNNL, ORNL)
- **Catalytic Fast Pyrolysis** (NREL, PNNL)
- **Electrocatalytic and Thermocatalytic CO_2 Utilization** (NREL, ORNL*)

*FY19 Seed Project

Enabling Capabilities

- **Advanced Catalyst Synthesis and Characterization** (NREL, ANL, ORNL, SNL)
- **Catalyst Cost Model Development** (NREL, PNNL)
- **Consortium for Computational Physics and Chemistry** (ORNL, NREL, PNNL, ANL, NETL)
- **Catalyst Deactivation Mitigation for Biomass Conversion** (PNNL)

Industry Partnerships (Directed Funding)

- **Gevo** (NREL)
- **ALD Nano/JM** (NREL)
- **Vertimass** (ORNL)
- **Opus 12**(NREL)
- **Visolis** (PNNL)
- **Lanzatech** (PNNL) - Fuel
- **Gevo** (LANL)
- **Lanzatech** (PNNL) - TPA
- **Sironix** (LANL)

Cross-Cutting Support

- **ChemCatBio Lead Team Support** (NREL)
- **ChemCatBio DataHUB** (NREL)

1 – Relevance: The Opportunity

Domestic Ethanol Production

$60-100/ton

$300-500 MM

> $290/ton

Fuels or Chemicals

>$1 B

- >60,000 million liters in 2017
- >4.5 million tonnes CO_2 annually (>98% pure)

CO_2 conversion to fuels/chemicals can significantly increase revenue and enhance profitability of biorefining efforts

1 – Relevance: Revenue from Waste

***The Challenge:** A cost effective, modular CO_2 conversion technology for globally dispersed waste streams*

Domestic US biorefineries

Fermentation/Anaerobic Digestion

Ethanol / Biogas(CH_4)

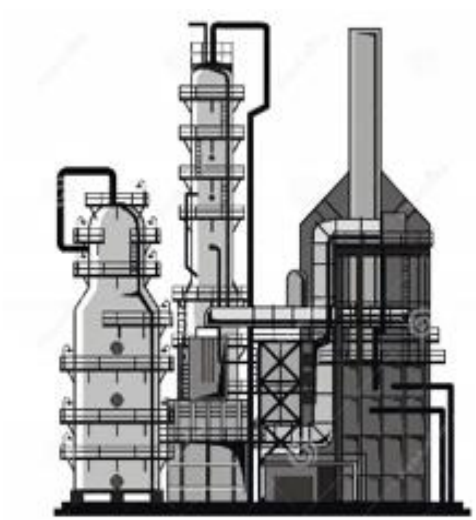
Revenue

CO_2

opus 12

EtOH/CH_4

50% Additional Product



Fuels/Chemicals Industry

Waste CO_2

opus 12

Syngas

bioreactor

Fuels

Chemicals

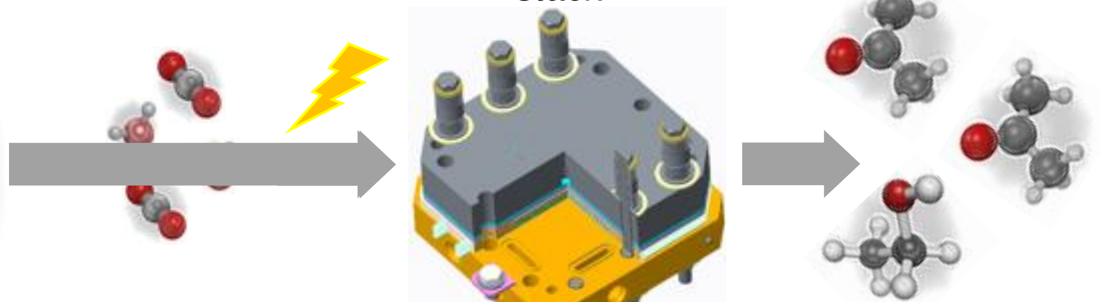
Opus 12's platform technology for CO_2 conversion can increase profitability across the bioenergy sector

1 – Relevance: The Opus 12 Platform

Core Technology

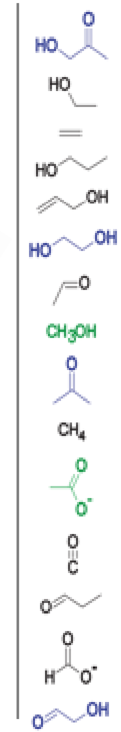
Uniquely formulated membrane-electrode assembly (MEA) converts a water electrolyzer stack into a CO_2 electrolyzer

