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Clean Fuels & Products™

Welcome Back to the Clean Fuels & Products Shot Summit

April 8: 11:00–2:00pm ET

Introduction Session | Session 1: Societal Considerations/Impacts

April 9: 11:00–4:00pm ET

Session 2: Resource/Feedstock Mobilization | Session 3: Carbon-Efficient Conversion Processes | Session 4: Technology Scaling and Demonstration

We will start momentarily…

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- We will collect questions and post responses along with the presentations as soon as possible
- If needed, participants can choose to turn on the Zoom close-captioning feature

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AGENDA | DAY 2 | APRIL 9 | 11:00 – 4:00 PM ET

Opening Remarks: 11:00-11:30am ET

SESSION 2: Resource/Feedstock Mobilization, 11:30-1pm ET

Moderator: Dr. Dana Mitchell, Technology Manager, DOE Bioenergy Technologies Office

SESSION 3: Carbon-Efficient Conversion Processes, 1-2:30pm ET

Moderator: Dr. Kristin Powell, Chemical Industry Technical Consultant, DOE Industrial Efficiency and Decarbonization Office

SESSION 4: Technology Scaling and Demonstration, 2:30-4pm ET

Moderators: Dr. Andrew Sumner, Project Manager, DOE Office of Clean Energy Demonstrations (OCED)
Olivia Corriere, Portfolio Strategy, Portfolio & Risk Management, DOE OCED

Closing Remarks: 4pm ET

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Office of the Under Secretary for Science and Innovation

Dr. Jennifer Arrigo

Director for Science and Energy Crosscuts

DOE Leadership Remarks

Jeff Marootian
Principal Deputy Assistant Secretary
Office of Energy Efficiency and
Renewable Energy
U.S. Department of Energy

Brad Crabtree
Assistant Secretary
Office of Fossil Energy and
Carbon Management
U.S. Department of Energy

Dr. Harriett Kung
Acting Director
Office of Science
U.S. Department of Energy

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Dr. Sarah Glaven

Principal Assistant Director for Biotechnology and Manufacturing
White House Office of Science and Technology Policy

DAY 2 KEYNOTE

Day 2 Session Lineup
Pillars/Core Research Areas

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Societal Considerations/Impacts	• Energy equity impacts and differentiated regional strategies • Cradle to grave life-cycle analysis and sustainability modeling to prioritize the most impactful R&D
Resource/Feedstock Mobilization	• New technologies to enable low cost, low-emissions feedstocks at scale • Increased carbon incorporation into biomass
Carbon-Efficient Conversion Processes	• New carbon-efficient conversion technologies • Innovation to improve CO_2 catalytic conversion efficiency • Solar fuels • Processes using green electricity and hydrogen
Technology Scaling & Demonstration	• Integrated pilot and demonstration scale facilities to de-risk technology for rapid industry adoption

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Session 2

Resource/Feedstock Mobilization

Pillar Overview

Resource/Feedstock Mobilization

Expand and Develop New Feedstocks:
Develop and utilize new technologies to expand and develop new low-cost, low-emissions feedstocks at scale as well as increase carbon incorporation into biomass..

Pillar Includes:
Production and yield, material handling, collection and harvest, storage, pre-processing, transportation, system logistics, life cycle analyses, feedstock quality and characterization, sustainability modeling and analysis, techno-economic analysis, and environmental justice.

Examples:
Forest residues, agricultural wastes, municipal solid waste, recycled materials, energy crops, algae, CO_2.

Basic & Foundational Science

Applied Research & Development

Session 2 | Day 2 | April 9 | 11:30am ET

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Session 2: Resource/Feedstock Mobilization, 11:30am ET

Moderator: Dr. Dana Mitchell, Technology Manager, DOE Bioenergy Technologies Office (BETO)

PRESENTATION	SPEAKER
U.S. Department of Energy Updates	Dr. Todd Anderson, Director, Biological Systems Science Division, DOE SC
	Dr. Dana Mitchell, Technology Manager, DOE BETO
	Rory Jacobson, Acting Division Director, DOE Carbon Dioxide Removal, DOE FECM
	Dr. Felicia Lucci, Technology Manager, DOE IEDO
	Tomas Green, Technology Manager, DOE HFTO
	Dr. Kathryn Peretti, Program Manager, DOE Advanced Materials & Manufacturing Technologies Office (AMMTO)
Keynotes	Dr. William Goldner, National Program Leader, U.S. Department of Agriculture
	Dr. Matthew Langholtz, Natural Resource and Environmental Economist, Oak Ridge National Laboratory
Panel	Harrison Pettit, Chief Development Officer, Pacific Ag
	Dr. Jennifer Aurandt-Pilgrim, Vice President of R&D, Marquis
	Dr. David Thompson, Chief Scientist – Bioenergy, Idaho National Laboratory

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Office of Science (SC)

Dr. Todd Anderson

Director Biological Systems Science Division

Office of Science Activities

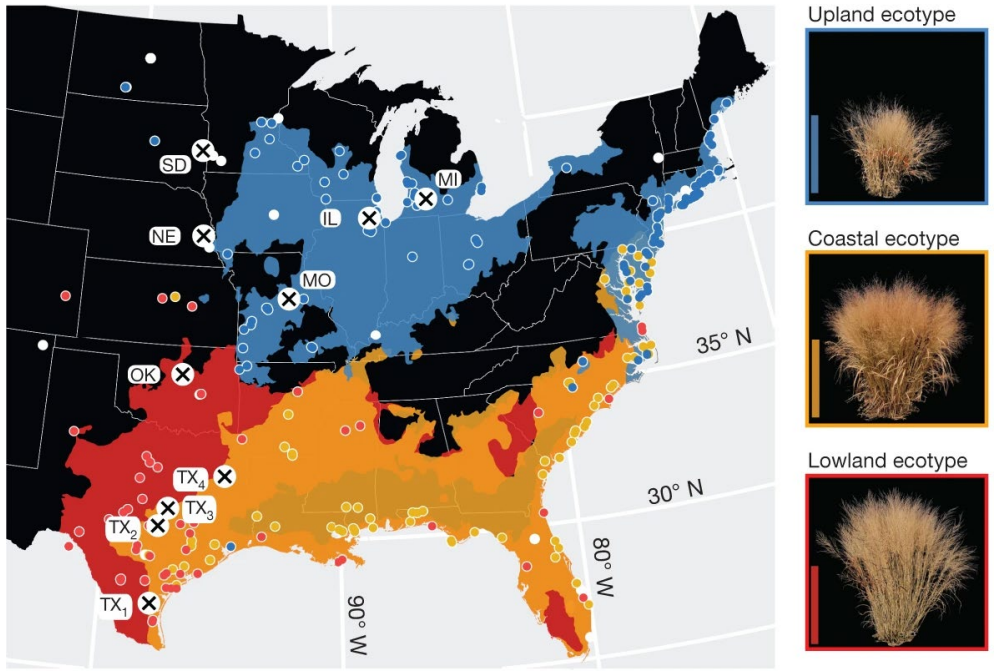
Basic Research to develop resilient bioenergy crops and mechanisms for capturing CO2 as feedstocks for later conversion to fuels, chemicals and materials

Plant Feedstock Development (BER)

- DOE Bioenergy Research Centers (BRCs)
- Genomic Science programs
  - Plant Biology
  - Resilient and Sustainable Bioenergy Crop Production
  - Biosystems Design

CO2 Capture (BES)

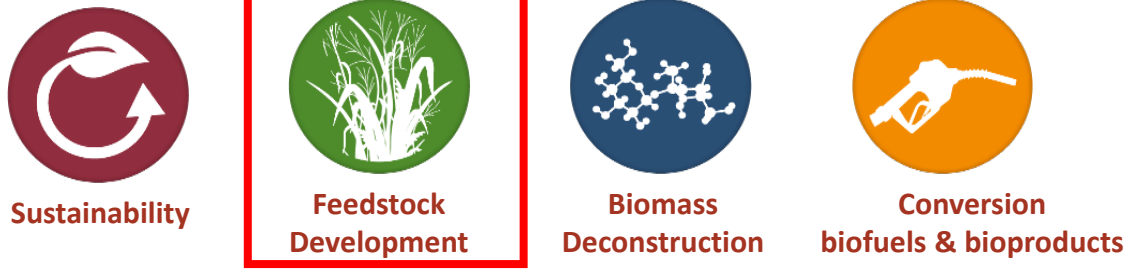
- Energy Frontier Research Centers (EFRCs)
- Fuels from Sunlight Hubs



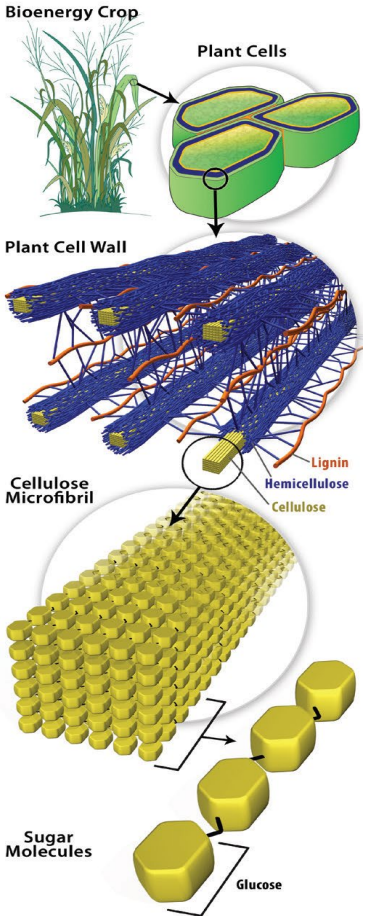
DOE Bioenergy Research Centers

- Great Lakes Bioenergy Research Center (GLBRC) – Dr. Tim Donohue
  - University of Wisconsin, Michigan State University (https://www.glbrc.org/)
- Joint BioEnergy Institute (JBEI) – Dr. Jay Keasling
  - Lawrence Berkeley National Laboratory (https://www.jbei.org/)
- Center for Bioenergy Innovation (CBI) - Dr. Gerald Tuskan
  - Oak Ridge National Laboratory (https://cbi.ornl.gov/)
- Center for Advanced Bioenergy and Bioproducts – Dr. Andrew Leakey
  - Innovation (CABBI)
  - University of Illinois (UIUC) (https://cabbi.bio/)

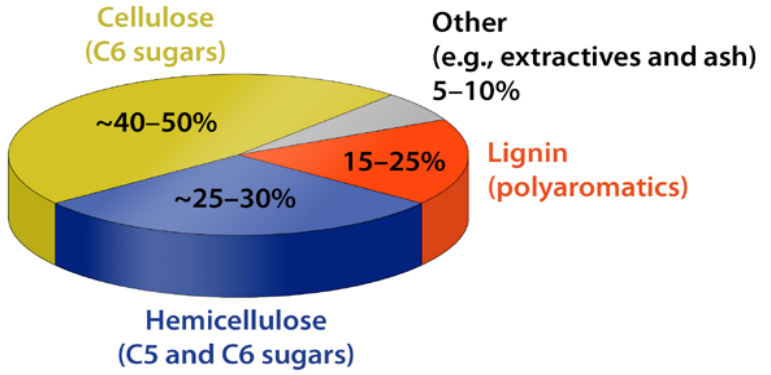
Team-oriented, integrated science addressing the basic science challenges to cost-effective conversion of plant biomass to fuels, chemicals and materials



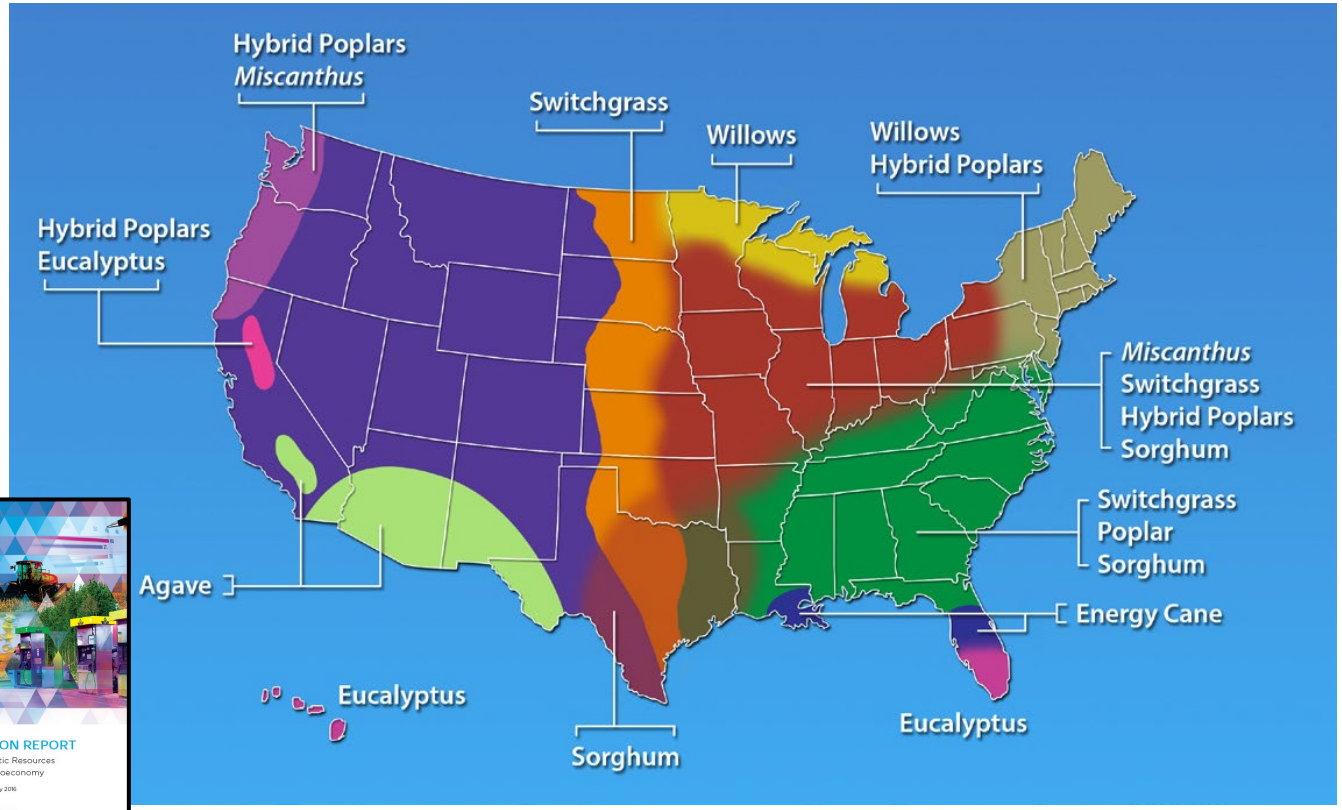
What is meant by the term “Plant Biomass?”

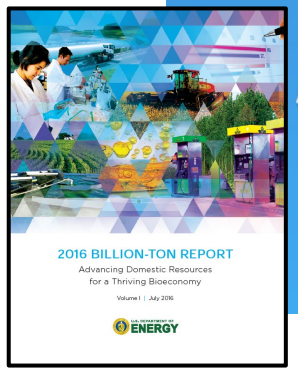


- Structural polymers in plants
- Cellulose and Hemicellulose
  - 5-6 carbon sugars (e.g. glucose, xylose etc)
  - Long, relatively ordered polymers
- Lignin
  - Polymer of polyaromatic components
  - Unregular structure
- Lignocellulosic Biomass



Plant Biomass as a Resource for a Broader Bioeconomy



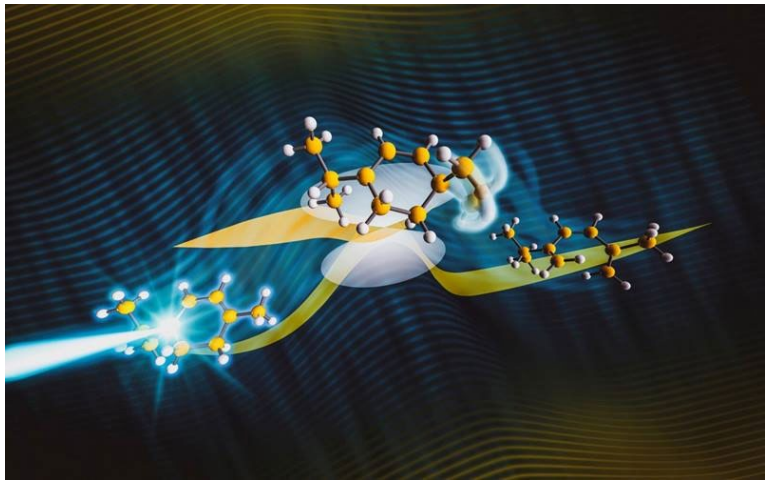


Research Emphasis

- Nonagricultural crops
  - Non-food crops
- Grown on underutilized lands
  - Arid land
  - Poor nutrients
  - Fallow land
  - Land not in agricultural use
- Up to Billion tons of biomass available every year

Understanding Mechanisms, Materials, and Processes for CO2 Capture and Conversion

- **Foundational knowledge for design of catalysts for efficient interconversion of electrical and chemical energy**
- Understanding the capture and conversion of solar energy in both natural (biological) and chemical systems
  - Photosynthesis in plants and microbes
  - Artificial photosynthesis for solar fuels production
- Discovery, design and synthesis of novel materials and pathways for CO_2 capture, release, and conversion
- Studies of enzyme active sites, metallocluster chemistry, and biochemistry of energy flow
- Understanding interfacial processes of CO_2 transport and reactivity for foundational knowledge that could advance new and improved CO_2 removal technologies



Viewing the transition state of a photochemical reaction

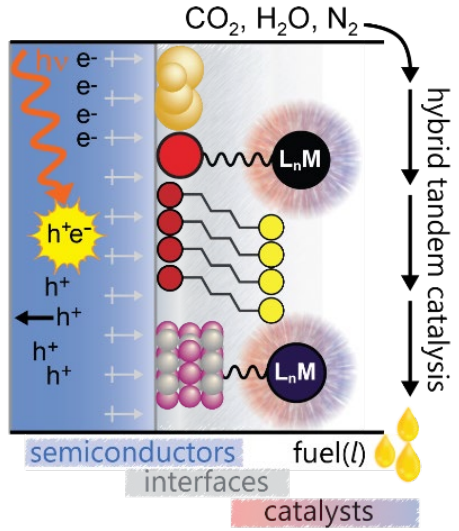
Fuels from Sunlight Hub Awards

Center for Hybrid Approaches in Solar Energy to Liquid Fuels (CHASE)

Gerald Meyer, Director

Scope: Develop a fundamental molecular level understanding of how hybrid photoelectrodes, comprised of molecular catalysts with tailored microenvironments integrated with semiconducting light absorbers, couple single photon absorptions to the multi-electron/multi-proton chemical transformations to generate liquid solar fuels.

Participants: UNC Chapel Hill (lead), BNL, Emory University, NC State University, University of Pennsylvania, Yale University

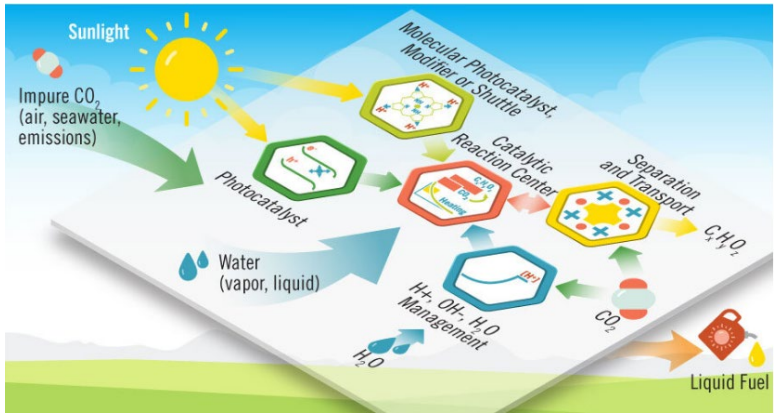


Liquid Sunlight Alliance (LiSA)

Harry Atwater, Director

Scope: Establish the science principles by which assemblies of microenvironments can directly generate liquid fuels from sunlight, water, & carbon dioxide. The principles will guide creation of microenvironment assemblies co-designed to harness sunlight-driven phenomena with unprecedented catalytic selectivity, durability, & efficiency under a fluctuating solar resource, using dilute or impure feedstocks.

Participants: Caltech (lead), LBNL, NREL, SLAC, University of Oregon, University of California Irvine, University of California San Diego



Energy Frontier Research Centers (EFRCs)

Center for Closing the Carbon Cycle (4C)

University of California, Irvine (Jenny Yang)

Advance synergistic capture and conversion of carbon dioxide from dilute streams into useful products through the convergent study of sorbents and catalysts

UCI Center for Closing the Carbon Cycle

Center for Catalysis in Biomimetic Confinement (CCBC)

Michigan State University (Cheryl Kerfeld)

Develop knowledge for characterization, prediction, and control of materials evolution in the presence of realistic contaminants, processes, and mixtures to accelerate materials discovery for sustainable production and utilization of H_2 and CO_2.