MEA electrolyzer stack



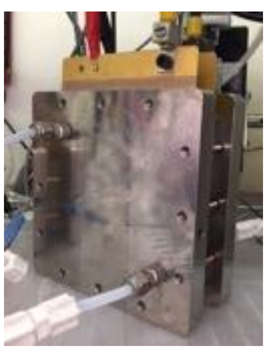
$CO_2 + H_2O$

16 compounds demonstrated to date

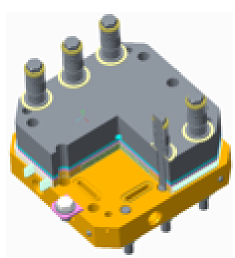


A clear path to large scale deployment

25cm^2



100cm^2



Stack of 100 cm^2

5 kW CO_2 Electrolyzer

Scale up to MW systems

1 – Challenges

*Transitioning from laboratory-scale MEAs to commercial stacks requires reproducible production of MEAs with suitable **lifetime and performance***

Challenges to overcome:

- ***More uniform smaller active catalyst metal NPs***
- Decreased hydrophilicity of conductive catalyst support
- ***Increased catalyst loading***
- **Determination of best practices for MEA diagnostics**

Outcomes:

- Decreased NP size and better uniformity ***increases performance and reduces cost***
- Better H_2O management ***reduces flooding and enhances diffusion to electrode***
- ***Increased performance*** at same MEA size
- MEA diagnostics provide feedback on the preparation of a ***commercially viable and reproducible***

Partnership with NREL and ChemCatBio offers a unique set of expertise to address these research challenges

1 – Approach: The Overarching Challenge

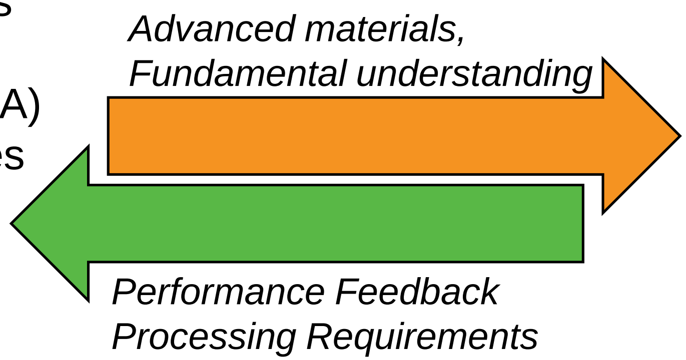
Limitations of commercially available catalysts requires the synthesis of advanced catalytic materials

Fundamental Research Challenges

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

New Cathode Catalyst Development

- Novel materials synthesis
- Characterization (e.g. TEM, SEM, XRD, EA)
- Supporting methodologies
- Surface treatment methodologies
- Scalable-synthesis
- Advanced diagnostics



Applied Research and Industrial Deployment

opus 12

New Cathode Catalyst Development Requirements

- Ink preparation
- MEA incorporation strategies
- Performance evaluation
- Lifetime evaluation (e.g. TEM, SEM, XRD, EA)

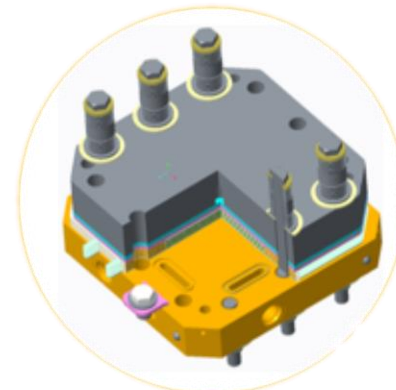
Unique synthesis and characterization capabilities within ChemCatBio can accelerate commercial deployment by partnering to develop CO_2 conversion catalysts

1 – Approach: Integration from Lab to Stack

Feedback and Performance Insight

Catalyst Design and Synthesis (NREL)

Membrane Electrode Assembly Fabrication (Opus 12)



Stack Assembly and Performance Evaluation (Opus 12)

FY19/20

Membrane Diagnostics (NREL)

Industry requirements
- Material targets
- Synthetic scale
- Performance targets

- Monthly conference calls
- Annual face-to-face meetings
- Data management through datahub

2 – Technical Accomplishments Overview

FY 2018/2019

Quarter 2
Establish a synthetic platform for ECO_2R catalysts (NREL)