Center for Catalysis in Biomimetic Confinement

Energy Frontier Research Center | Center For Catalysis In Biomimetic Confinement (ccbc-efrc.org)

Opportunities Relevant to the Clean Fuels & Products Shot

Funding Opportunity Announcements (FOAs)

Reaching a New Energy Workforce (RENEW) – All SC
Funding for Accelerated, Inclusive Research (FAIR) – All SC
Advances in Artificial Intelligence for Science - ASCR
Energy Frontier Research Centers - BES
Early Career Research Program – All SC
Data Reduction for Science – ASCR

Opportunity Number	Opportunity Title	Agency	Opportunity Status	Posted Date	Close Date
DE-FOA-0003280	FY 2024 Reaching a New Energy Sciences Workforce (RENEW)	PAMS-SC	Posted	03/12/2024	07/23/2024
DE-FOA-0003207	FY 2024 Funding for Accelerated, Inclusive Research (FAIR)	PAMS-SC	Posted	03/12/2024	07/16/2024
DE-FOA-0003279	FY 2024 Phase II Release 2	PAMS-SC	Posted	02/26/2024	04/30/2024
DE-FOA-0003267	Research on General Plasma Science Collaborative Research Facilities	PAMS-SC	Posted	02/21/2024	04/29/2024
DE-FOA-0003264	Advancements in Artificial Intelligence for Science	PAMS-SC	Posted	02/13/2024	05/21/2024
DE-FOA-0003265	Accelerated Research in Quantum Computing	PAMS-SC	Posted	02/07/2024	05/08/2024
DE-FOA-0003258	Energy Frontier Research Centers (EFRC)	PAMS-SC	Posted	01/22/2024	05/08/2024
DE-FOA-0003300	EXPRESS: 2024 Exploratory Research for Extreme Scale Science	PAMS-SC	Posted	01/19/2024	05/02/2024
DE-FOA-0003266	Data Reduction for Science	PAMS-SC	Posted	01/16/2024	05/07/2024
DE-FOA-0003238	Nuclear Data Interagency Working Group (NDIAWG) Research Program	PAMS-SC	Posted	01/04/2024	04/04/2024
DE-FOA-0003281	Integrated Biological and Computational Low-Dose Radiation Research	PAMS-SC	Posted	12/21/2023	04/02/2024
DE-FOA-0003176	Early Career Research Program	PAMS-SC	Posted	12/15/2023	04/25/2024
DE-FOA-0003177	FY 2024 Continuation of Solicitation for the Office of Science Financial Assistance Program	PAMS-SC	Posted	09/29/2023	09/30/2024

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Bioenergy Technologies Office (BETO)

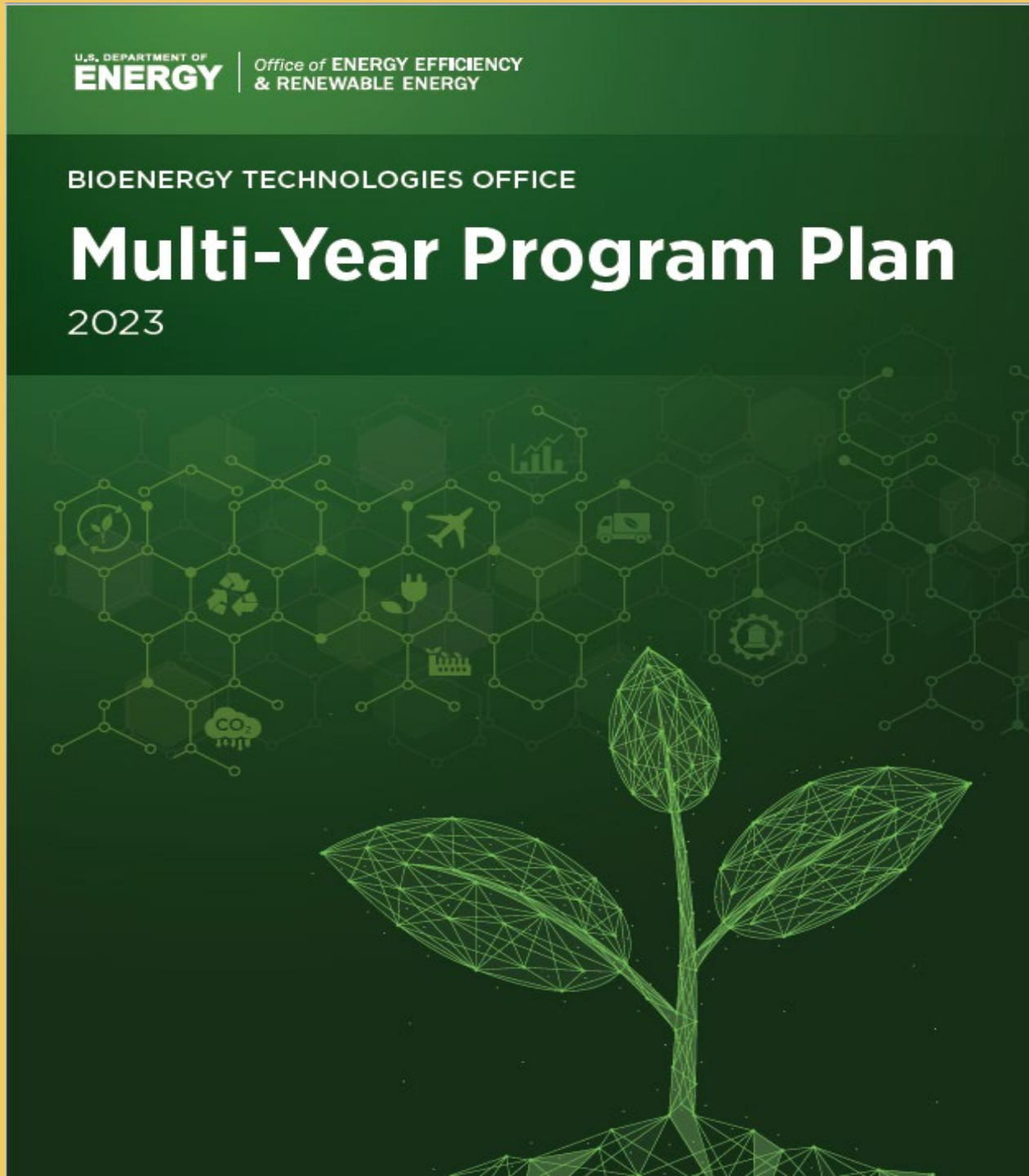
Dr. Dana Mitchell

Technology Manager

Multi-Year Program Plan 2023

- BETO Mission: To develop and demonstrate technologies to accelerate reduction of GHG emissions through the cost-effective, sustainable use of biomass and waste feedstocks across the U.S. economy.
- The RCR RD&D subprogram's strategic objective is to develop technologies to mobilize renewable carbon resources to enable the production of bioenergy and renewable chemicals and materials.
- RCR feedstocks include, but are not limited to agricultural residues, forestry residues, purpose-grown energy crops (including algae), waste streams, resources from ecosystem restoration or maintenance, and commodity crops.

https://www.energy.gov/eere/bioenergy/articles/2023-multi-year-program-plan



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Key Challenges and Barriers

- Feedstock Availability and Cost
- Production
- Feedstock Genetics and Variety Improvement
- Sustainable Harvesting
- Feedstock Quality
- Biomass Storage Systems
- Biomass Physical State Alteration
- Material Handling and Transportation
- Feedstock Supply System Integration & Infrastructure
- Operational Reliability

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Recent Funding Opportunity Announcements

- FY22: Bioenergy Technologies Office (BETO) Waste Feedstocks and Conversion R&D FOA (DE-FOA-002636)
  - Advanced MSW preprocessing for conversion-ready feedstocks
  - High value co-product development from MSW
- FY23: Reducing Agricultural Carbon Intensity and Protecting Algal Crops (DE-FOA-0002910)
  - Climate-smart agricultural practice for low carbon intensity feedstocks
  - Algal crop protection
- FY24: Regional Resource Hubs for Purpose-Grown Energy Crops (DE-FOA-0003209)
  - Algae
  - Herbaceous Energy Crops
  - Intermediate Energy Crops
  - Short-Rotation Woody Crops

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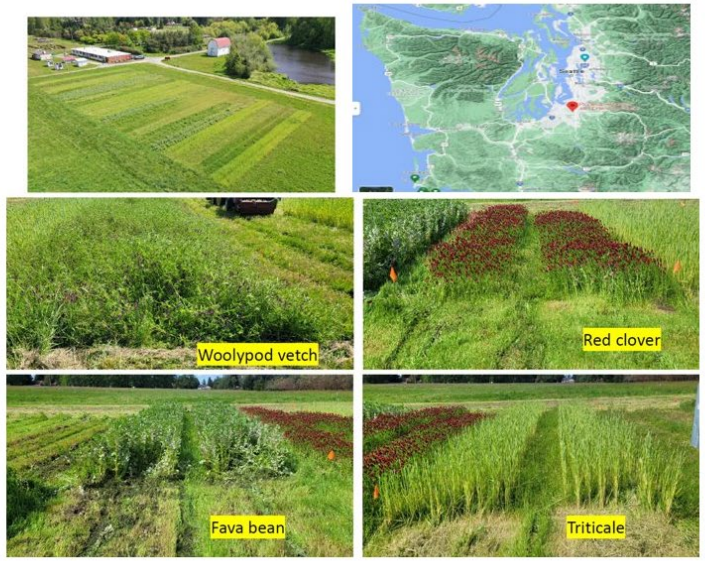
RCR National Lab Projects

Pacific Northwest NATIONAL LABORATORY

2. Progress and Outcomes: COVER CROP GROWTH AND HARVESTING IN THREE LOCATIONS WAS *SUCCESSFUL*



- Weeds are suppressed by cover crops.
- Biomass CMA is evaluated based on lipid, protein, carbohydrate, ash, and moisture content.

1ST YEAR RESULT:

Triticale and Vetch produced the most biomass above ground in the high precipitation area.

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Regional Biomass Resource Hub Initiative
LED BY IDAHO NATIONAL LABORATORY

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Industry and Stakeholder Input

Participate in workshops

- 2021: Advancing Synergistic Waste Utilization as Biofuels Feedstocks: Preprocessing, Coproducts, and Sustainability
- 2022: Bioenergy's Role in Soil Carbon Storage
- 2023: Deploying Purpose-Grown Energy Crops for Sustainable Aviation Fuel

Respond to Requests for Information (RFI)

Subscribe for updates:
https://www.energy.gov/eere/bioenergy/bioenergy-technologies-office

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Office of Fossil Energy and Carbon Management (FECM)

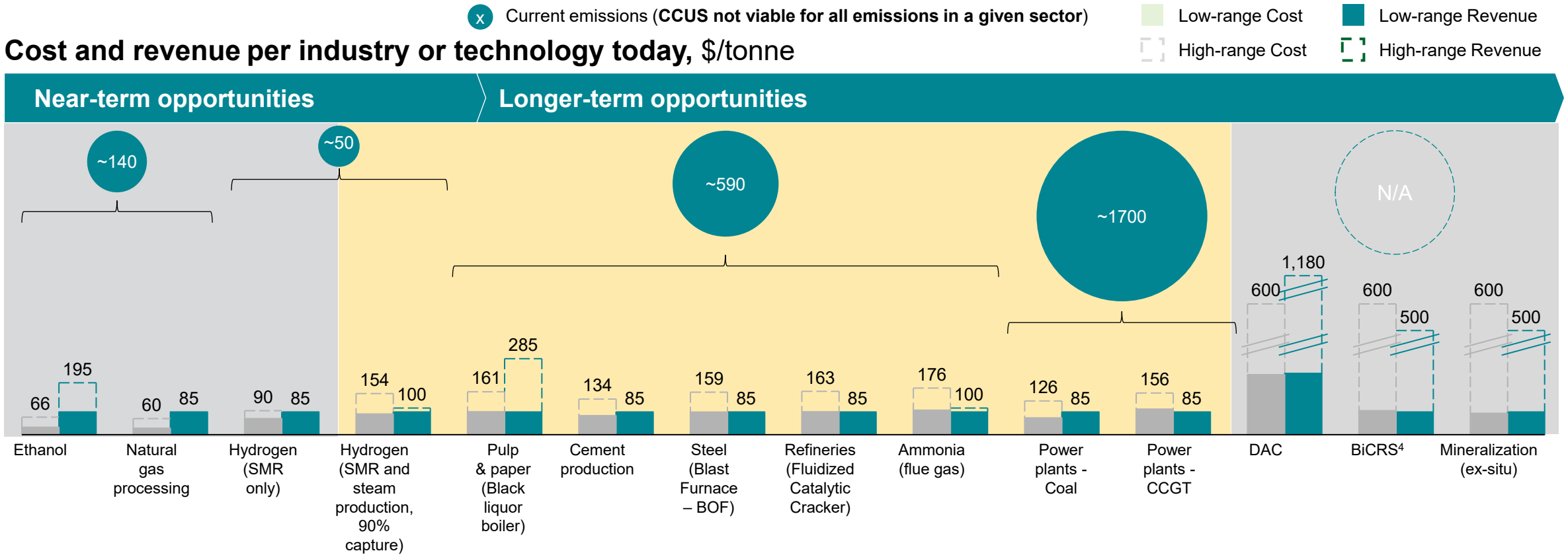
Rory Jacobson

Division Director for Carbon Dioxide Removal

Carbon Oxides as Clean Feedstocks

The Opportunity

Cost and revenue per industry or technology today, $/tonne



Currently profitable	Developing economics	Nascent technology

Sources and references can be found in DOE's "Pathways to Commercial Liftoff: Carbon Management" report at liftoff.energy.gov

Project specific economics dependent on CO_2 capture capacity, utilization, distance to storage and existing equipment

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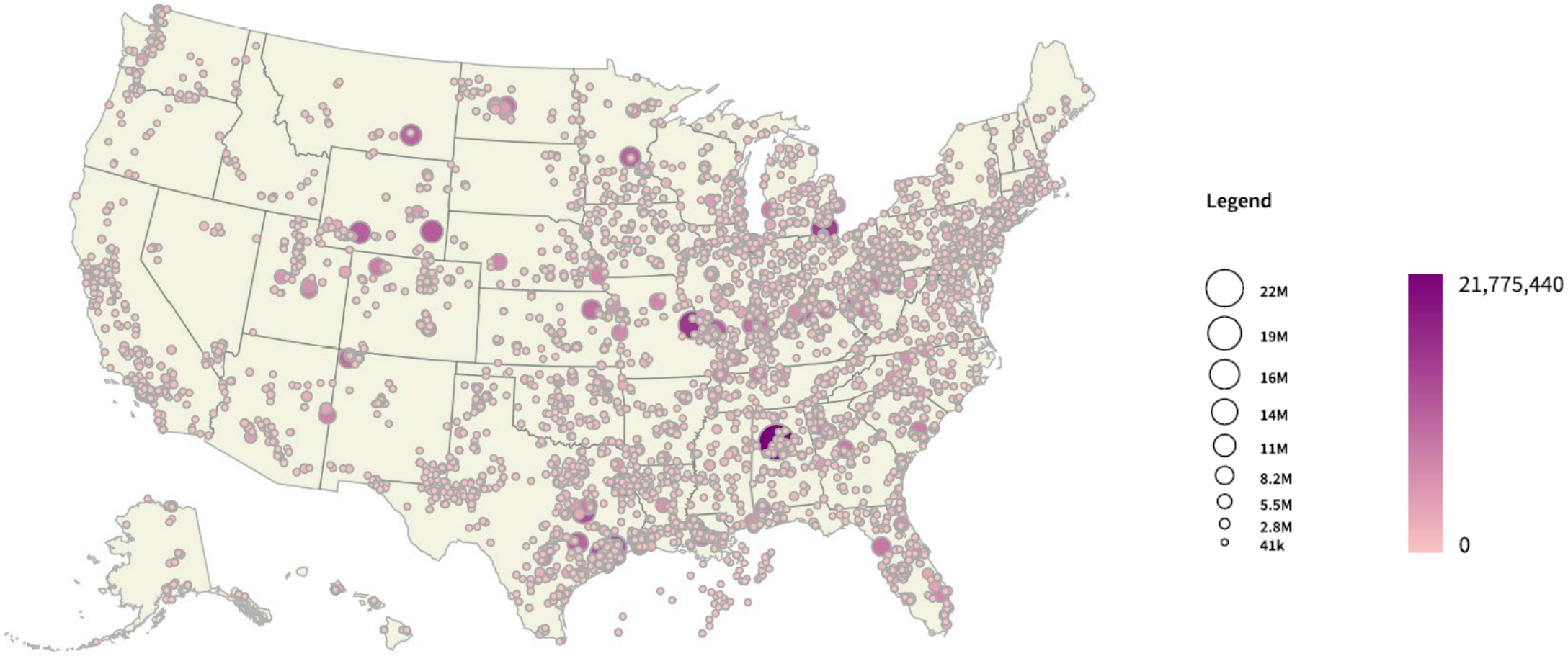
Regional Emphasis



EPA GHGRP 2022: [GHGRP Emissions by Location | US EPA]

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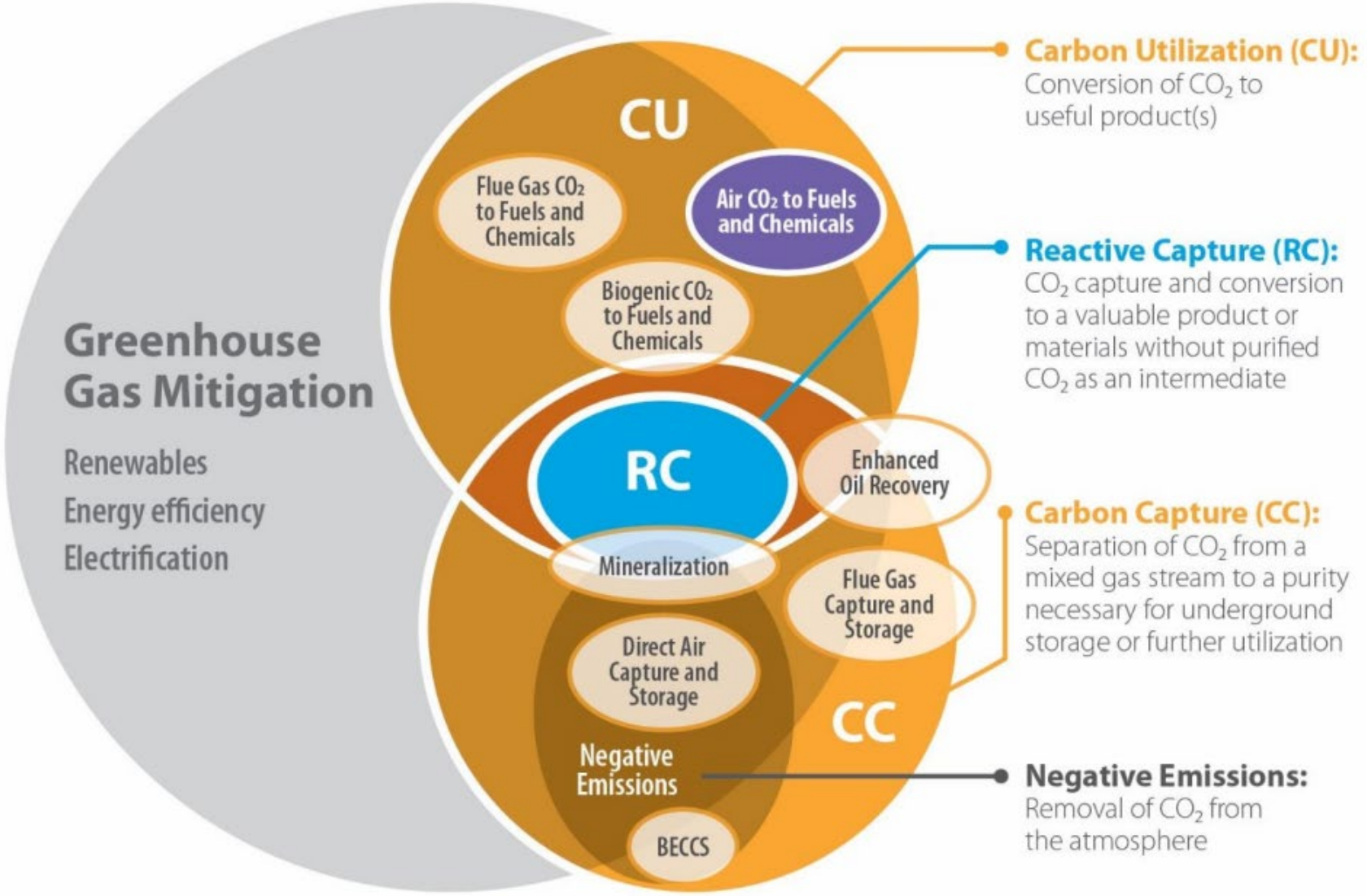
Process



Deutsch, T., Baker, S., Agbo, P., Kauffman, D., Vickers, J., and Schaidle, J. Summary Report of the Reactive CO2 Capture: Process Integration for the New Carbon Economy Workshop, February 18–19, 2020. Published by NETL

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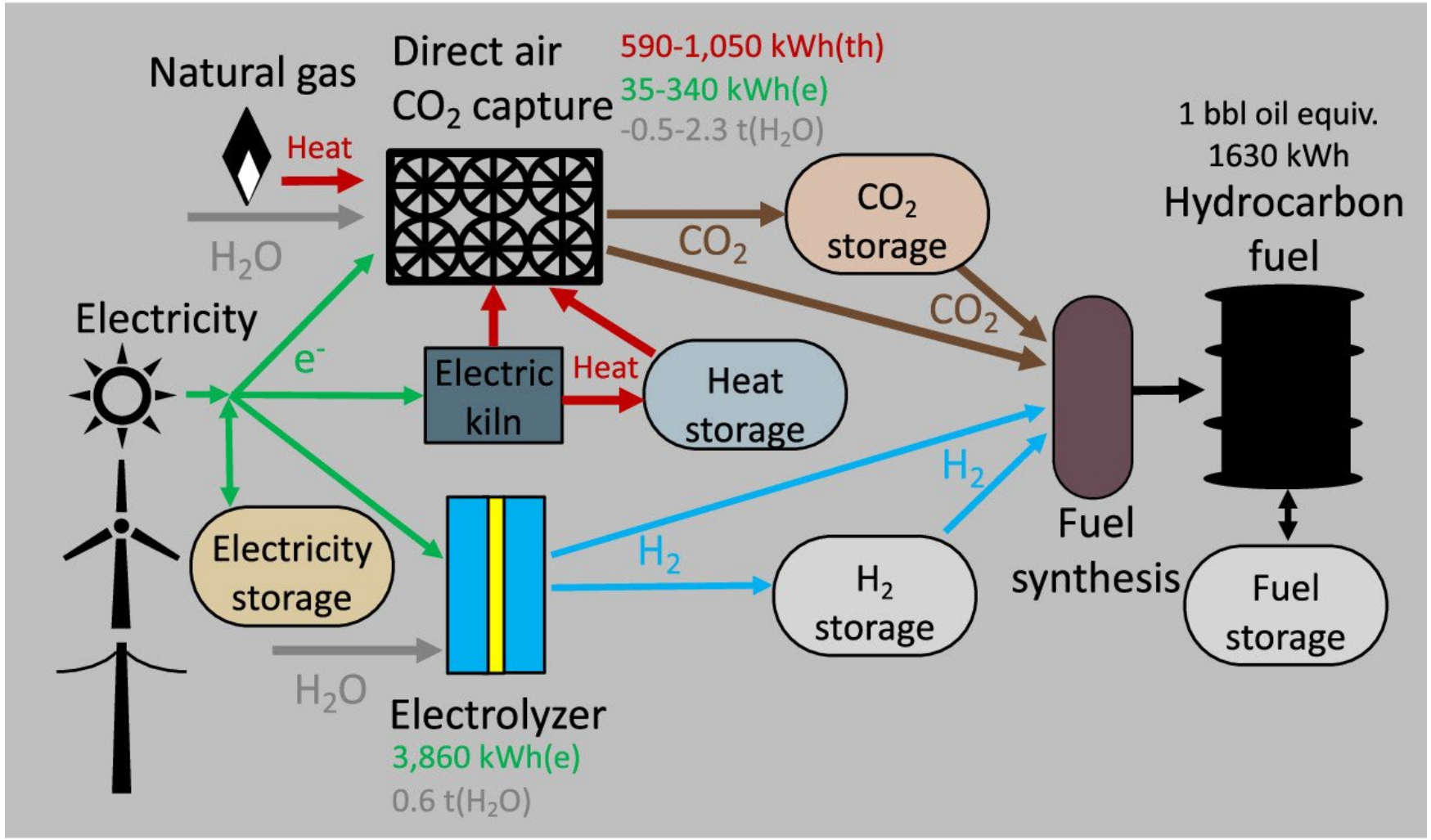
Example: E-Fuels For Aviation



Sherwin, E. D. (2021). Electrofuel synthesis from variable renewable electricity: An optimization-based techno-economic analysis. *Environmental science & technology*, *55*(11), 7583-7594.

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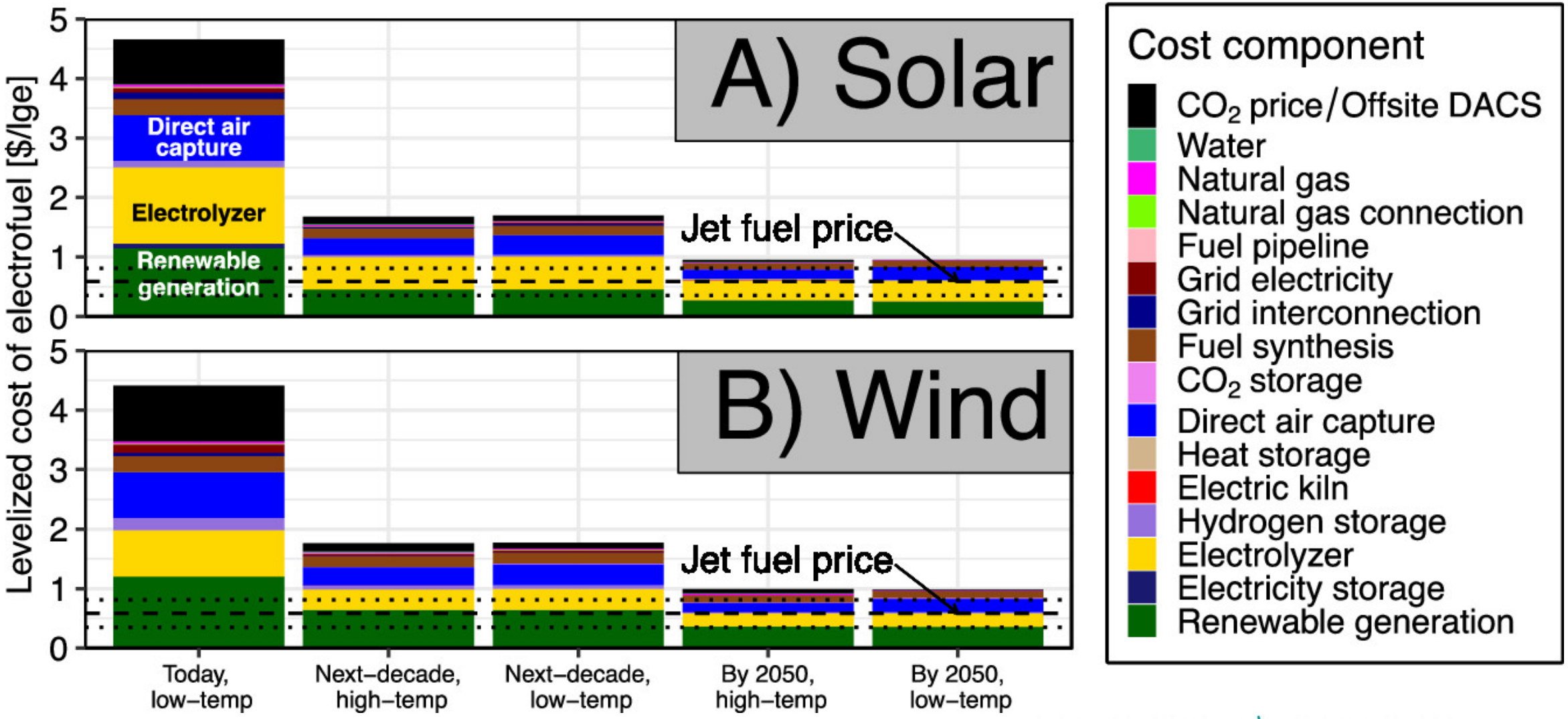
Example: SAF



Sherwin, E. D. (2021). Electrofuel synthesis from variable renewable electricity: An optimization-based techno-economic analysis. *Environmental science & technology*, 55(11), 7583-7594.

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2023 BILLION TON REPORT

CAPTURED CO2 FOR U.S. REGIONAL MICROALGAE CULTIVATION OPPORTUNITIES

CO_2 Source	West		Central		East	
	Thousand tons CO_2/yr [% of regional]	# sites [% of regional]	Thousand tons CO_2/yr [% of regional]	# sites [% of regional]	Thousand tons CO_2/yr [% of regional]	# sites [% of regional]
Agricultural processing	353.8	8	0	0	401.9	5
	[7.1%]	[10.1%]	[0%]	[0%]	[5.0%]	[4.0%]
Cement plant	3,629.1	4	6,258.3	10	1,081.8	3
	[19.3%]	[9.5%]	[17.5%]	[21.3%]	[2.6%]	3.5%
Electricity generation	39,725.0	33	209,318.5	67	71,826.2	39
	[12.5%]	[11.0%]	[74.1%]	[14.8%]	[6.6%]	[5.8%]
Ethanol production	25.4	1	0	0	0	0
	[6.0%]	[12.5%]	[0%]	[0%]	[0%]	[0%]
Fertilizer production	0	0	7,883.6	3	453.2	3
	[0%]	[0%]	[37.0%]	[15%]	[6.2%]	[17.6%]
Industrial	282.2	8	1,570.1	20	215.1	2
	[3.2%]	[7.1%]	[2.6%]	[6.0%]	[0.2%]	[0.4%]
Petroleum/natural gas processing	5,046.0	20	10,109.0	103	92.4	2
	[13.3%]	[6.4%]	[19.5%]	[15.4%]	[0.6%]	[0.7%]
Refineries/ chemicals	0	0	70,214.8	53	28.8	1
	[0%]	[0%]	[33.1%]	[19.1%]	[0.1%]	[0.6%]

Davis, R., A. Coleman, T. R. Hawkins, B. Klein, J. Zhang, Y. Zhu, S. Gao, et al. 2024. “Chapter 7.1: Microalgae.” In 2023 Billion-Ton Report. M. H. Langholtz (Lead). Oak Ridge, TN: Oak Ridge National Laboratory. doi: 10.23720/BT2023/2316175.

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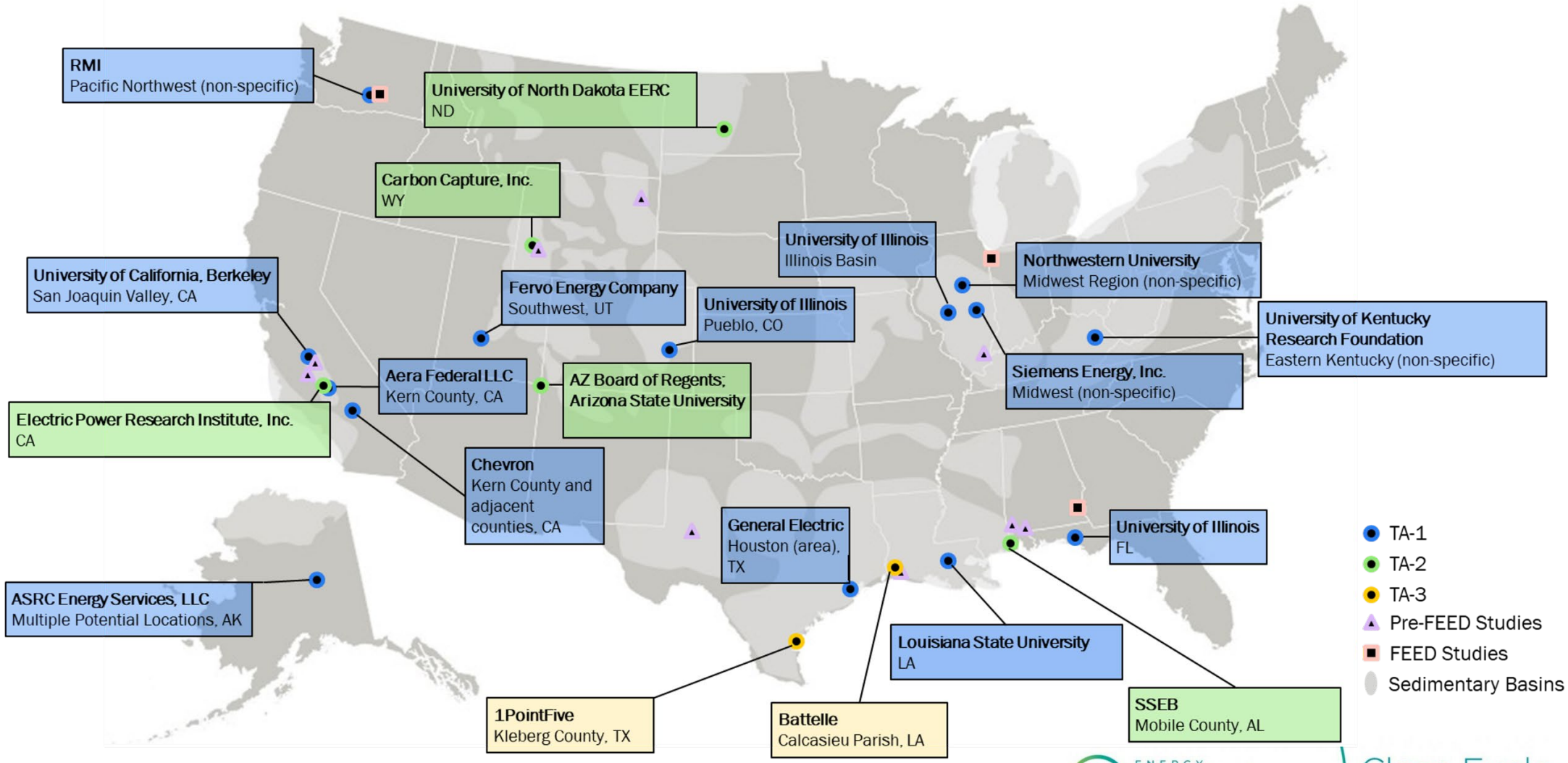
Near-Term DAC Employment Opportunities

Proposed Regional DAC Hub Locations



[Biden-Harris Administration Announces Up To $1.2 Billion For Nation's First Direct Air Capture Demonstrations in Texas and Louisiana | Department of Energy]

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Industrial Efficiency and Decarbonization Office (IEDO)

Dr. Felicia Lucci

Technology Manager

IEDO Strategy for Carbon Capture & Utilization

- Address technical challenges in CCUS process integration at Industrial Facilities
- Strong emphasis on carbon utilization
  - Accelerating emerging technologies – reactive capture
  - De-risking near term solutions – co-location and stranded CO_2

Sector specific focuses:

- Unique R&D challenges on a sector-by-sector basis
  - Chemicals – Catalysts require high purity CO_2 sources to avoid poisoning from impurities in stream
  - Cement/concrete – Mineralizing CO_2 sources has low conversion, limiting CO_2 uptake/sequestration
  - Forest Products – Integration of carbon utilization increases complexity

Cross sector focuses:

- De-risk technologies that bisect multiple industries to accelerate adoption
- R&D strategy is open to a broad range of topics including
  - Co-benefits of industrial-scale carbon capture
  - Improving manufacturability of CC materials
  - CC for power generation <20MW

IEDO Portfolio

>$60M in CCUS investments with majority focused on CO_2 utilization across all sectors

Stakeholder Engagement

Science of Scaling Up Technologies for Carbon Capture and Utilization Workshop

- Fall 2024 in Bay Area, CA
- Assess the current state of carbon capture and utilization technology and address the technical challenges facing scale-up and deployment

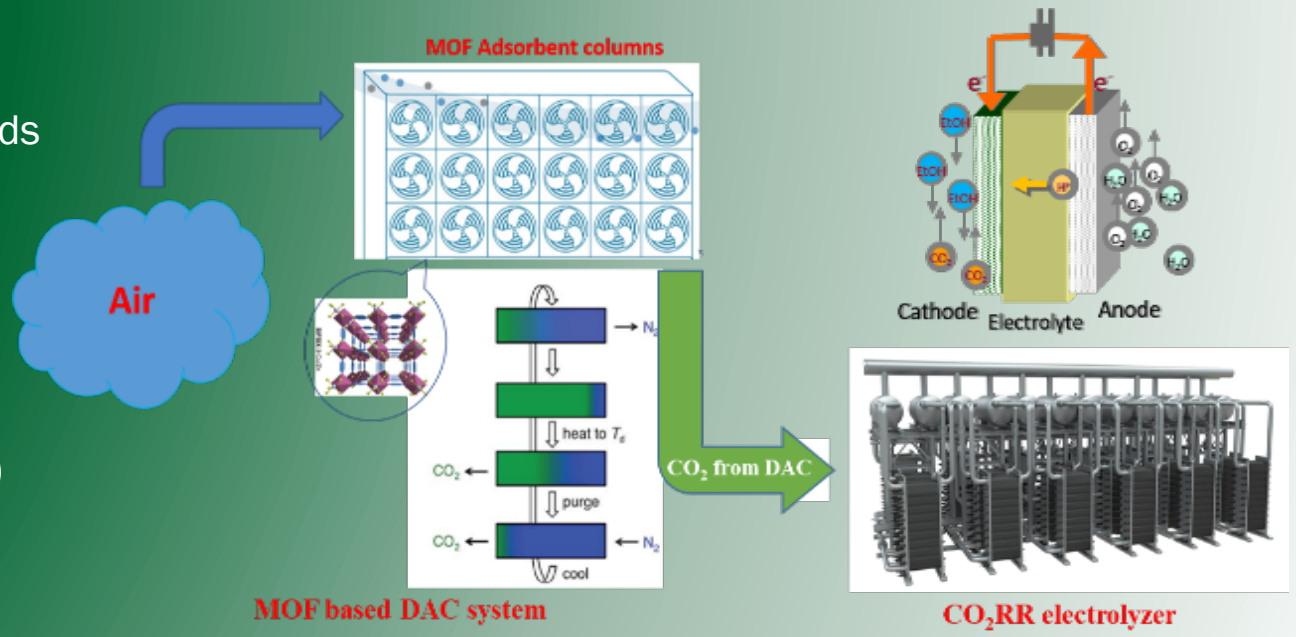
Integration of CO_2 Capture and Electrocatalytic Conversion to Organic Liquids

Innovation:

- Integrating direct CO_2 air capture with highly efficient electrochemical conversion of CO_2 to value-added organic liquids
- Superior metal organic framework (MOF) DAC adsorbents combined with state-of-the-art electrocatalysts

Project Impact:

- Dramatic improvements in CO_2-to-ethanol FE (>90% vs. 41% SOA) and current density (>200 mA/cm^2 vs. 124 mA/cm^2 SOA)
- Potential to produce ethanol with zero or negative emissions



Project Lead: Tao Xu, Northern Illinois University

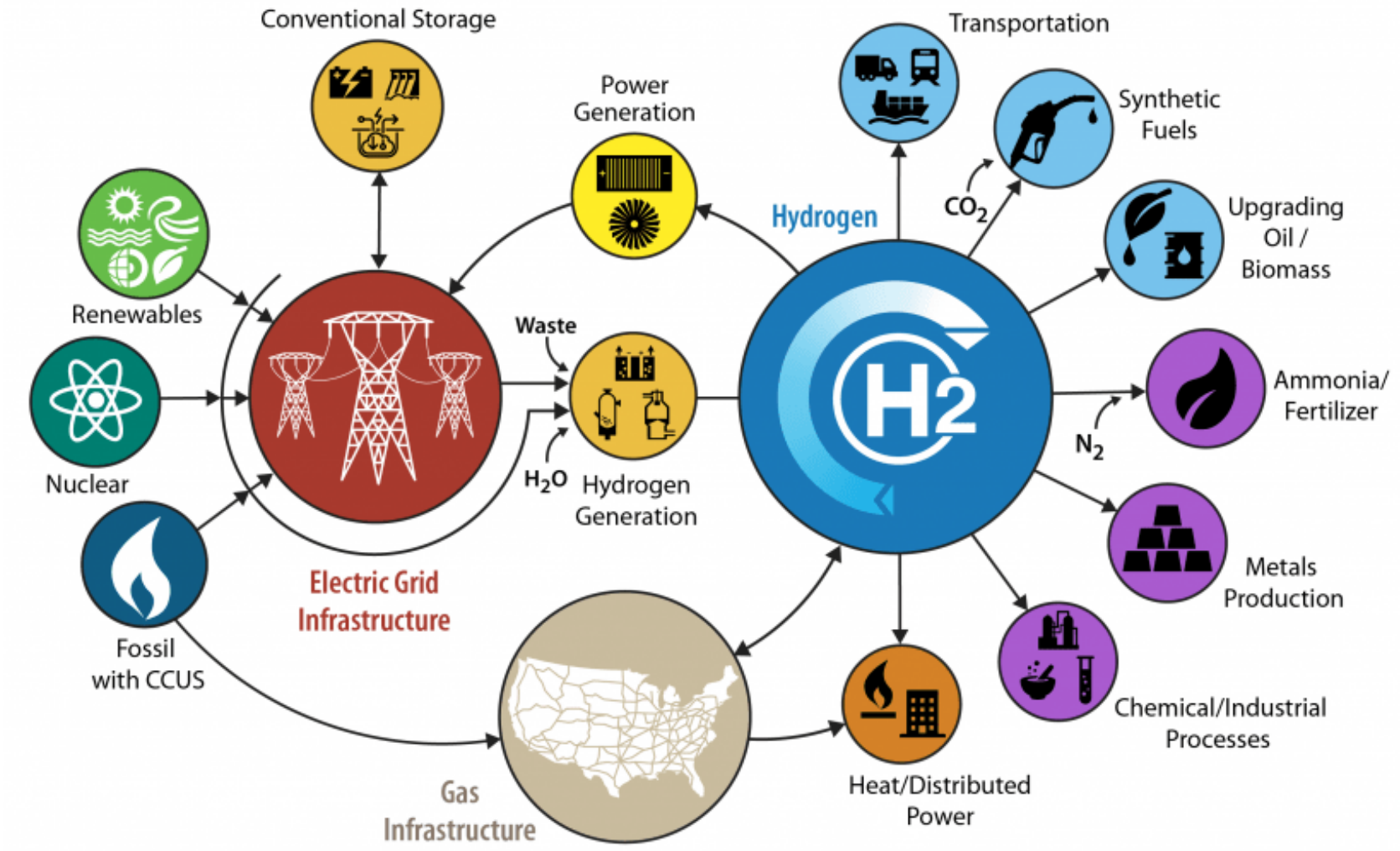
Project Partners: Di-Jia Liu (Argonne National Laboratory)
Shengqian Ma (University of North Texas); Angstrom Advanced Inc.

Hydrogen and Fuel Cell Technologies Office (HFTO)

Tomas Green

Technology Manager

Clean Hydrogen Plays Role as Feedstock in Decarbonization



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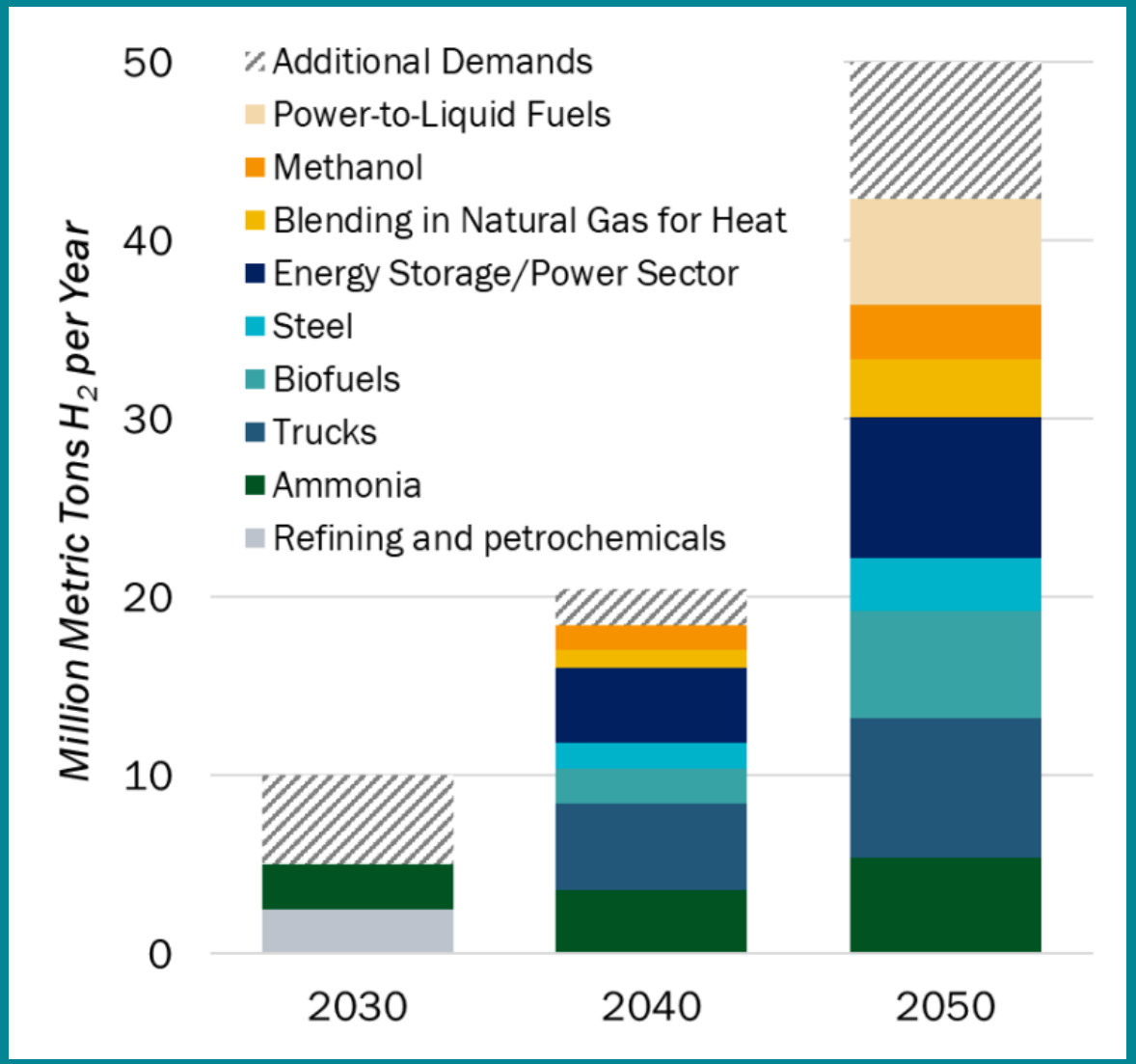

Clean Fuels and Products in the U.S. National Hydrogen Strategy and Roadmap

- 10 million metric tons of demand by 2030
- 50 million metric tons of demand by 2050
- Up to 10% economy-wide emissions reductions
- Strategic deployments in:
  - ✓ Biofuel production (especially Sustainable Aviation Fuels)
  - ✓ Ammonia/Methanol
  - ✓ Power-to-Liquid Fuels