Successfully ***developed synthetic methods*** *to prepare quantities of nanoparticle with physical properties specified by Opus 12 in quantities suitable to fabricate >3 25cm² MEAs*

Quarter 3
Dispersion method development (NREL)

Successfully ***developed dispersion methods*** to prepare supported catalysts incorporating previously synthesized nanoparticles

- 1.5-2g batches of >10 wt% catalysts were prepared
- Multiple surface treatments and stabilization methods developed

Quarter 4
Assembly of 1st generation MEAs (Opus 12)

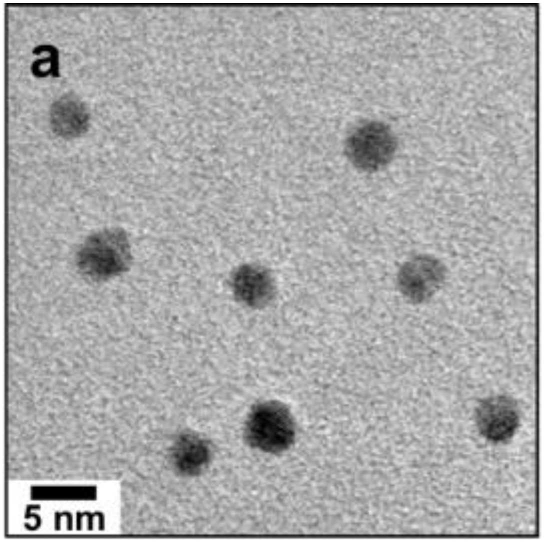
A baseline MEA was prepared based using the catalysts synthesized using the methods developed in Q2

Quarter 1
Performance evaluation of 1st generation MEAs (Opus 12)

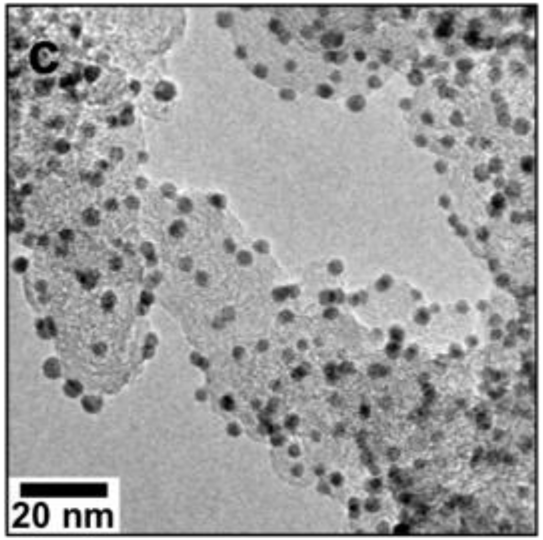
1st generation MEAs using NREL developed ***catalysts exceeded 10% overpotential reduction and +10% current density to products***

FY18Q2-Q3

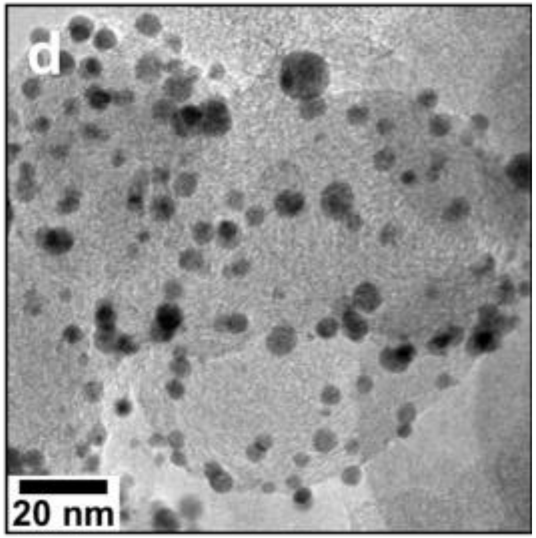
Particles meet size and morphology requirements



Developed effective supporting methodologies



Synthesis translated to large-scale (>3g)