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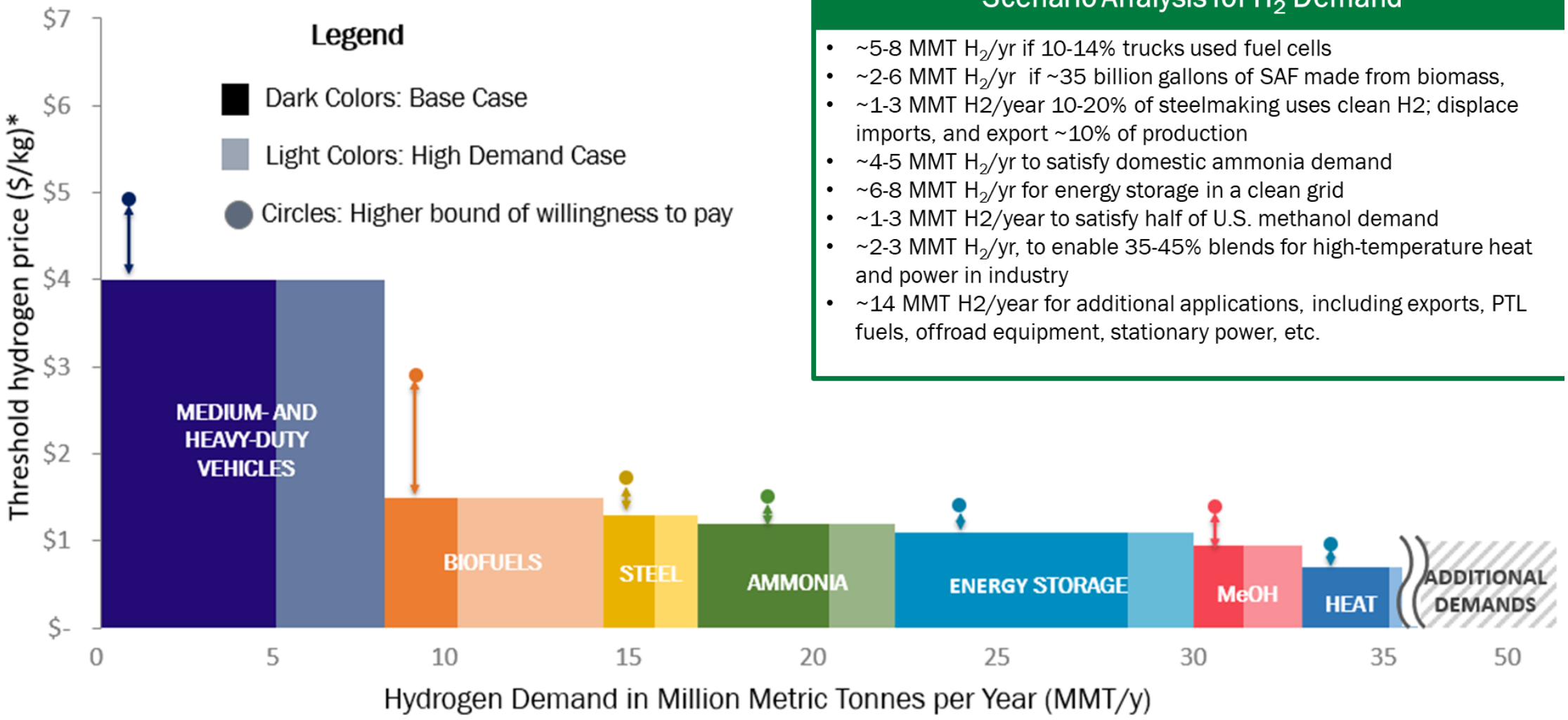
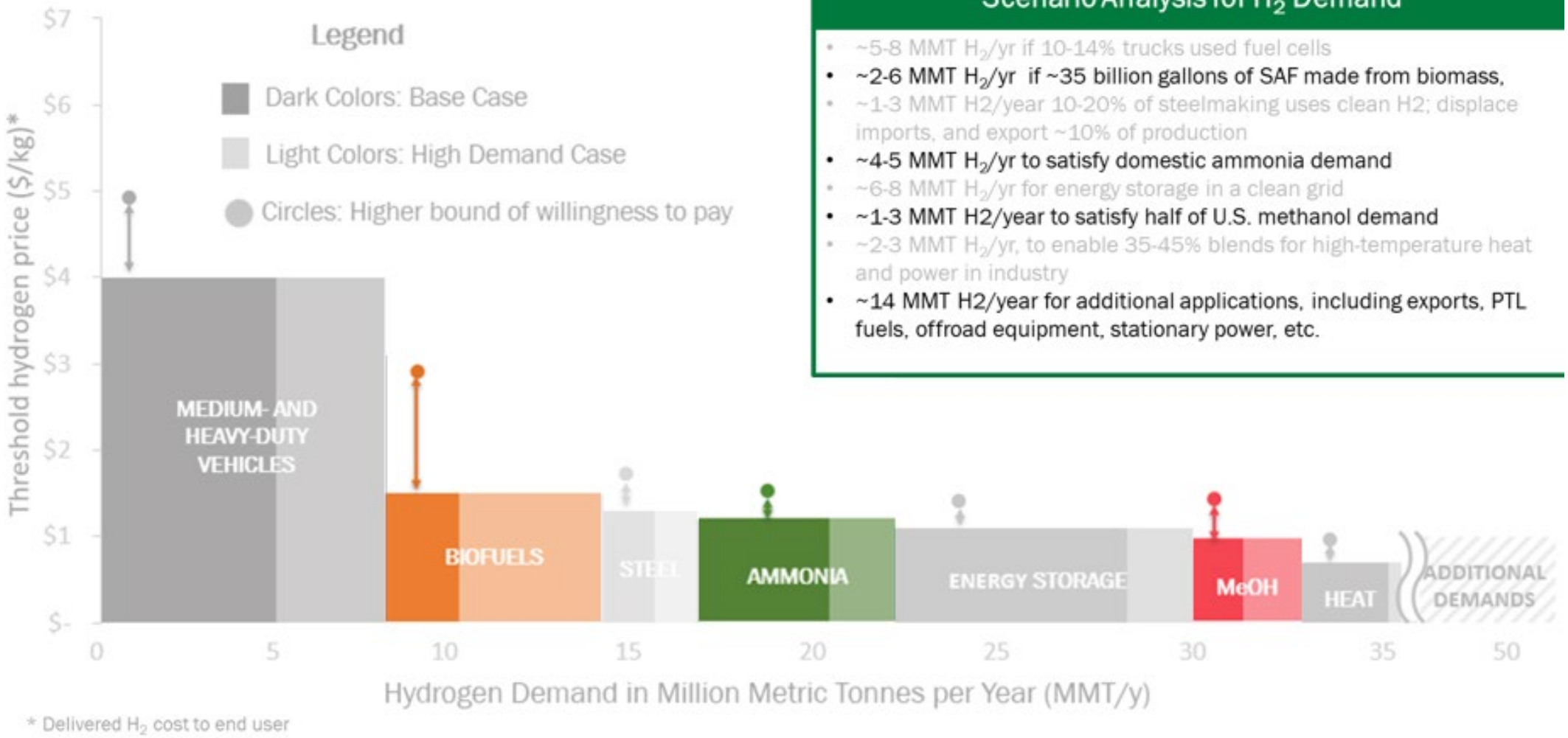


Scenario Analysis for H_2 Demand

- ~5-8 MMT H_2/yr if 10-14% trucks used fuel cells
- ~2-6 MMT H_2/yr if ~35 billion gallons of SAF made from biomass,
- ~1-3 MMT H2/year 10-20% of steelmaking uses clean H2; displace imports, and export ~10% of production
- ~4-5 MMT H_2/yr to satisfy domestic ammonia demand
- ~6-8 MMT H_2/yr for energy storage in a clean grid
- ~1-3 MMT H2/year to satisfy half of U.S. methanol demand
- ~2-3 MMT H_2/yr, to enable 35-45% blends for high-temperature heat and power in industry
- ~14 MMT H2/year for additional applications, including exports, PTL fuels, offroad equipment, stationary power, etc.

* Delivered H_2 cost to end user



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Selected Regional Clean Hydrogen Hubs

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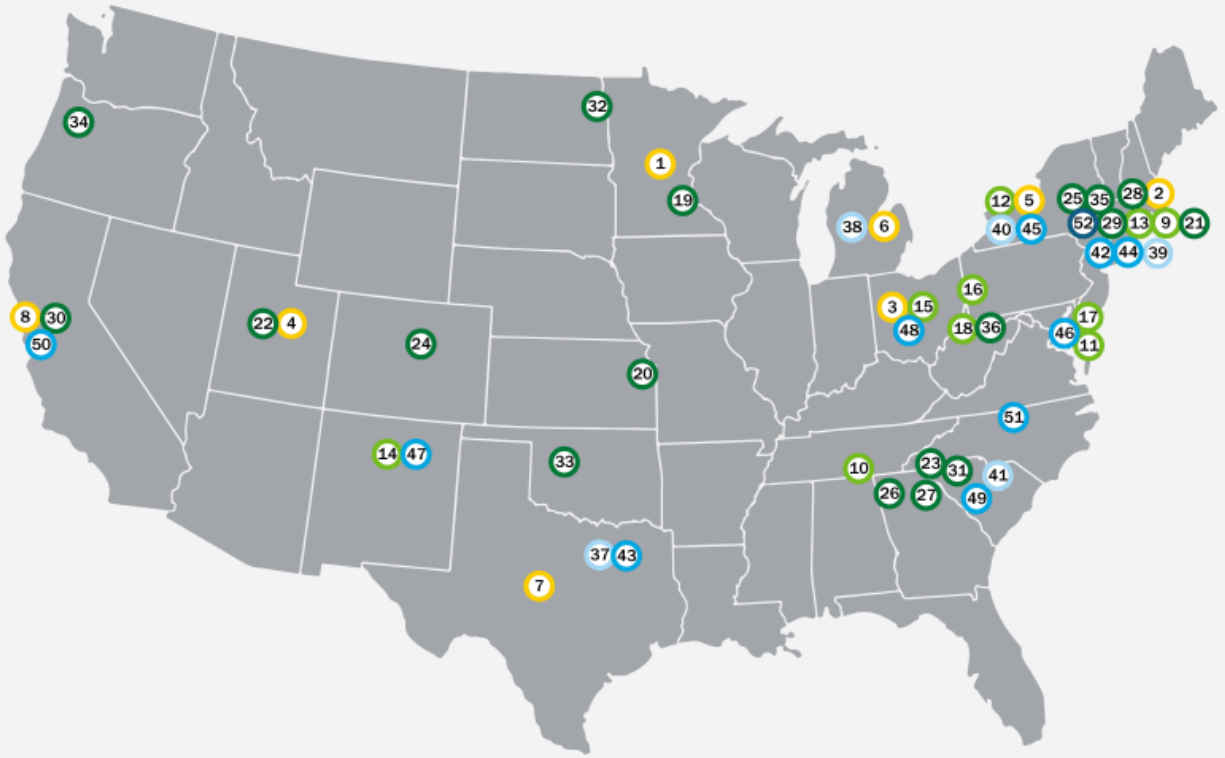
Funding Announced to Lower Hydrogen Costs

- $750 million in funding for 52 projects across 24 states
- Funding supports the Hydrogen Shot target:
  $1 per kilogram in one decade
- Funding tackles multiple areas, including:
  - Electrolyzer & fuel cell manufacturing
  - Electrolyzer & fuel cell supply chain development
  - Recycling



Electrolyzer Manufacturing
1. Cummins
2. Electric Hydrogen
3. NexTech Materials
4. OxEon Energy
5. Plug Power
6. Nel Hydrogen
7. thyssenkrupp nucera
8. Verdagy

Electrolyzer Supply Chain
9. ACS Industries
10. eSpin Technologies
11. HighT-Tech
12. Ionomr Innovations
13. Mott Corporation
14. Pajarito Powder
15. Power to Hydrogen
16. PPG Industries
17. The Chemours Company
18. West Virginia University

Electrolyzer Components
19. 3M Company
20. Avium
21. Boston University
22. Chemtronergy
23. Clemson University
24. Colorado School of Mines
25. Ecolectro
26. Georgia Tech
27. Georgia Tech
28. Nel Hydrogen
29. Plug Power
30. Stanford University
31. Tetramer Technologies
32. University of North Dakota
33. University of Oklahoma
34. University of Oregon
35. W. L. Gore & Associates
36. West Virginia University

Fuel Cell Manufacturing
37. Ballard Power Systems
38. General Motors
39. Nuvera Fuel Cells
40. Plug Power
41. Robert Bosch

Fuel Cell Supply Chain
42. AvCarb Material Solutions
43. Ballard Power Systems
44. Cabot Corporation
45. Ionomr Innovations
46. Materic
47. Pajarito Powder
48. pH Matter
49. Robert Bosch
50. Robert Bosch
51. Saueressig

Recycling Consortium
52. American Institute of Chemical Engineers

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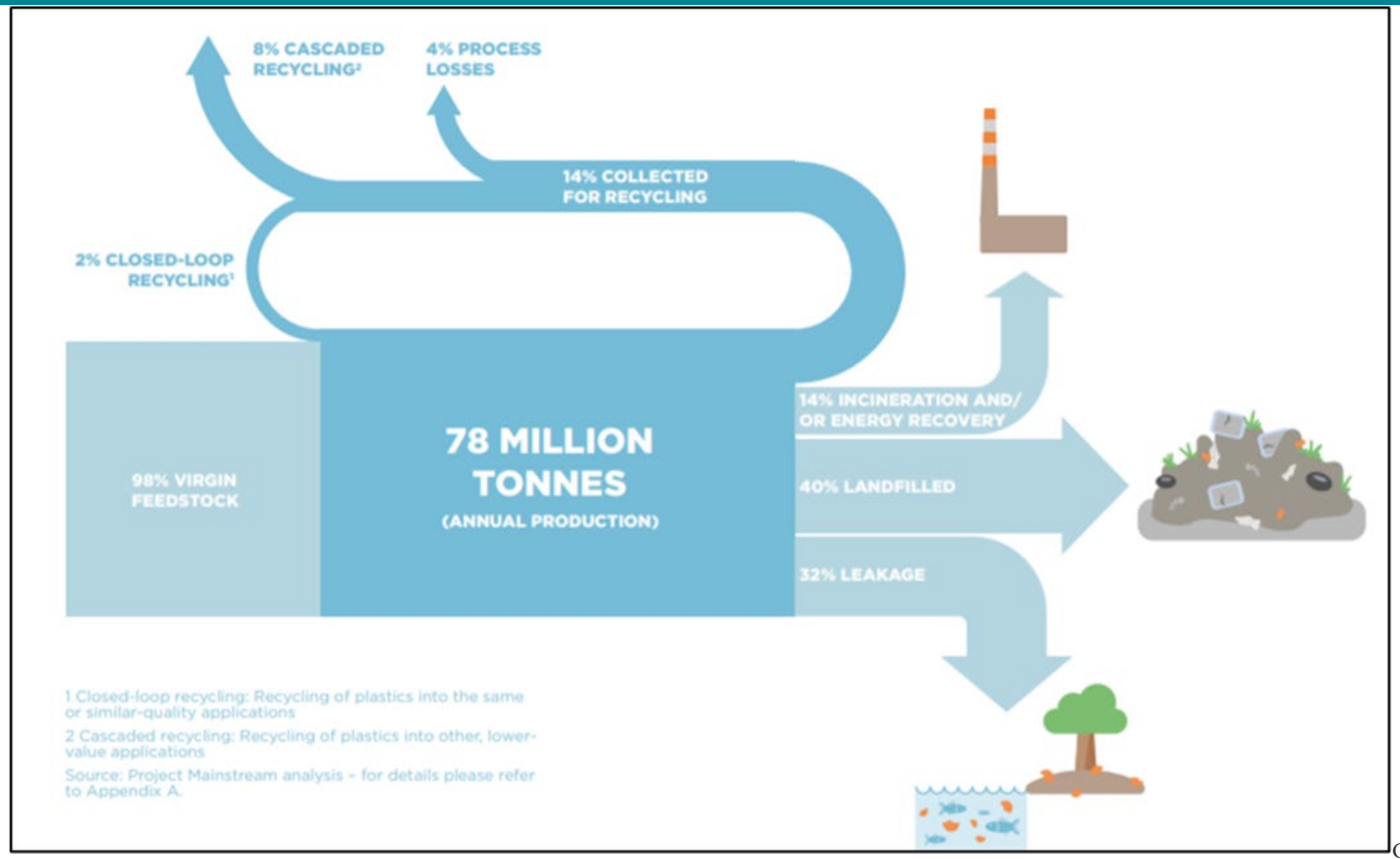
Advanced Materials and Manufacturing Technologies Office (AMMTO)

Dr. Kathryn Peretti, Program Manager

Recycled Feedstock Mobilization for Products with Lower Embodied Emissions

Plastic Waste Is a Resource for Chemicals and Products

In 2019, the United States recycled 5% of its plastics and disposed of 86%, resulting in market value losses totaling $7.2 billion. Plastic consumption accounts for 3% of US GHG Emissions and, globally, plastic waste is projected to triple by 2060.



Geyer et al. Science Advances 2017

REMADE – www.remadeinstitute.org

REMADE MISSION: Reduce embodied energy and carbon emissions through early-stage applied research & development

Systems Analysis & Integration

Design for Re-X

Manufacturing Materials Optimization

Remanufacturing & EOL Reuse

Recycling & Recovery

MATERIAL CLASSES

Metals

Polymers/Plastics

E-Waste

Fibers

 Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Advanced Manufacturing Office Award Number DE-EE0007897.

Examples of REMADE Material Recovery R&D

Novel Sorting Technologies

Rapid Sorting of Scrap Aluminum
Sorting & Recycling of Mixed Flexible Packaging

Contamination Removal

Purification of Recycled Metals, Fibers, and Plastics

Artificial Intelligence

Identification of Mixed Plastic & Valuable Electronics / Contaminant Removal from Recycled Plastics

Improved Material Recovery

Low-Cost, High-Value Metal Recovery from Electronic Scrap

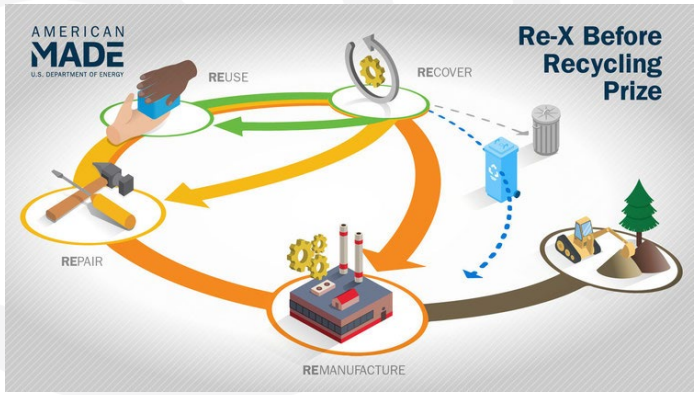
Novel Waste Processing Methods

Delamination to Enable Recycling of Polymer-Based Multilayer Packaging

Condition Assessment

Condition Assessment of Used Electronics and Non-Destructive Evaluation of Metal Fatigue Damage

Diversifying ReX Approaches: ReX Before Recycling Prize



Prize aims to develop innovative, novel supply chains for Re-X pathways that extend product lifespans.

Phase 1 winners will be announced this summer.

Phase 2 does not require participation in phase 1.

Circular Economy

Increasing Circularity

Linear Economy

	Strategy	Description
Smarter product use and manufacture	R0 - Refuse	Making products redundant by abandoning their function or by offering the same function with a radically different product
	R1 - Rethink	Make product use more intensive
	R2 - Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of products and their parts	R3 - Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfills its original function
	R4 - Repair	Repair and maintenance of defective product so it can be used for its original function
	R5 - Refurbish	Restore an old product and bring it up to date
	R6 - Remanufacture	Use parts of discarded products in a new product with the same function
	R7 - Repurpose	Use discarded products or their parts in a new product with a different function
Useful application of materials	R8 - Recycle	Process materials to a commodity level with same or lower quality
	R9 - Recover	Incineration of materials with energy recovery

Figure ES 2. Circular economy strategies (collectively Re-X) with descriptions and circularity ranking

After Potting et al. (2017), which is based on RIi (2015).

Sustainable Manufacturing and the Circular Economy, DOE (2023).

Dr. Bill Goldner

National Program Leader

U.S. Department of Agriculture

Session 2 Keynote

SAF Grand Challenge Supply Chain

Dr. Matthew Langholtz

Natural Resource and Environmental Economist

Oak Ridge National Laboratory

Session 2 Keynote

2023 Billion-Ton Report

Session 2 Panel

Resource/Feedstock Mobilization

Mr. Harrison Pettit

Chief Development Officer

Pacific Ag

Session 2 Panel

Resource/Feedstock Mobilization

Dr. Jennifer Aurandt-Pilgrim

Vice President of R&D

Marquis

Session 2 Panel

Resource/Feedstock Mobilization

Dr. David Thompson

Chief Scientist - Bioenergy
Idaho National Lab

Session 2 Panel

Resource/Feedstock Mobilization

Panel Q&A

Session 2 Panel

Resource/Feedstock Mobilization

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Session 3

Carbon-Efficient Conversion Processes

Pillar Overview

Carbon-Efficient Conversion Processes

New Conversion Paradigm:
Develop technologies to enable & maximize conversion of non-fossil resources into fuels and chemicals

Pillar Includes:
Reactors, separations, process design & optimization
Integration of clean hydrogen, clean electricity, & clean heat
Thermo-catalytic, biocatalytic, & electrochemical pathways

Examples:
Biomass gasification to SAF, power to liquids, catalytic conversion of CO_2, conversion of waste plastic, solar fuels

Basic & Foundational Science

Applied Research & Development

Session Agenda

Presentation	SPEAKER
U.S. Department of Energy Updates	Dr. Todd Anderson, Director, Biological Systems Science Division, DOE SC
	Dr. Jay Fitzgerald, Chief Scientist and Program Manager, Conversion Technologies, DOE BETO
	Emily Connor, Acting Division Director/Program Manager, Carbon Conversion, DOE FECM
	Dr. Felicia Lucci, Technology Manager, DOE IEDO
	Dr. Kathryn Peretti, Program Manager, DOE AMMTO
Keynotes	***Fuels***: Dr. Zia Abdullah, Laboratory Program Manager, National Renewable Energy Laboratory
	Chemicals: Dr. Joel Tickner, Founder and Executive Director, Change Chemistry
Industry Panel	Dr. Stafford Sheehan, Co-Founder and Chief Technology Officer, AIR COMPANY
	Dr. Aanindeeta Banerjee, Co-Founder and CEO, ReSource Chemical
	Dr. Christophe Schilling, Co-Founder and CEO, Geno

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DOE Office Updates

- Dr. Todd Anderson | Office of Science
- Dr. Jay Fitzgerald | Bioenergy Technologies Office
- Emily Connor | Office of Fossil Energy and Carbon Management
- Dr. Felicia Lucci | Industrial Efficiency and Decarbonization Office
- Dr. Kathryn Peretti | Advanced Materials & Manufacturing Technologies Office

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Office of Science (SC)

Dr. Todd Anderson

Director Biological Systems Science Division

Office of Science Activities

Basic research on carbon-efficient chemical and biological conversion mechanisms and separations science needed to enable broader production of renewable fuels, chemicals and materials

Biological Conversion Processes (BER)

- DOE Bioenergy Research Centers (BRCs)
- Genomic Science programs
  - Microbial biology
  - Biosystems Design

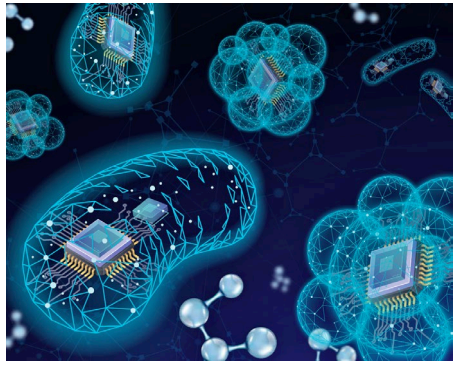
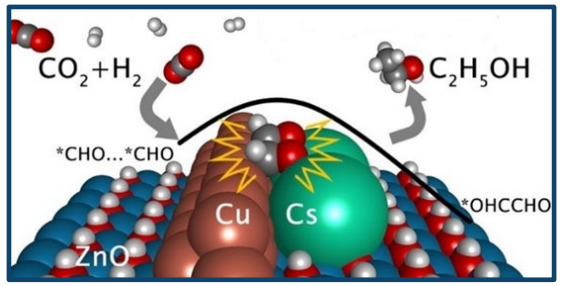


Illustration imagining the molecular machinery inside microbes as technology. (Wayne Keefe/Berkeley Lab)

Catalysis and Separations (BES)

- Energy Frontier Research Centers (EFRCs)
- Catalysis research
- Separations research



BER DOE Bioenergy Research Centers

- **Great Lakes Bioenergy Research Center (GLBRC)** – Dr. Tim Donohue University of Wisconsin, Michigan State University (https://www.glbrc.org/)
- **Joint BioEnergy Institute (JBEI)** – Dr. Jay Keasling Lawrence Berkeley National Laboratory (https://www.jbei.org/)
- **Center for Bioenergy Innovation (CBI)** - Dr. Gerald Tuskan Oak Ridge National Laboratory (https://cbi.ornl.gov/)
- **Center for Advanced Bioenergy and Bioproducts – Dr. Andrew Leakey Innovation (CABBI)** University of Illinois (UIUC) (https://cabbi.bio/)

Team-oriented, integrated science addressing the basic science challenges to cost-effective conversion of plant biomass to fuels, chemicals and materials

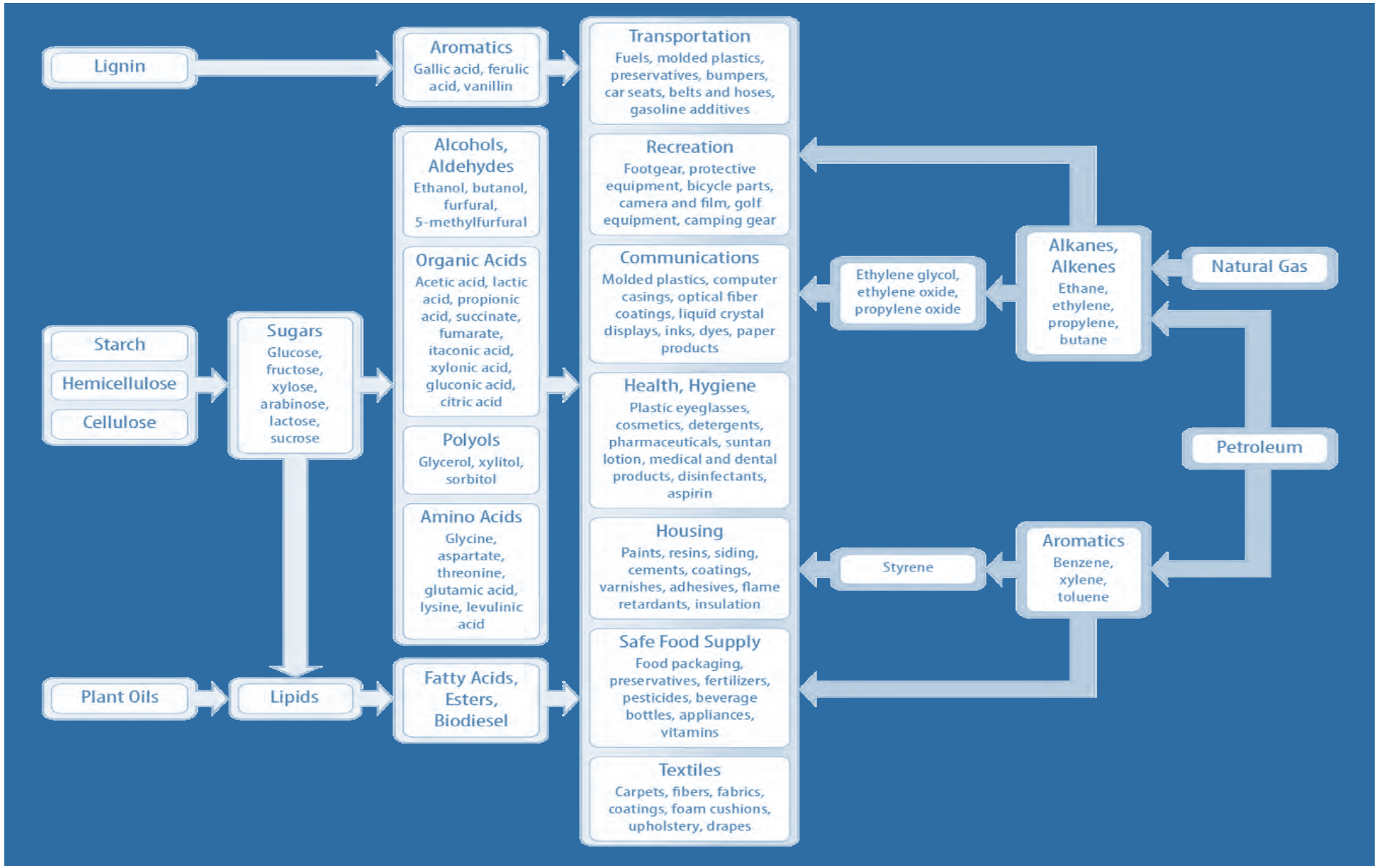

Sustainability

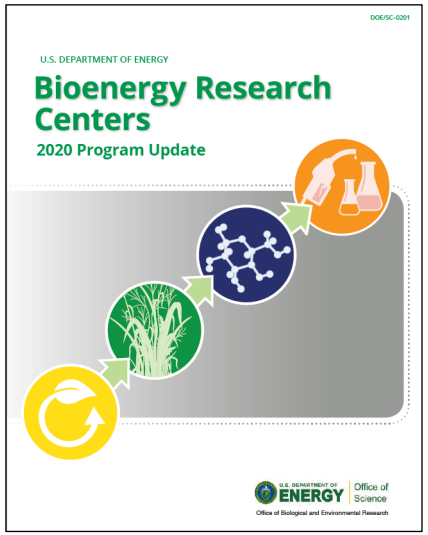

Feedstock Development


Biomass Deconstruction


Conversion biofuels & bioproducts

Renewable Feedstocks Underpinning a more Sustainable Bioeconomy



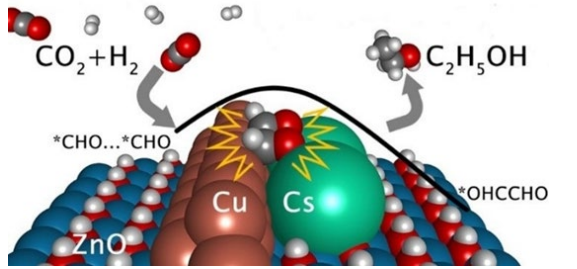


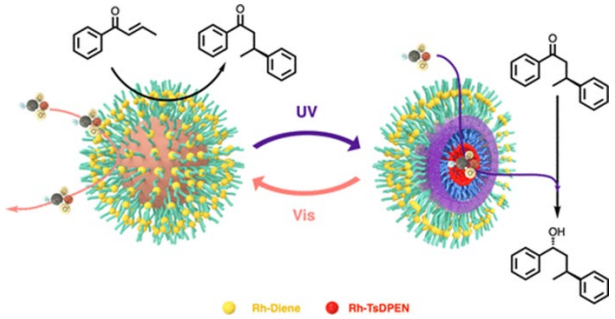
https://genomicscience.energy.gov/centers/BRC_Booklet_2020LR.pdf

BES Catalysis Science Program

- Discover fundamental principles and novel approaches to predict structure-reactivity behavior.
- Understand and control the chemical conversion of natural and artificial feedstocks.
- Impact the efficiency of conversion of natural resources into fuels, chemicals, materials, or other forms of energy, while minimizing environmental impact.

Conversion Research





Feedstocks

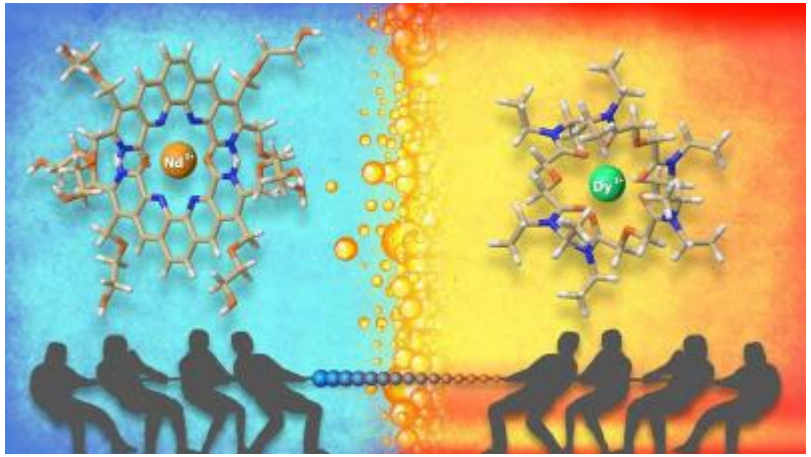
- Low-T light hydrocarbon valorization and methane transformations to liquid fuels and aromatics.
- Catalysis of biomass-derived oxygenates to fuels and value-added chemicals.
- Small molecule activation/transformation , including carbon management and hydrogen production/utilization.

Approaches

- Sustainable and efficient routes for chemical and fuel production (electro-driven processes and polymer upcycling).
- Mastering control of the active site environment (nano-, single-atom, and multi-metallic structures, multi-functionality/site cooperativity, solvent effects, secondary ligand effects, and confinement).
- Operando studies/catalyst dynamics by development of transformative tools.
- Data science and theoretical approaches for catalyst discovery/development.

BES Separations Science Program

Separations Research



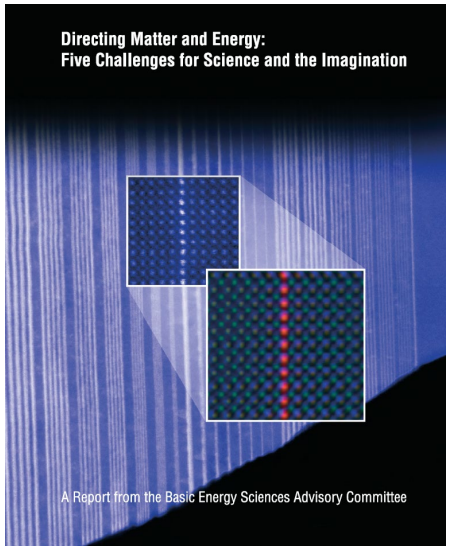
- Discover, understand, predict, and control de-mixing transitions with the goal of enabling chemical separation paradigms that may serve as a basis for solutions to the current and long-term energy challenges.
- Understand chemical and physical properties at multiple scales, molecular interactions, and energy exchanges that determine the efficiency of chemical separations.

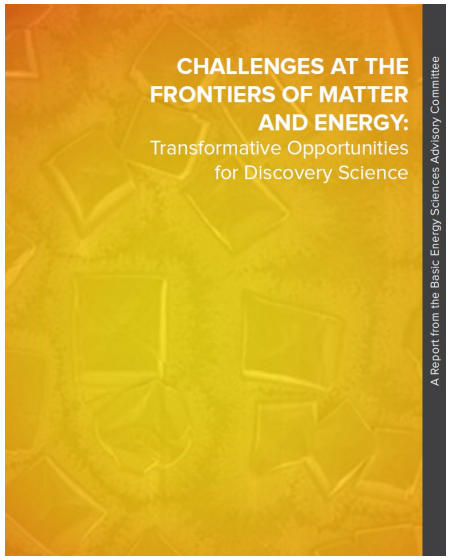
Selected Topics of Interest include:

- Discovering, understanding, and predicting paradigms for removal of dilute constituents from a mixture, such as reactive separations, intermolecular interactions leading to formation of a new phase enriched in the target species, and emergent phenomena that result from correlation and amplification of individual atomic or molecular effects
- Understanding factors that cause a separation system to approach mass transfer limitation in the source mixture
- Understanding non-thermal mechanisms that have potential to drive efficient and selective energy-relevant separations, such as magnetic, mechanic, electromagnetic, magneto-reactive, and other means to affect transport kinetics and bonding
- Understanding and control of temporal changes, such as degradation
- Foundational knowledge that can enable or enhance strategies for critical materials recovery from natural and unconventional feedstocks
- Development of scalable approaches to carbon oxide removal from low-concentration sources such as air and water

BES Energy Frontier Research Centers (EFRCs)

- Multidisciplinary, multi-institutional team research that couples "**basic research needs**" for energy applications and "**grand-challenge science**"
- Brings the academic community and national labs together to enable transformative **team science** with relevance to energy science and technology
- Demonstrates **scientific productivity and world leadership**, and makes progress in ways that would not have been likely through individual efforts
- Develops a diverse and inclusive **next generation of scientists** with a passion for energy science.

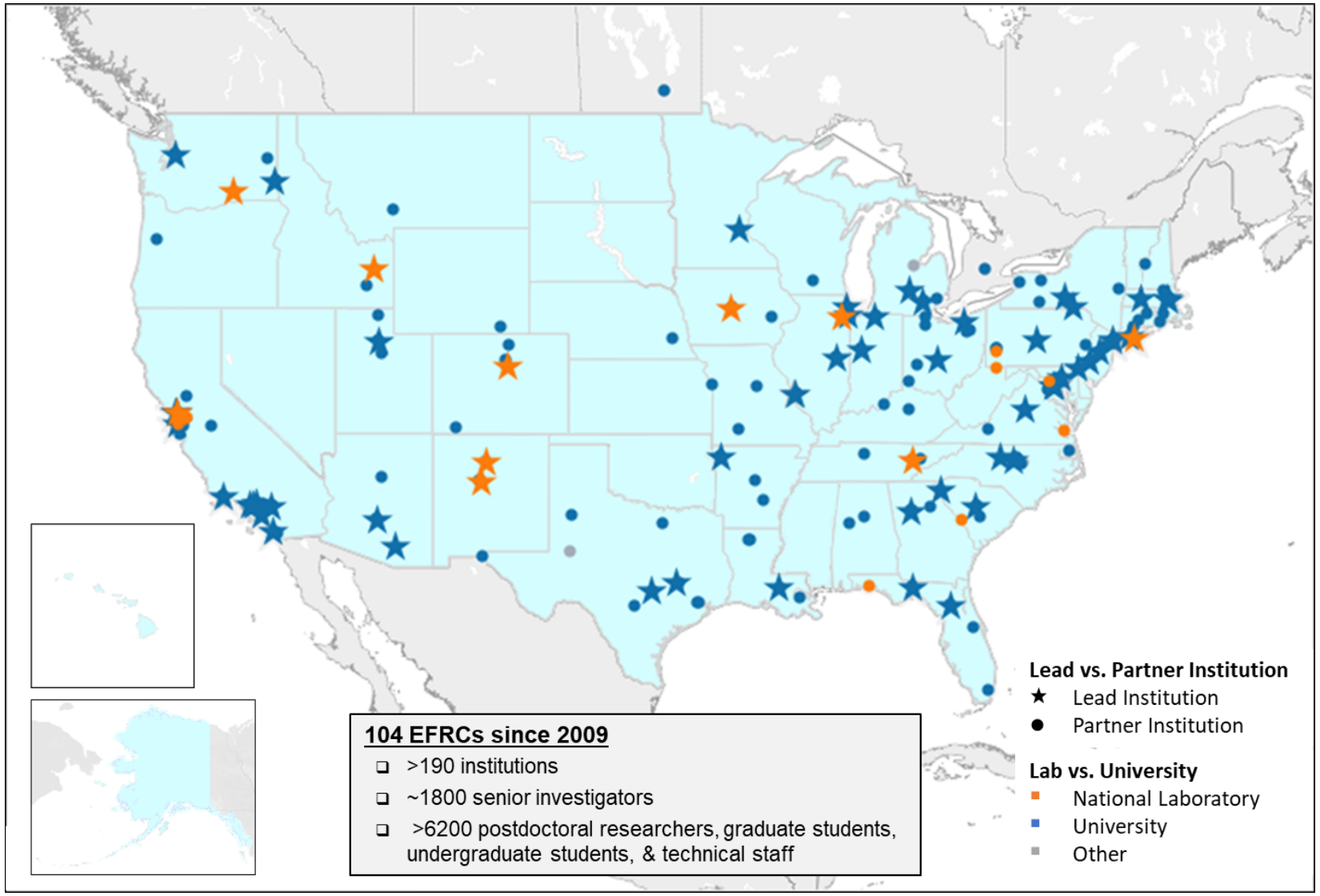




https://science.osti.gov/bes/Community-Resources/Reports

EFRCs: Nationwide Participation

- Large number of Institutions involved over the life-time of the program.
- DOE Laboratory and University-led projects.
- Numerous collaborating Institutions



EFRCs Relevant to Clean Fuels & Products

Ensembles of Photosynthetic Nanoreactors (EPN)

University of California, Irvine (Shane Ardo)

Understand, predict, and control the activity, selectivity, and stability of solar water splitting nanoreactors in isolation and as ensembles

Ensembles of Photosynthetic Nanoreactors (uci.edu)

Understanding and Controlling Accelerated and Gradual Evolution of Materials for Energy (UNCAGE-ME)

Georgia Institute of Technology (Ryan Lively)

Develop knowledge for characterization, prediction, and control of materials evolution in the presence of realistic contaminants, processes, and mixtures to accelerate materials discovery for sustainable production and utilization of H_2 and CO_2.

UNCAGE-ME EFRC (gatech.edu)

Center for Plastics Innovation (CPI)

University of Delaware (LaShanda Korley)

Develop catalytic and functionalization approaches and fundamental tools applicable to the upcycling, upgrading, and recycling of polymer plastics waste (PPW) with a focus on mixed-stream transformations in varied material forms

CENTER *for* PLASTICS INNOVATION (CPI)

Center for Plastics Innovation | udel.edu

Institute for Cooperative Upcycling of Plastics (iCOUP)

Ames National Laboratory (Aaron Sadow)

Uncover macromolecular and catalytic phenomena at the interface of molecular-scale chemistry and mesoscale materials science in order to enable upcycling of energy-rich polymers (plastics)

Institute for Cooperative Upcycling of Plastics | Ames Laboratory

Opportunities Relevant to the Clean Fuels & Products Shot

Funding Opportunity Announcements (FOAs)

- *Reaching a New Energy Workforce (RENEW)* – All SC
- *Funding for Accelerated, Inclusive Research (FAIR)* – All SC
- *Advances in Artificial Intelligence for Science* - ASCR
- *Energy Frontier Research Centers* - BES
- *Early Career Research Program* – All SC
- *Data Reduction for Science* – ASCR

Grants.gov

Search Grants [Tab]

[Tab] Department of Energy – Office of Science

Opportunity Number	Opportunity Title	Agency	Opportunity Status	Posted Date	Close Date
DE-FOA-0003280	FY 2024 Reaching a New Energy Sciences Workforce (RENEW)	PAMS-SC	Posted	03/12/2024	07/23/2024
DE-FOA-0003207	FY 2024 Funding for Accelerated, Inclusive Research (FAIR)	PAMS-SC	Posted	03/12/2024	07/16/2024
DE-FOA-0003279	FY 2024 Phase II Release 2	PAMS-SC	Posted	02/26/2024	04/30/2024
DE-FOA-0003267	Research on General Plasma Science Collaborative Research Facilities	PAMS-SC	Posted	02/21/2024	04/29/2024
DE-FOA-0003264	Advancements in Artificial Intelligence for Science	PAMS-SC	Posted	02/13/2024	05/21/2024
DE-FOA-0003265	Accelerated Research in Quantum Computing	PAMS-SC	Posted	02/07/2024	05/08/2024
DE-FOA-0003258	Energy Frontier Research Centers (EFRC)	PAMS-SC	Posted	01/22/2024	05/08/2024
DE-FOA-0003300	EXPRESS: 2024 Exploratory Research for Extreme Scale Science	PAMS-SC	Posted	01/19/2024	05/02/2024
DE-FOA-0003266	Data Reduction for Science	PAMS-SC	Posted	01/16/2024	05/07/2024
DE-FOA-0003238	Nuclear Data Interagency Working Group (NDIAWG) Research Program	PAMS-SC	Posted	01/04/2024	04/04/2024
DE-FOA-0003281	Integrated Biological and Computational Low-Dose Radiation Research	PAMS-SC	Posted	12/21/2023	04/02/2024
DE-FOA-0003176	Early Career Research Program	PAMS-SC	Posted	12/15/2023	04/25/2024
DE-FOA-0003177	FY 2024 Continuation of Solicitation for the Office of Science Financial Assistance Program	PAMS-SC	Posted	09/29/2023	09/30/2024

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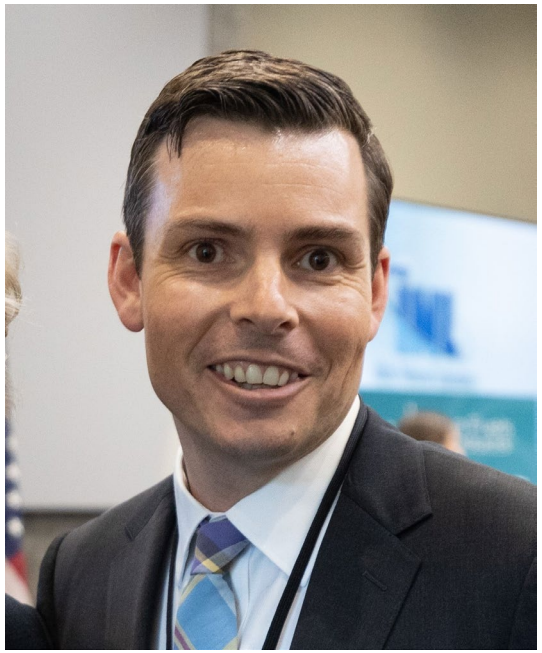
Bioenergy Technologies Office (BETO)

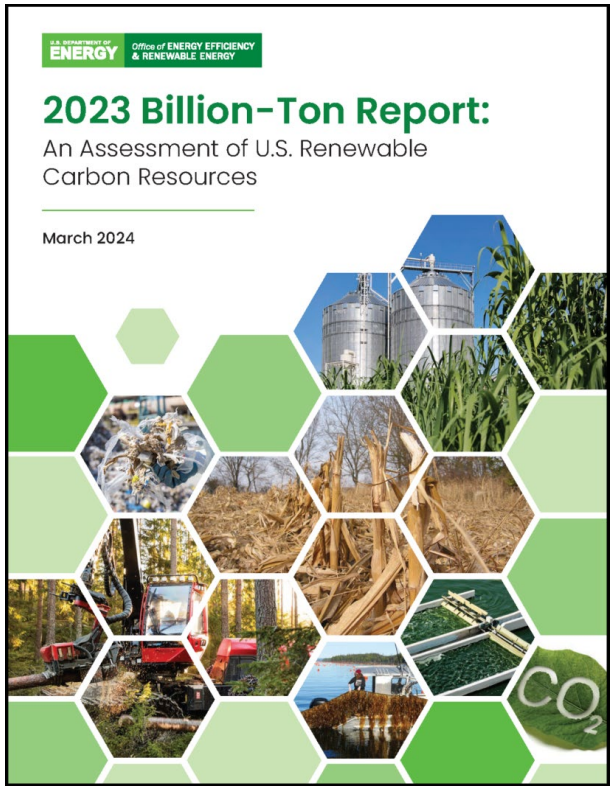
Dr. Jay Fitzgerald

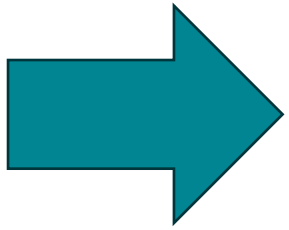
Chief Scientist and Program Manager



WHAT IS CONVERSION R&D?