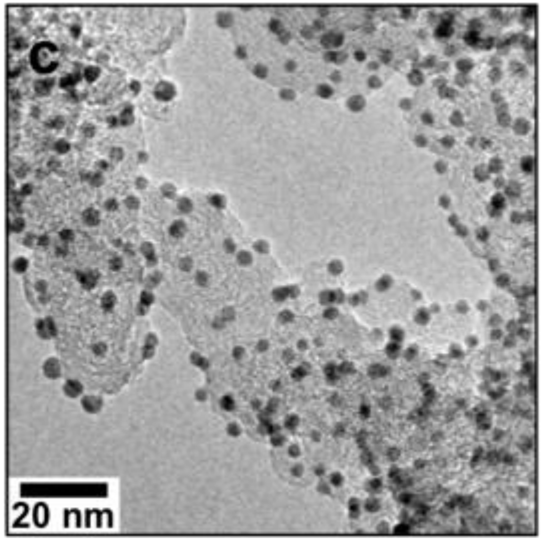
Challenge Addressed: ***More uniform smaller active catalyst metal NPs***

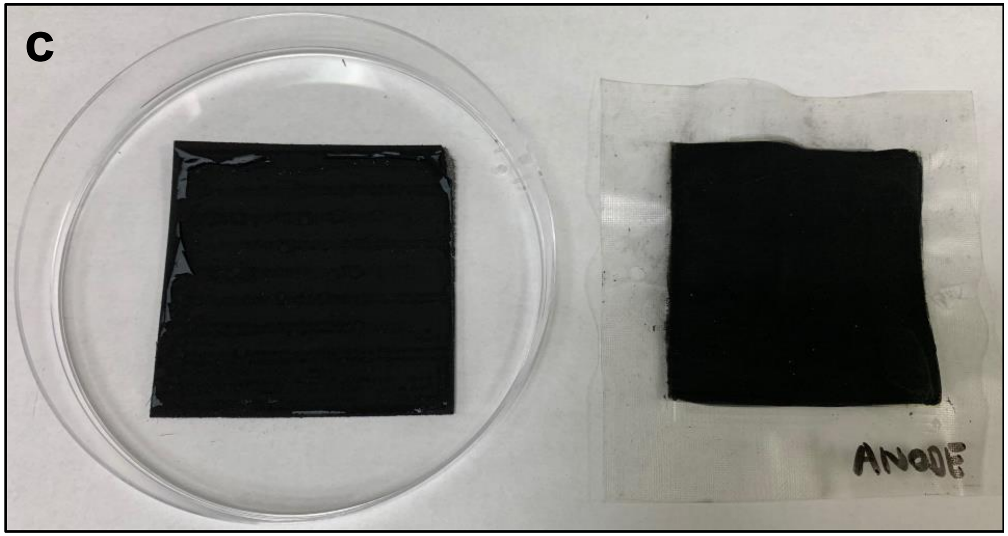
Increased active catalyst loading

Successfully developed synthetic methods to prepare nanoparticle catalysts at suitable scales for performance evaluation

2 – Technical Accomplishments: Catalyst Development

Catalysts successfully incorporated into MEAs

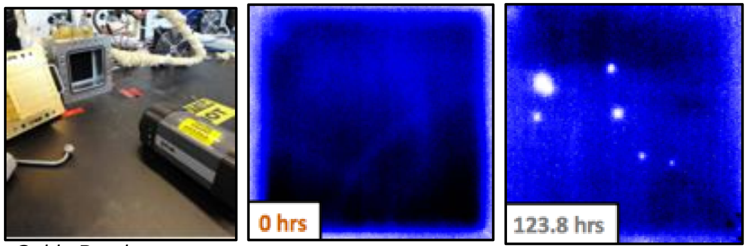




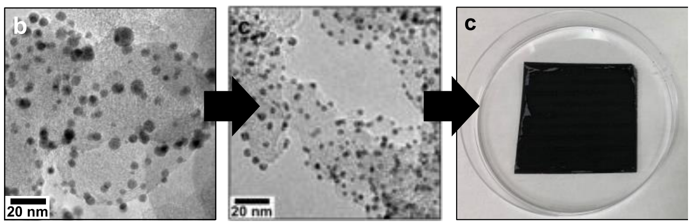
	Percent change compared to baseline commercial catalyst @160mA/cm^2			
Catalyst Description	**Prod. Current Efficiency (%)**	**Prod. Current Efficiency Change (%/hr)**	**Voltage (V)**	**Voltage Decay (mV/hr)**
Commercial Baseline	–	–	–	–
Cat 1	-1.4%	450%	4%	-1080%
Cat 2 (oxidized)	1.7%	50%	-4%	120%
Cat 3 (oxidized)	1.5%	200%	-5%	420%