How do we turn the carbon we have into the carbon we need?





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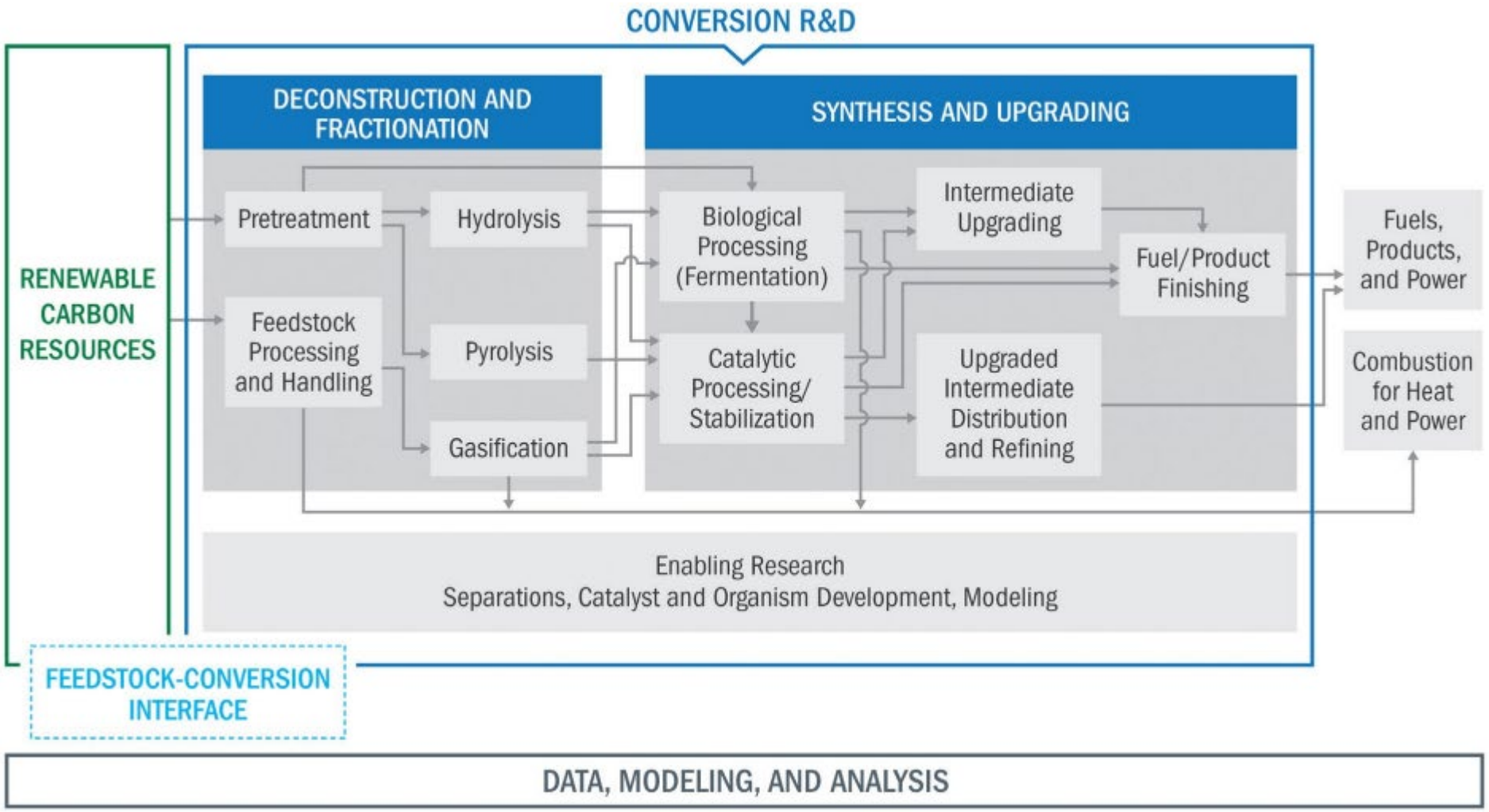
BETO CONVERSION R&D OVERVIEW



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CAPABILITY HIGHLIGHT: CHEMCATBIO

Materials Synthesis >

Evaluation of Catalyst Performance >

Modeling, Interactive Tools, and Databases >

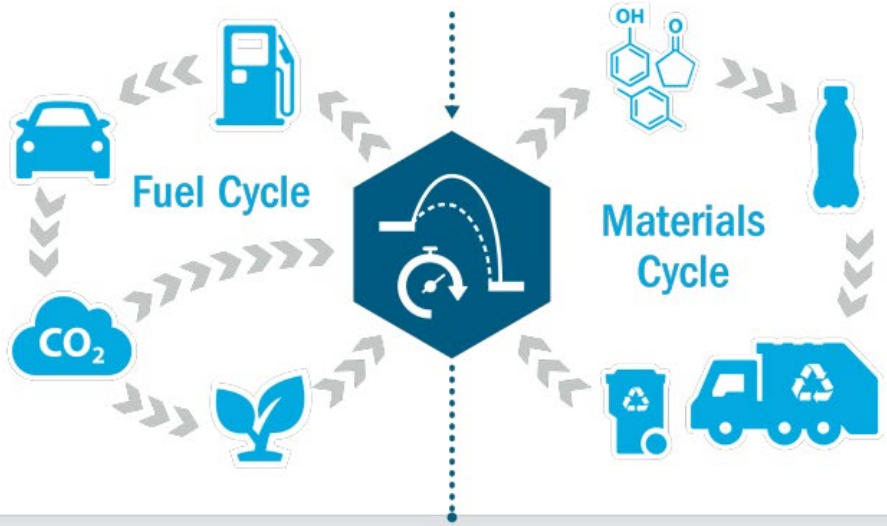
Advanced Catalyst Characterization >

Techno-Economic and Sustainability Analysis >

ChemCatBio
Chemical Catalysis for Bioenergy

Catalysis enables a circular carbon economy.

85% of industrial chemical processes rely on catalysts.



ChemCatBio is accelerating catalyst development for bioenergy applications

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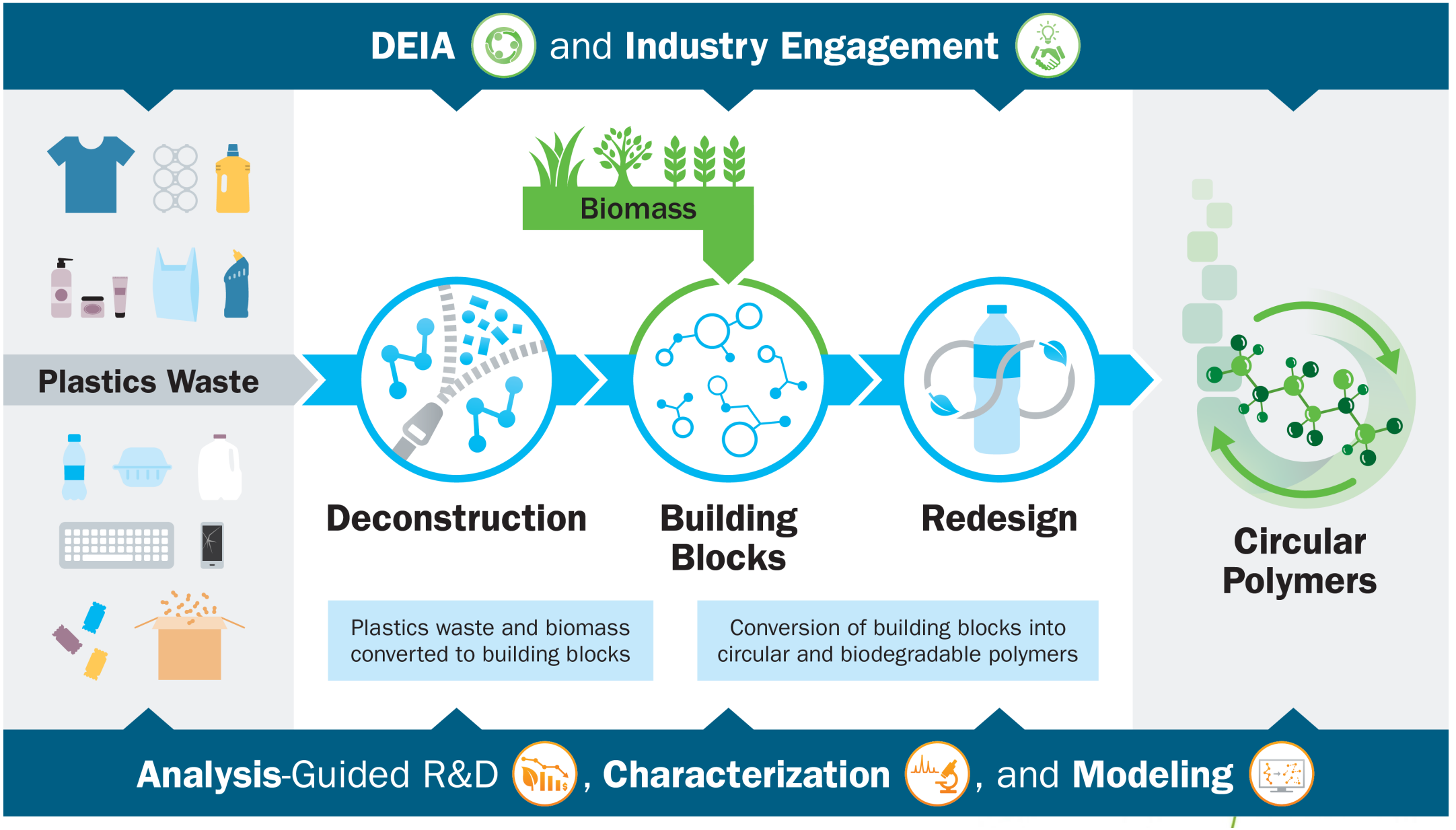
CAPABILITY HIGHLIGHT: BOTTLE CONSORTIUM



CAPABILITY HIGHLIGHT: AGILE BIOFOUNDRY

KEY CAPABILITIES

Available to industry for onboarding hosts and improving titers, rates, and yields

AUTOMATED RECOMMENDATION TOOL

Machine learning and probabilistic modeling techniques for guiding synthetic biology systematically

SAGE DNA EDITING TOOL

Broadly applicable toolkit to engineer microbes faster and easier

SCALE-UP

Multiple scales of integrated bioreactor cultivation equipment to translate your technology to industrial scale

PROTEOMICS AND METABOLOMICS

Both targeted & untargeted

BIOSENSORS

Responsive, tailorable sensor-reporters indicate the amount of a metabolite both non-invasively and in real time

We are currently leveraging these capabilities to develop:

- High titer, rate, and yield production of alkanes for sustainable aviation fuels
- Muconate
- 3-hydroxypropionic acid

Argonne NATIONAL LABORATORY · BERKELEY LAB · Los Alamos NATIONAL LABORATORY · NREL

OAK RIDGE National Laboratory · Pacific Northwest NATIONAL LABORATORY · Sandia National Laboratories

Partnering with industry to enable sustainable biomanufacturing of affordable fuels and chemicals

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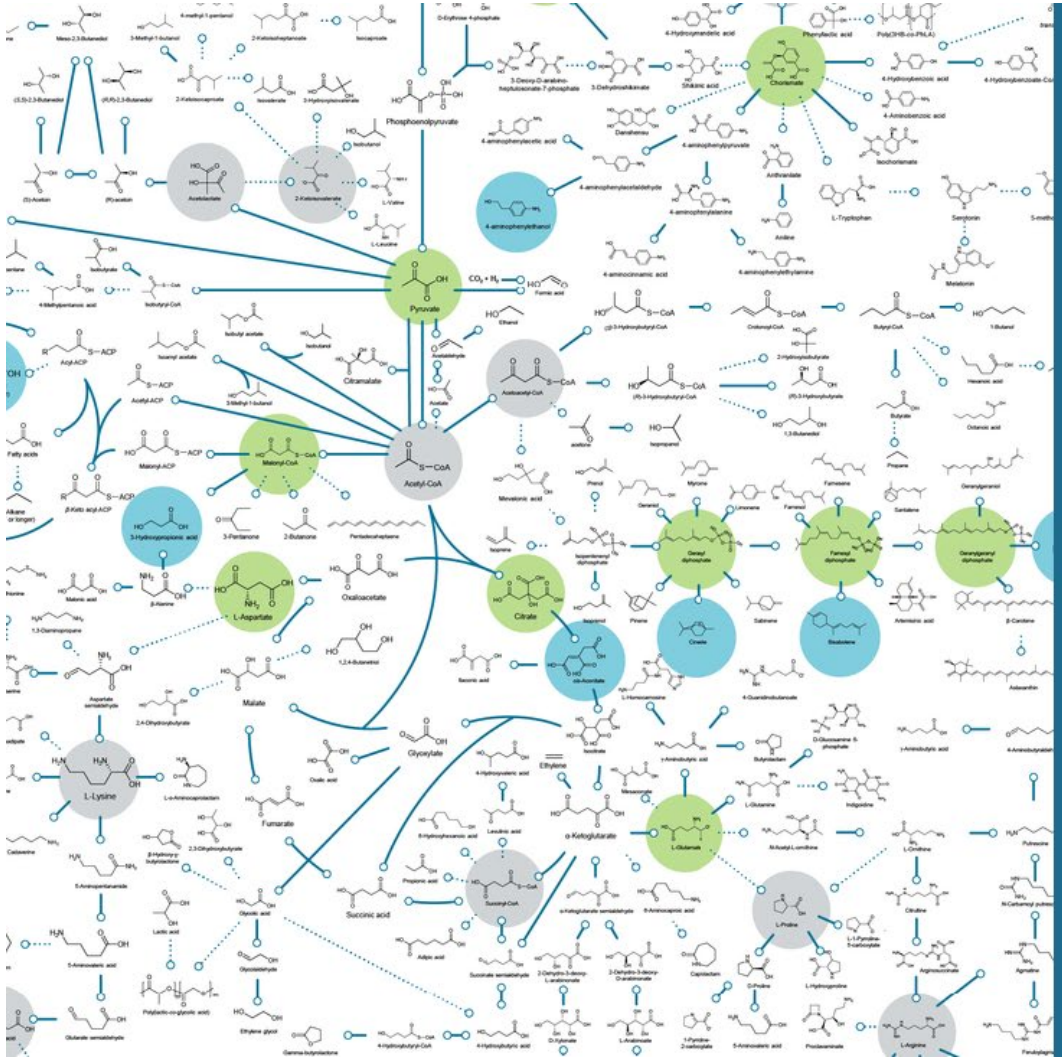
AGILE BIOFOUNDRY: CARBON HIGHWAYS



Get where you want to go, faster.

Leverage millions of dollars of DOE infrastructure and expert researchers with deep experience working with industry to get innovative products to market faster, with higher return on investment.

- Current ABF target molecule
- Current ABF beachhead molecule
- Potential beachhead molecule

Map adapted by permission from Springer Nature Customer Service Centre GmbH: Nature, Nature Catalysis, A comprehensive metabolic map for production of bio-based chemicals, Lee, S.Y., et al., © 2019

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CONCLUSIONS

- The BETO Conversion program supports R&D on transforming renewable carbon resources into fuels, chemicals, and materials
- Funding through open FOA announcements
- Capabilities at the DOE National Laboratories

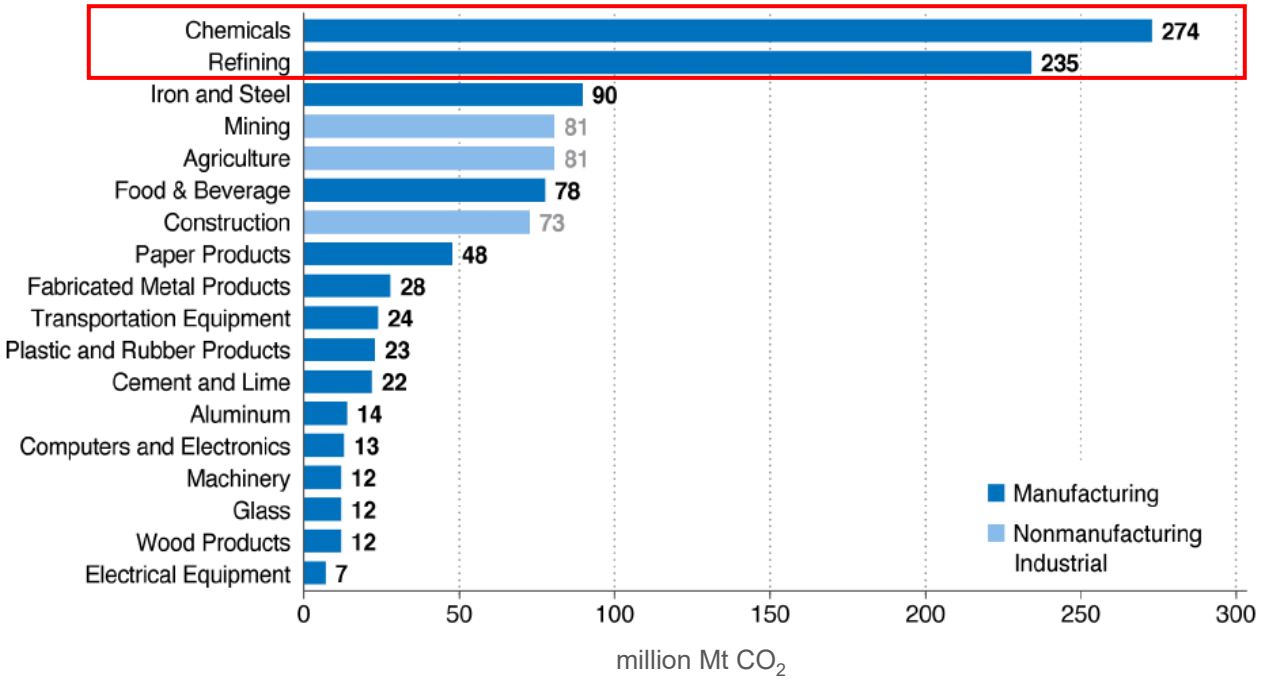
Office of Fossil Energy & Carbon Management (FECM)

Emily Connor

Acting Division Director/Program Manager

Why Carbon Conversion & Utilization

Energy-related CO_2 emissions by industrial subsector in 2020



To meet U.S. decarbonization goals of net- zero GHG emissions by 2050, chemicals & refining production must reduce emissions by ~35% through 2030 and more than ~90% by 2050.

- CO_2 conversion & utilization transforms anthropogenic carbon dioxide into a feedstock for products and fuels
- It can provide lower-carbon or net-negative alternatives for industries and processes that are hard to decarbonize
  - For example, long-haul aviation, long-haul shipping, plastics production, and concrete
- U.S. chemicals production and oil refining contribute about 8% to GDP and are critical for energy security but also generate 11% of US emissions
  - Produces fuels for transportation, power, and heat and essential inputs to widely used downstream products, including plastics, fertilizer, and pharmaceuticals

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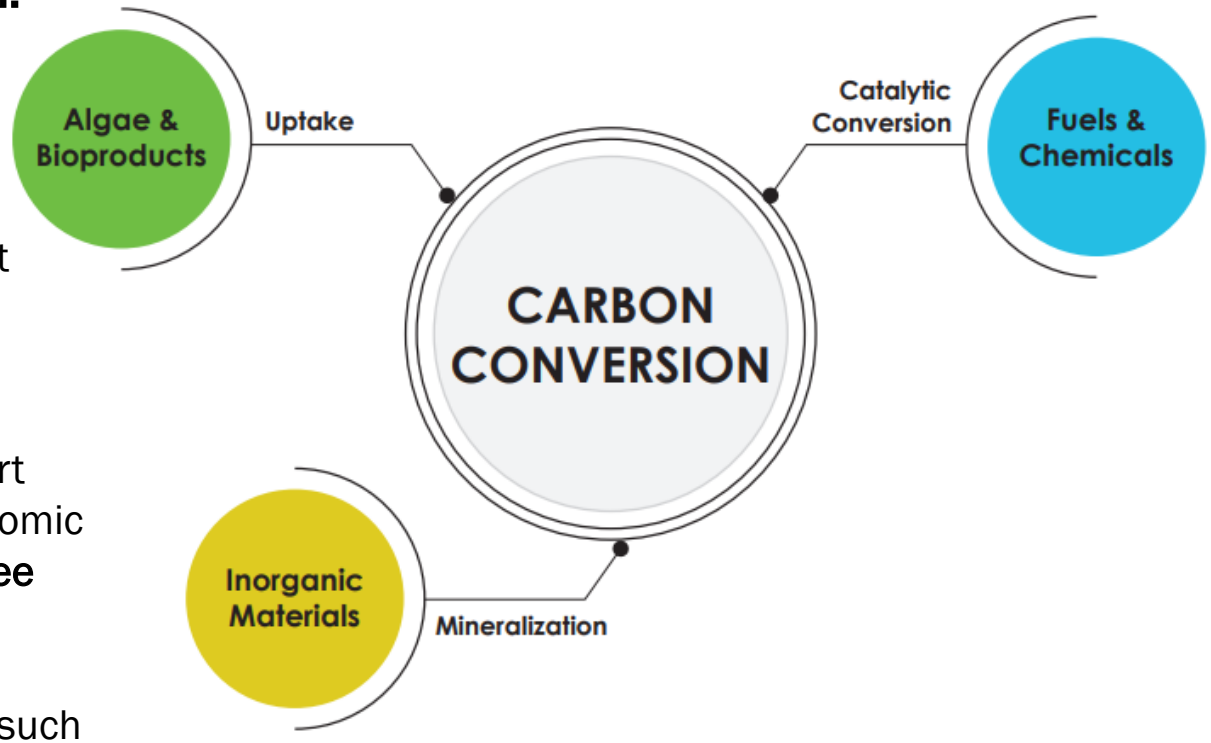
FECM Carbon Conversion Program

Vision Statement for the Carbon Conversion Program:

> "Research, develop, and demonstrate a broad suite of technologies that convert CO_2 into environmentally responsible, equitable, and economically valuable products, and enable low-carbon supply chains to meet the goal of a decarbonized economy by 2050."
> – FECM Strategic Vision 2022



- Annual appropriations in conjunction with IIJA will support overall program goals to advance the performance, economic viability and commercialization of technologies along **three** conversion pathways

- Each pathway has unique challenges, but certain areas, such as improved TEA/LCA capabilities and support for FOAK demonstration/pilot sites are critical for all technologies

Conversion Goals

Research, develop, and demonstrate a broad suite of technologies that convert CO_2 into environmentally responsible, and economically valuable products, which provide a conversion option for anthropogenic CO_2.

Create open source LCA/TEA tools to create verifiable carbon accounting foundations to support technology development and policies such as 45Q tax credits.

Accelerate large-scale conversion of CO_2 into products that advance net-zero and justice goals –accelerate the pathway to net-zero refineries, advance mineral carbonation approaches, maturation of algae conversion, and expand the availability of CO_2-based synthetic fuels.

Challenges

- Scale & rate of CO_2 emissions relative to of CO_2 conversion
- Determining economic viability and environmental impact requires significant resources - very place-based

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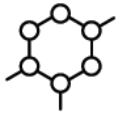
Conversion Opportunities & Challenges

$0.5 – $2 trillion / year opportunity		2 – 8 Gigatons of CO_2 / year	
		Annual Market Opportunity (Billion USD)	Annual CO_2 Consumption (Million Tons)
	**Construction Materials** Concrete, aggregates	165 - 550	900 - 5000
	**Fuels** Natural gas replacement, gasoline, diesel fuel, jet fuel	10 - 250	700 - 2100
	**Chemicals** Solvents, detergents	200 - 750	135 - 565
	**Engineered Materials** Carbon fiber, carbon nanotubes, graphene, carbon ceramics	140 - 400	30 - 84
	**Polymers** Plastic foils, containers, furniture, plastic housings, toys	2 - 25	1 - 20
	**Agriculture and Food** Fertilizer, protein for human consumption, animal feed	> 25	> 40

CO_2 is a new ingredient

CO_2 replaces fossil carbon

CO_2 is a new ingredient

Conversion and utilization can support the transition from status quo to a **future 2050 carbon neutral chemicals & fuels** scenario

Ongoing funding requires robust **LCA and TEA** analysis to evaluate the full lifecycle emissions impacts of all new and developing technologies to ensure overall emissions reductions

National Academies of Sciences, Engineering, and Medicine. 2023. Carbon Dioxide Utilization Markets and Infrastructure: Status and Opportunities: A First Report. Washington, DC: The National Academies Press.

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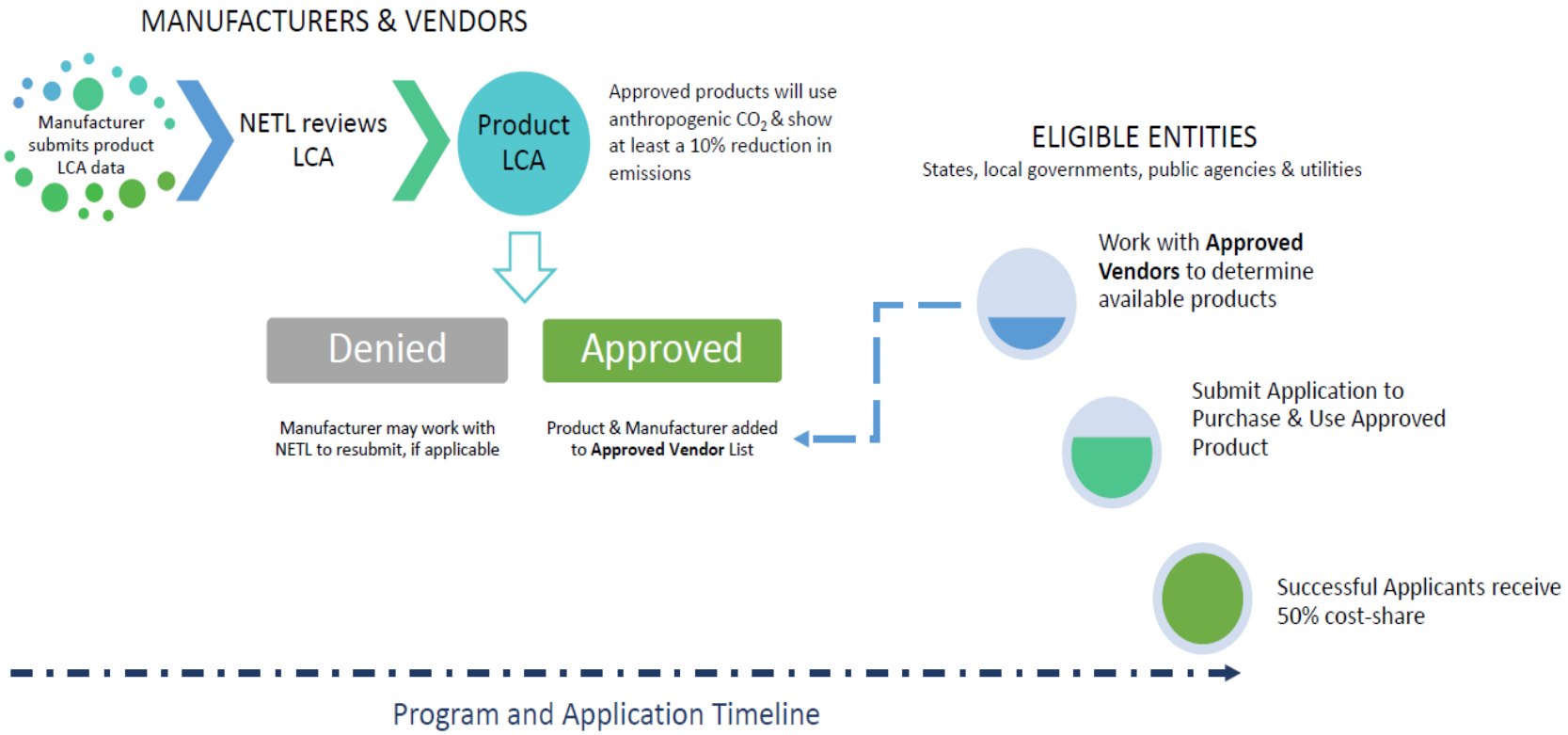
Products from CO2: Upgrants Programs

Current Funding Opportunity

- $100 million available to states, local governments, and public agencies & utilities to purchase products derived from converted carbon emissions
- Products must demonstrate at least 10% reduction in emissions compared to incumbent products
- Product LCAs are reviewed and approved by DOE's National Energy Technology Laboratory (NETL)



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FECM/NETL CO_2U LCA Toolkit

- Initially created for Carbon Utilization/Conversion Program research projects
- LCA guidance, open source LCA software (openLCA), NETL data, and results reporting tools
- A living document with overall version improvements and addendums to adapt the methodology for new use cases

Toolkit available at netl.doe.gov/LCA/CO2U

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Funding Opportunities

FY23/24 Funding Announcements:

- FOA 2614 Carbon Management FOA, multiple issuances
- FOA Carbon Utilization & Procurement Grants (UPGrants)
    - $100 million for procurement of carbon utilization products
- NOI Issued December 2023
    - Clean Fuels & Products Shot: Supporting Carbon Utilization
      Products via Electrochemical Conversion and Refinery and Petrochemical Facilities Retrofitting

Additional Market Drivers:

- 45Q tax credit opportunities for conversion
- Adoption of performance-based standards for new products such as CO_2 cured cement
- Buy Clean & procurement incentives, including UPGrants

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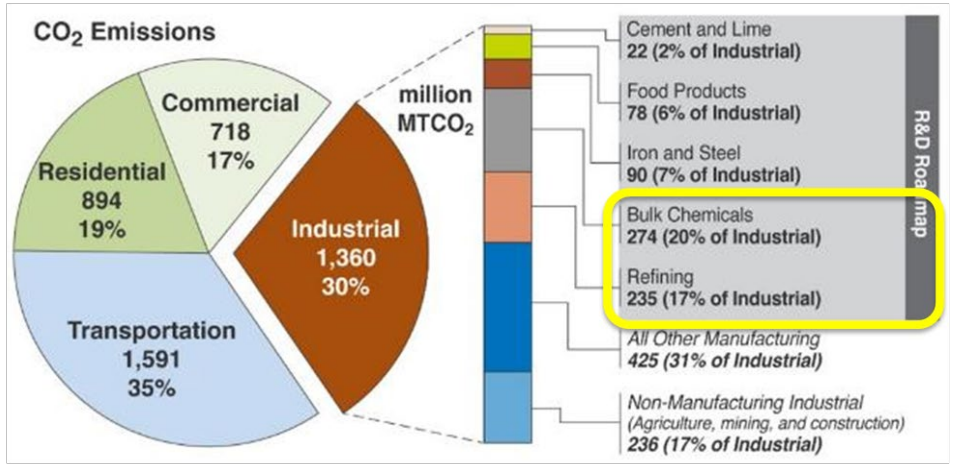
Industrial Efficiency and Decarbonization Office (IEDO)

Dr. Felicia Lucci

Technology Manager

Chemicals Sector Crucial for Economy-wide Decarbonization

U.S. Energy-related CO_2 Emissions by Sector and Subsector (2020)



Share of the **4,563 million metric tons of CO_2** emitted by the U.S. in 2020 (EIA 2021)

Major Economic Impact

- Chemicals is a capital-intensive industry supporting to 25% of U.S. GDP

Large Manufacturing Footprint

- The domestic manufacturing footprint of major U.S. chemical companies are about 20-30% of global operations
- 30% of chemical manufacturing facilities are owned by small and medium enterprises (CISA)

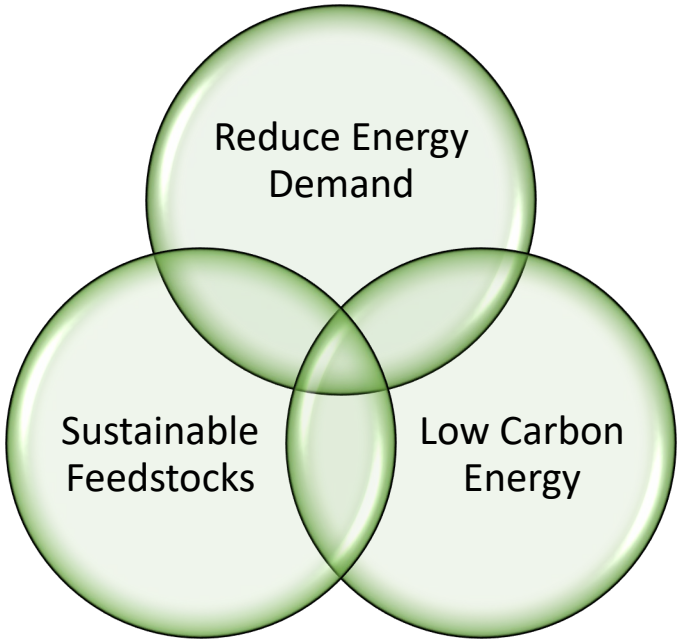
Significant Emissions

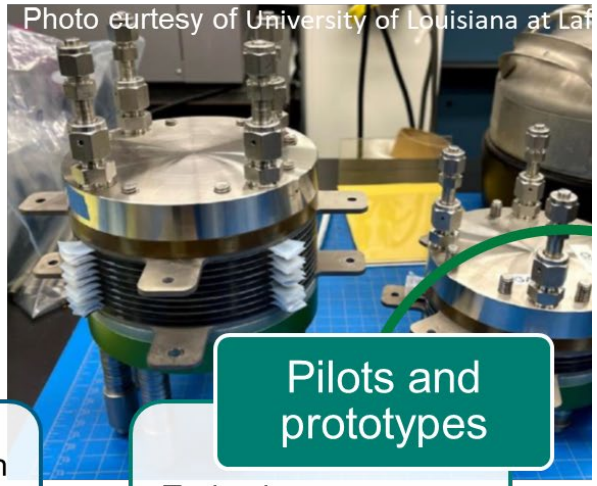
- U.S. bulk chemicals and refining industries are by far the highest emitting industrial subsectors, accounting for 513 MMT of energy-related CO_2 emissions
- Heavily dependent on petroleum and other fossil resources

IEDO Supports Applied R&D & First-of-a-Kind Pilots & Demonstrations

Accelerating development of next-generation process technologies capable of transforming chemicals and fuels production

- Full value chain of high-volume, energy intensive, high emissions chemicals & specialty/performance chemicals





Pilots and prototypes

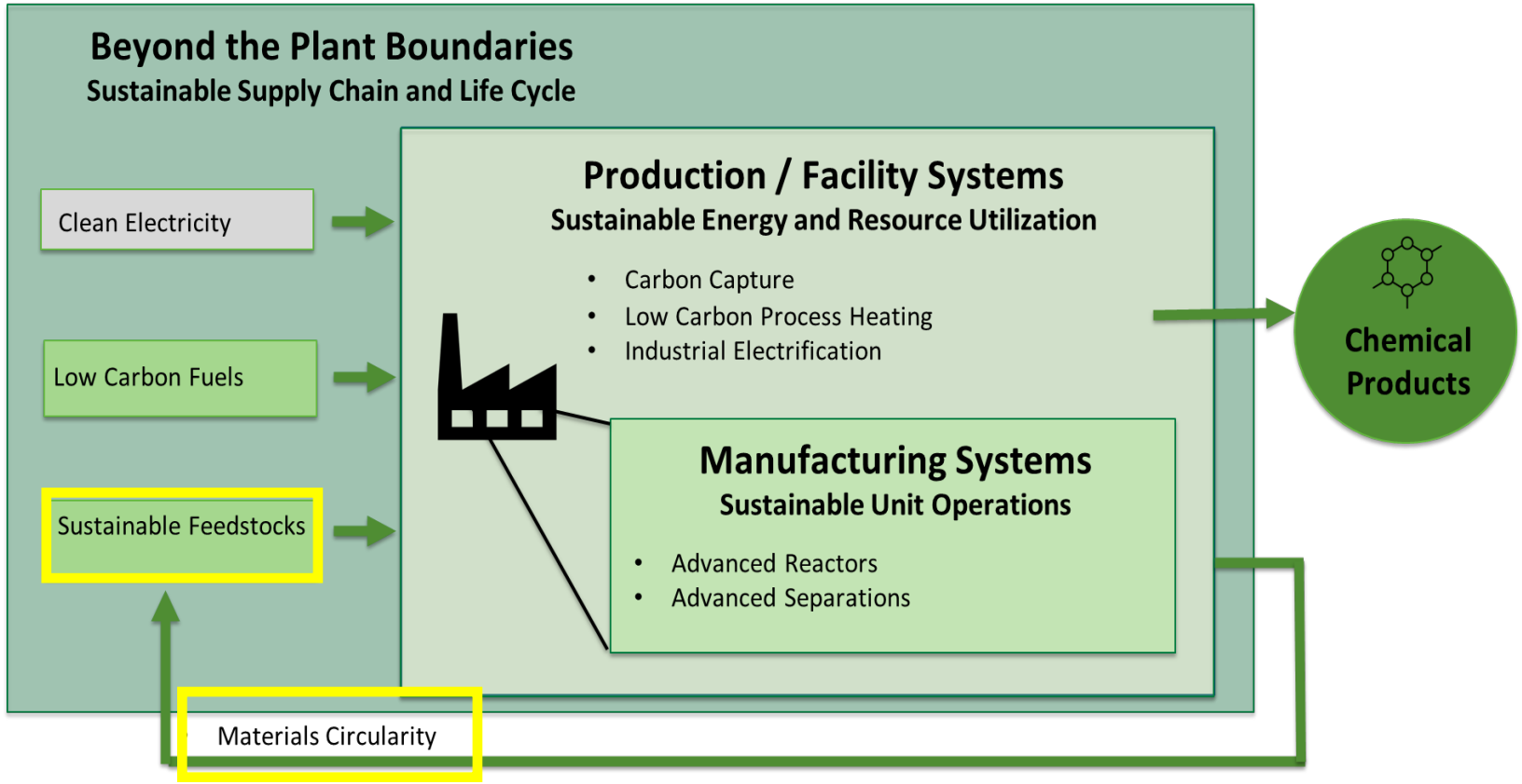
- Technology components validation in **laboratory**
- 1/100th commercial scale

Applied R&D

- Technology components validation in a **relevant environment**
- 1/50th commercial scale

IEDO's Chemicals and Fuels RD&D

Holistically decarbonizing chemicals manufacturing facility from unit operations to supply chains.



IEDO Portfolio:

$70M+ for advanced processes to enable conversion of sustainable feedstocks including CO_2 utilization

Advanced reactor systems to produce (or reduce demand of) high-volume chemicals from

- waste gases (CO_2, CO)
- industrial waste
- plastics
- biomass

Addressing Fundamental Challenges for Scaling CO_2/CO Electrochemical Reactors

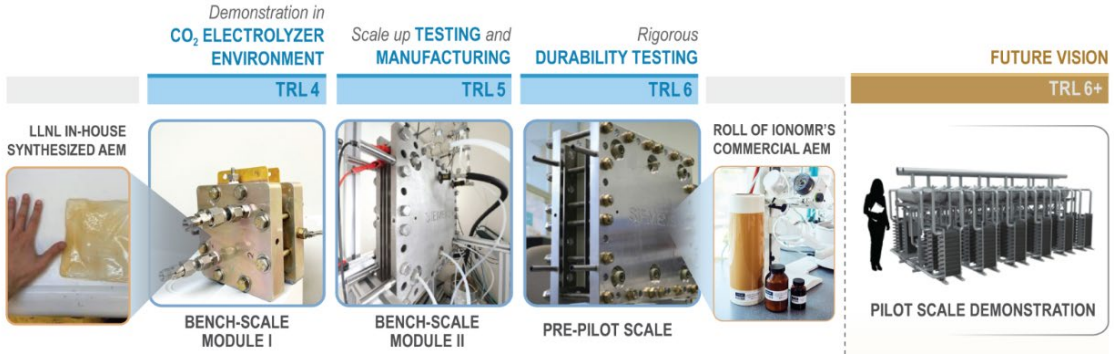
Lawrence Livermore National Laboratory

Advanced Reactor Design

- Address knowledge gap regarding critical parameters to **maintain performance at increasing scales, over long time, and with variable feedstock for CO_2 to ethylene**

Durability and Performance of Anion Exchange Membranes

- Demonstrate a **lab-scale prototype CO_2 to ethylene electrolyzer** with a 1000-hour durability



Giner

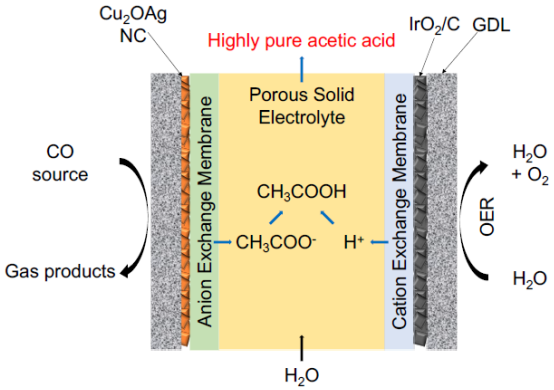
Dual-Recycle Reactor

- Develop and integrate **dual-recycle CO_2 conversion system to produce ethylene from CO_2** using pressure swing adsorption (PSA) to recycle CO_2/CO and purify ethylene

Rice University

Solid Electrolyte Reactor

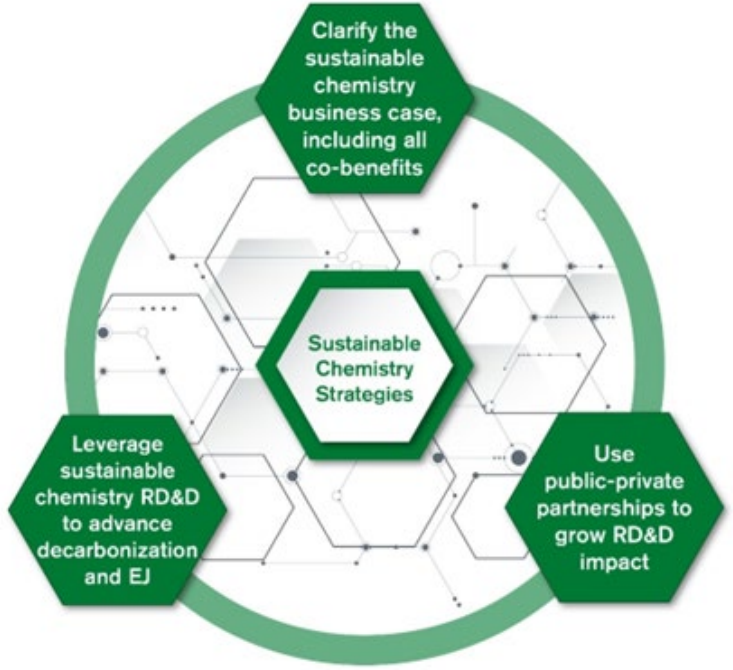
- Demonstrate a scaled-up porous solid electrolyte reactor for **synthesis of high-purity acetic acid solutions, eliminating the need for downstream separation**



IEDO Chemicals Focus on Sustainable Chemistry

Pillars of Sustainable Chemistry

- Are less toxic to human health and the environment
- Have lower energy consumption and related emissions
- Have reduced natural resource impacts
- Include optimized product design that results in the reduction of waste and the reuse or recycling of chemicals and materials across the product lifecycle



[Sustainable Chemistry in Manufacturing Roundtable]

[Sustainable Chemistry in RD&D to Transform the Chemicals Industry Roundtable]

Stakeholder Engagement

Scaling Sustainable Chemistry for an Industrial Transformation Workshop

- Summer 2024 – Washington, D.C. Metro Area
- Evaluate the technologies, policy and regulatory reforms, and collaborations needed to scale sustainable chemistry from the lab to the market

IEDO FY24 Funding Opportunities – In Progress

FY24 Energy- and Emissions-Intensive Industries

- **$83M** to focus on applied RD&D for the highest GHG-emitting industrial subsectors
- Sector-specific opportunities for seedling research, applied R&D, and first-of-a-kind pilots
- **Chemicals focus on advanced processes to enable conversion of sustainable feedstocks for hydrocarbons and fuels.**
- Joint topic with Hydrogen and Fuel Cell Technology Office (HFTO) and Office of Fossil Energy and Carbon Management (FECM) focused on pre-Front End Engineering and Design (pre-FEED) studies that support the development of decarbonized industrial processes

Looking Forward:
DOE's Industrial Efficiency & Decarbonization Office

Stay up-to-date on stakeholder engagement including: Requests for Information, Workshops, Webinars, and Funding Opportunity Announcements

Subscribe:
www.energy.gov/eere/iedo/subscribe-iedo-newsletter

Email: felicia.lucci@ee.doe.gov

IEDO is Hiring!
https://www.energy.gov/eere/iedo/iedo-careers

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Advanced Materials and Manufacturing Technologies Office (AMMTO)

Dr. Kathryn Peretti, Program Manager

Utilizing Waste as a Resource

What is AMMTO All About?