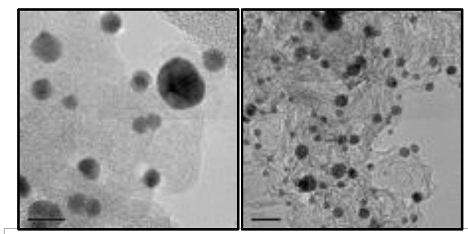
Cat 2 demonstrated s a nearly 2-fold (190%) improvement in current efficiency per USD

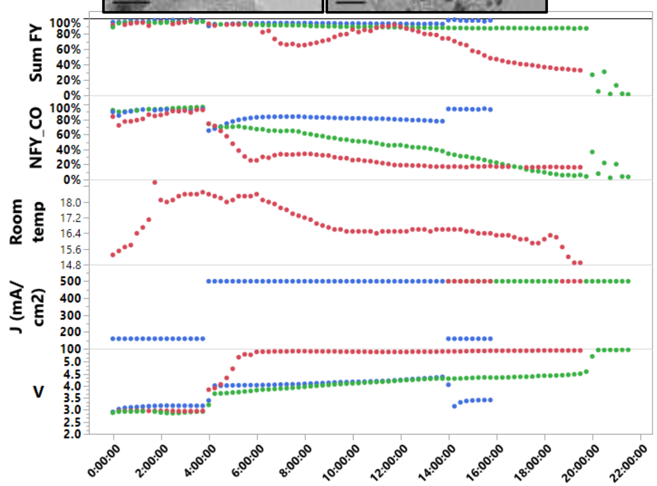
3 – Future Work: Roadmap FY19/20



Guido Bender







FY 19 Quarter 2

- PEM diagnostics to ***optimize reactor architecture*** (e.g. in-situ pinhole failure detection)
- Synthesis ***2nd generation NP catalysts***

FY 19 Quarter 3

MEA assembly and performance evaluation

FY 19 Quarter 4

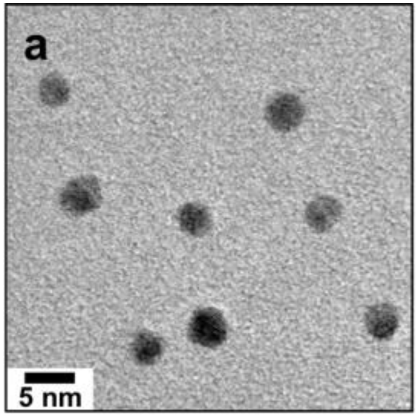
Conductive support modification and 2nd generation MEA diagnostics

FY20 Quarter 1

MEA assembly and performance evaluation with 2nd NP catalysts and surface modified supports

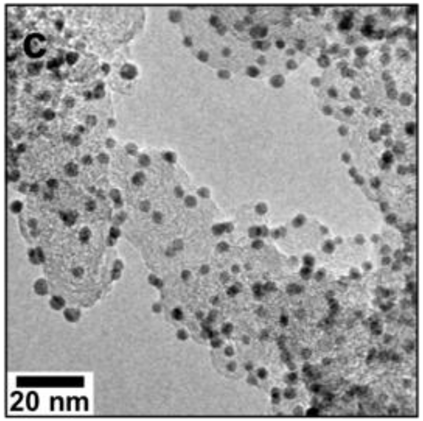
Summary

Industry Challenge: ***More uniform smaller active catalyst metal NPs***



Developed synthetic methods *to prepare quantities of nanoparticle with physical properties specified by Opus 12 in quantities suitable to fabricate >3 25cm^2 MEAs*

Industry Challenge: ***Increase active catalyst loading***



Developed effective supporting methodology *to retain particle size and morphology at increased loadings*

"This partnership has enabled us to ***connect with expertise and capabilities*** not readily available outside of the national laboratory complex. ***These capabilities have allowed us to evaluate a greater diversity of catalysts for CO_2 conversion applications.***" **– Opus 12**

Acknowledgements

NREL

Susan Habas

Guido Bender

Bryan Pivovar

Kenneth Neyerlin

Courtney Downes

Opus 12

Kendra Kuhl

Ziyang Huo

Sichao Ma

This research was supported by the DOE Bioenergy Technology Office under Contract no. DE-AC36-08-GO28308 with the National Renewable Energy Laboratory

This work was performed in collaboration with the Chemical Catalysis for Bioenergy Consortium (ChemCatBio, CCB), a member of the Energy Materials Network (EMN)