Vision

A globally competitive U.S. manufacturing sector that accelerates the adoption of innovative materials and manufacturing technologies in support of a clean, decarbonized economy.

Mission

We inspire people and drive innovation to transform materials and manufacturing for America's energy future.

Material Circularity Supports AMMTO's Mission

- Securing domestic supply chains for clean energy technologies, including carbon-based products
- Advancing economy-wide decarbonization through material efficiency and producing feedstocks with lower embodied energy and emissions.
- Increasing US manufacturing competitiveness

Strategy for Plastics Innovation

Vision

For the United States to lead the world in developing and deploying technologies that minimize plastic waste and promote energy-efficient and economic plastic and bioplastic design, production, reuse, and recycling.

Objectives/Metrics

- Address **end-of-life fate for >90%** of plastics
- **≥50% energy savings** relative to virgin material production
- Achieve **≥75% carbon utilization** from waste plastics
- Develop **cost-competitive** recyclable-by-design plastic
- Design recycling strategies that **mitigate ≥50% GHG emissions** relative to virgin resin or plastic intermediates

Strategy for Plastics Innovation | Department of Energy

Current Portfolio

BOTTLE FOA Projects ($17M) – Broadly covers plastic deconstruction, upcycling, and redesign for circularity.

SUPR FOA Projects ($9M) – Targeted at addressing recycling challenges for flexible packaging.

Circular Economy Regional Demonstrations ($10M) – Seeking to scale technologies and bring together supply chains for a regional pilot demonstration.

Research & Development

Innovation Ecosystem Development

Strategic Analysis

REMADE Institute ($70M) is a Manufacturing USA™ Institute that enables R&D promoting circular material solutions across the value chain for metals, fibers, plastics, and e-waste.

BOTTLE Consortium ($30M) is a lab-led consortium that conducts collaborative RD&D to develop scalable technologies for plastic deconstruction, valorization, and redesign.

Strategic analysis is incorporated into larger efforts like REMADE and BOTTLE to guide their efforts.

In addition, AMMTO funds analysis efforts that can guide and support decision making at DOE and throughout the community.

BOTTLE Consortium – www.bottle.org

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Vision

- Deliver scalable technologies that enable cost-effective recycling, upcycling, and energy efficiency for plastics

bottle
changing the way we recycle
U.S. DEPARTMENT OF ENERGY

Mission

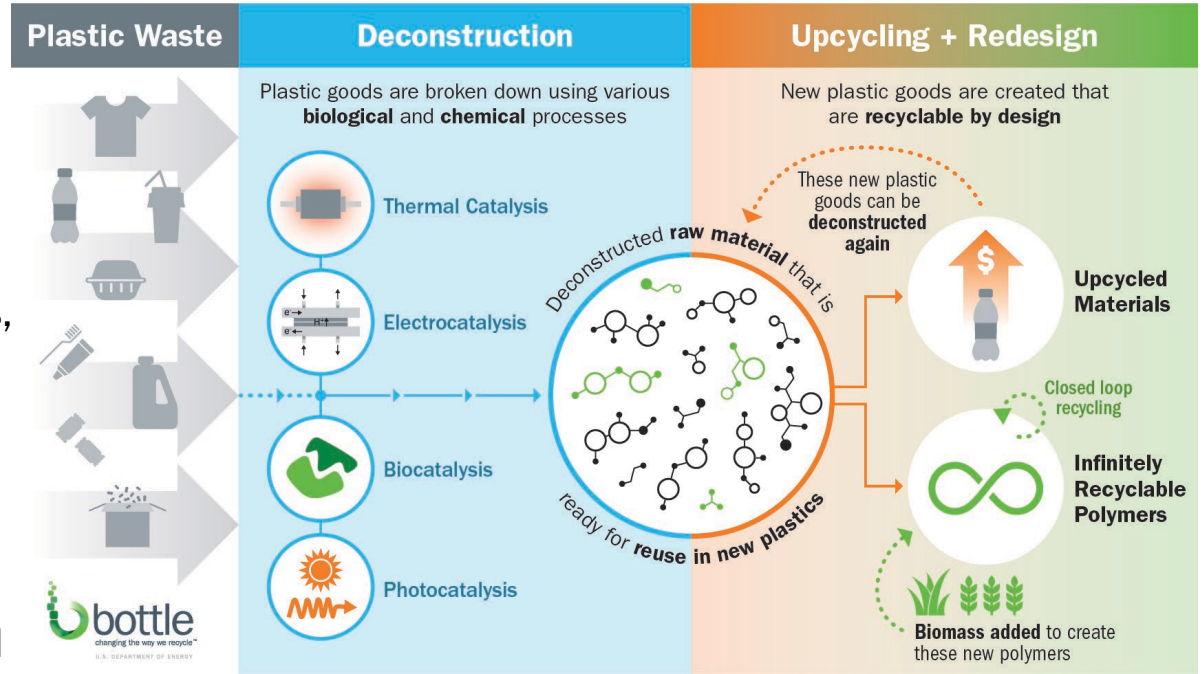
- Develop robust processes to upcycle existing waste plastics
- Develop new plastics that are recyclable-by-design

Goals

- Work with industry to deploy new recycling and redesign paradigms
- Leverage DOE investments in process development, catalysis, materials, and analysis-driven R&D

DEI

- A diverse and inclusive consortium that fosters the growth of researchers across their career, engages broadly to educate the public on our work, and ultimately contributes to the local community and the world broadly



Focus on Conversion Processes

The BOTTLE FOA and Single-Use Plastic Recycling (SUPR) FOA were designed to improve plastic circularity by developing deconstruction and upcycling pathways for plastic waste and redesign polymers for circularity.

Efforts were designed to be complementary to the BOTTLE™ Consortium and the REMADE Institute.

BOTTLE FOA:

- Develop novel polymers that are designed for infinite recyclability or biodegradability.
- Create innovative deconstruction pathways for existing polymers that generate high-value products.
- BOTTLE Consortium Collaborations to Tackle Challenges in Plastic Waste.

SUPR FOA:

- Develop recycling and upcycling pathways for plastic films that are economically favorable, lower greenhouse gas emissions, and reduce the embodied energy of plastics.
- Redesign of multi-layer films to be inherently recyclable or biodegradable.

Example Project From BOTTLE FOA

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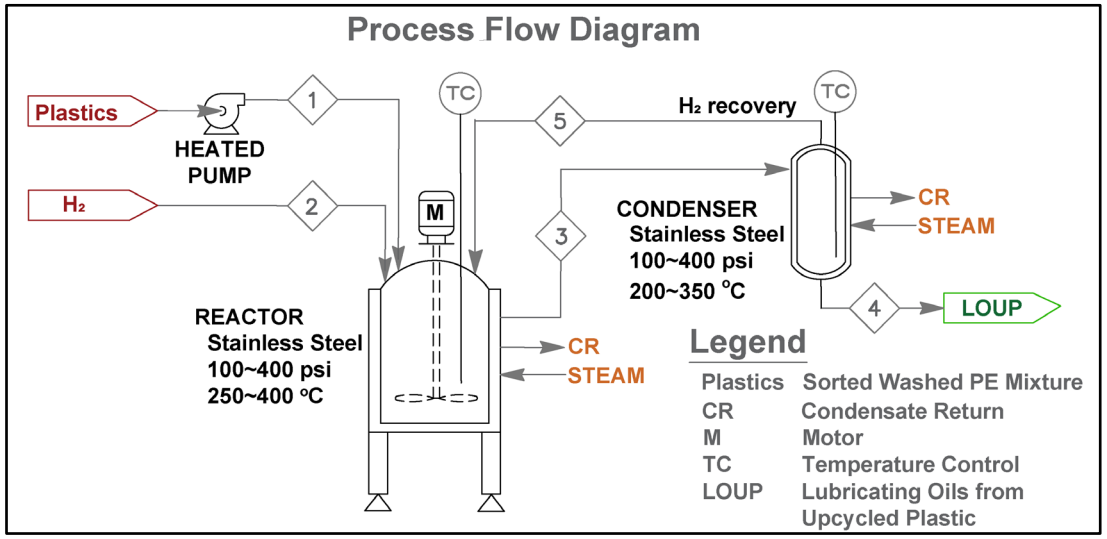
Project Goal: Develop a modular, low-temperature (< 300 °C) and low pressure (15 bar) continuous lab-scale process for the catalytic conversion of single-use waste polyolefins (POs) to higher value high performance LOUPs.

Federal funds:	$2,500,000
Cost-share:	$702,509
Total budget:	$3,202,509

Start of project status: batch process that converts polyethylene using Pt/STO by hydrogenolysis to a lube oil in >95% yield by mass.

Proposed work includes:

- Optimizing and scaling catalyst production
- Scaling production of the lube oil through conversion to a continuous process
- Converting feedstock from "clean" to real feedstocks
- Characterization of the lube oil product to ensure benefits over incumbent



	Key Milestones & Deliverables
BP 1	• Produce LOUPs (3 g) from waste HDPE films using Pt/STO catalyst in >35% yield
BP 2	• Large-scale Pt/STO synthesis and LOUPs production • 20% improvement in tribological properties
BP 3	• Produce LOUPs on 100 mL scale • Demonstrate tribological properties under ASTM test conditions to verify commercial viability

Chevron Phillips CHEMICAL
Performance by design. Caring by choice.™
TEXAS A&M UNIVERSITY
Argonne NATIONAL LABORATORY

Circular Economy – FY 2023 Priorities and Beyond

Build the supply chains needed to deploy novel technologies

Identify circular economy technology needs that will serve a breadth of material classes

- Material and product design for circularity
- Smart/Digital Manufacturing
- Sorting and Separations
- Rapid Characterization Methods

Develop LCA capabilities and access to good data for better decision making

Dr. Zia Abdullah

Laboratory Program Manager

National Renewable Energy Laboratory

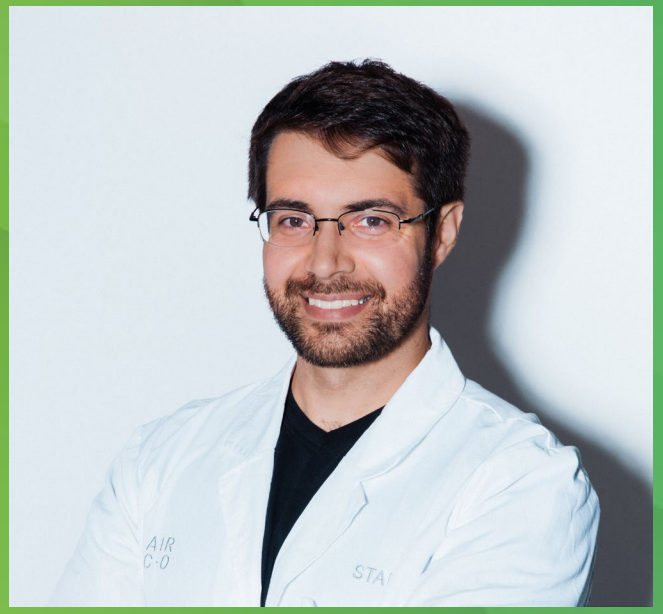
Session 3 Keynote

Fuels

Dr. Joel Tickner

Founder and Executive Director
Change Chemistry

Session 3 Keynote
Chemicals



Dr. Stafford Sheehan
Co-Founder and CTO
AIR COMPANY

Dr. Aanindeeta Banerjee
Co-Founder and CEO
ReSource Chemical

Dr. Christophe Schilling
Co-Founder and CEO
Geno

Session 3 Panel

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Session 4

Technology Scaling and Demonstration

Session 4 Moderators

Dr. Andrew Sumner

Project Manager

DOE Office of Clean Energy Demonstrations (“OCED”)

Olivia Corriere

Portfolio Risk Analyst

DOE Office of Clean Energy Demonstrations (“OCED”)

Session 4 Agenda

- **Demonstration projects unlocking Commercialization**
  - Olivia Corriere, DOE OCED

- **Private sector perspective on demonstration projects**
  - Sharon Nolen, Program Manager and Fellow, Eastman Chemical
  - Jimmy Samartzis, Chief Executive Officer and Board Director, LanzaJet

- **DOE Updates**
  - Jim Spaeth, DOE BETO
  - Dr. Felicia Lucci, DOE IEDO
  - Tomas Green, DOE HFTO
  - Dr. Andrew Sumner, DOE OCED

- **Pathway to liftoff: Decarbonizing chemicals and refining**
  - Maressa Brennan, DOE OCED

Demonstration Projects as Part of Commercialization

Olivia Corriere, DOE OCED (Office of Clean Energy Demonstrations)

Sharon Nolen
Eastman Chemical,
Program Manager and Fellow

Jimmy Samartzis
LanzaJet,
Chief Executive Officer and Board Director

Private Sector Perspective on Demonstration Projects

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DOE Office Updates

- Jim Spaeth | Bioenergy Technologies Office
- Dr. Felicia Lucci | Industrial Efficiency and Decarbonization Office
- Tomas Green | Hydrogen and Fuel Cell Technologies Office
- Dr. Andrew Sumner | Office of Clean Energy Demonstrations

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Bioenergy Technologies Office (BETO)

Jim Spaeth

Program Manager, Systems Development and Integration

Sustainable Aviation Fuel (SAF) Grand Challenge

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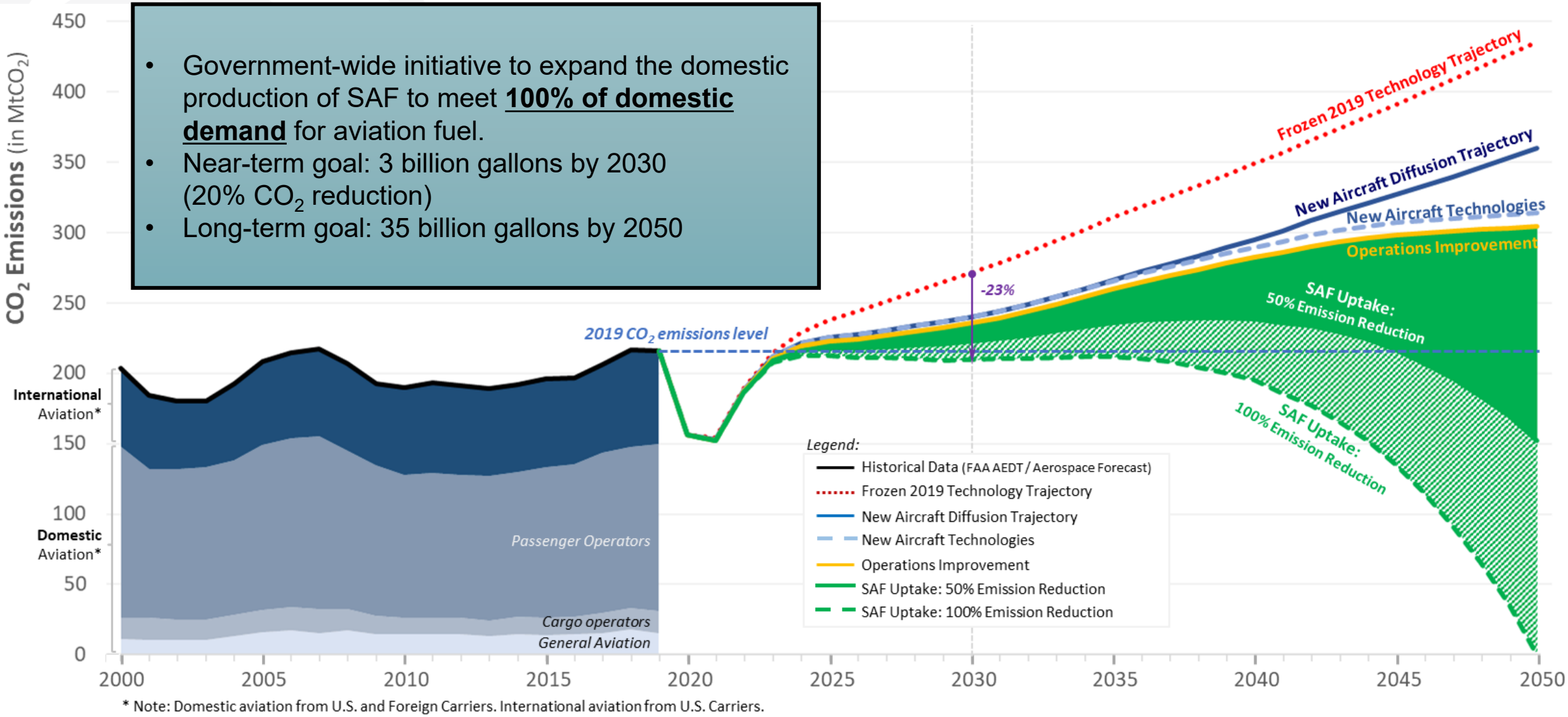
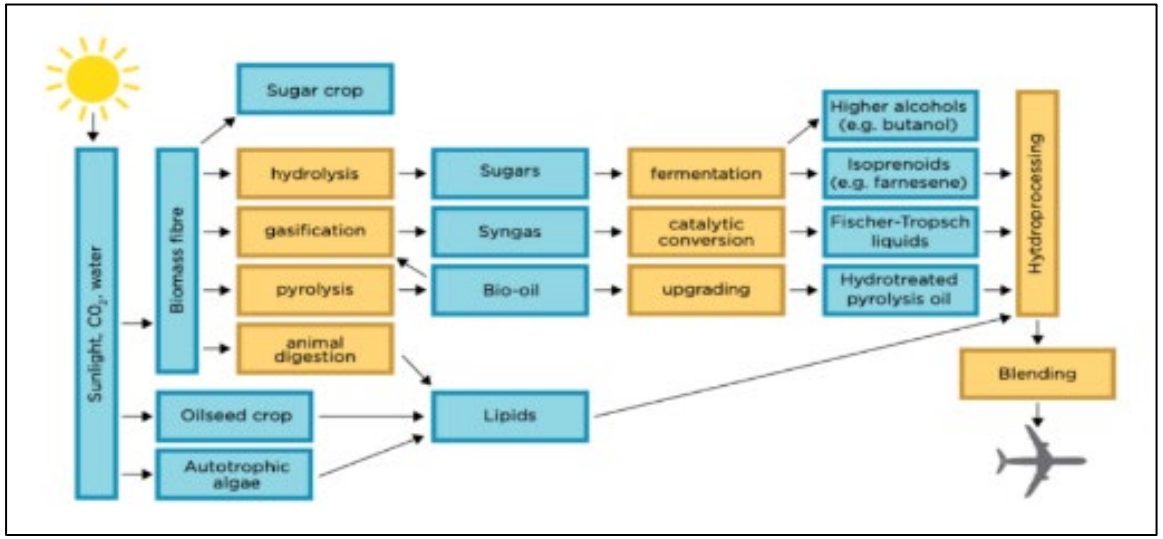
- Government-wide initiative to expand the domestic production of SAF to meet **100% of domestic demand** for aviation fuel.
- Near-term goal: 3 billion gallons by 2030 (20% CO_2 reduction)
- Long-term goal: 35 billion gallons by 2050



* Note: Domestic aviation from U.S. and Foreign Carriers. International aviation from U.S. Carriers.

DOE SAF Scale-up Strategy

- Annual opportunities for pre-pilot, pilot, and demonstration scale projects
- Wide variety of feedstocks
  - Traditional cellulosic feedstocks
  - MSW, CO_2, CO, flue gas, and biogas
  - Corn starch and oilseeds
- Allow bioproduct opportunities
- Leveraging existing industrial infrastructure supply chains
  - 1st Generation ethanol, pulp and paper, petroleum refineries
- Predictive models and high-performance computing



Scaling Strategy – Pre-Pilot to Demonstration Prior to Commercialization

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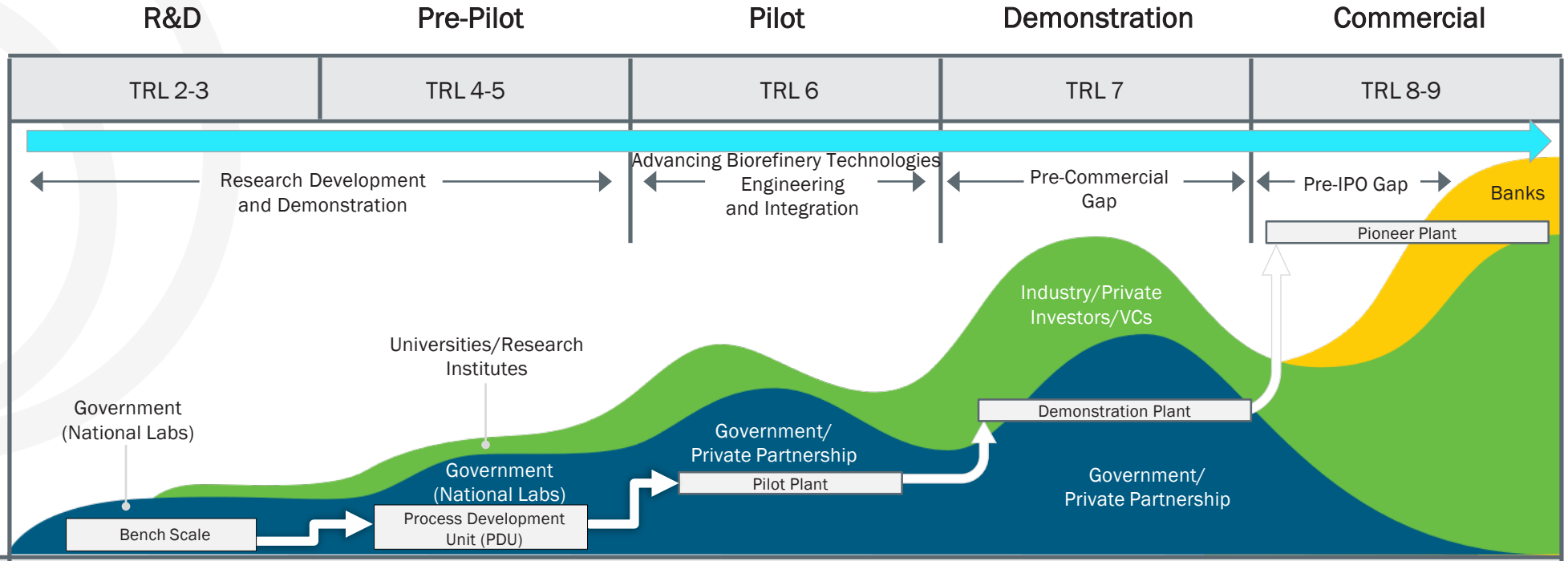

	R&D	Pre-Pilot	Pilot	Demonstration	Commercial
Average Total Project Cost	$1–$5 Million	$5–$10 Million	$25–$50 Million	$100–$500 Million	$250–$500 Million
Average Biomass Throughput	Grams/Day	Kilograms/Day	<50 Tonnes/Day	50–250 Tonnes/Day	+250 Tonnes/Day
Production Volumes	mL/L (batch)	Liters/Gallons (batch)	0.1–1 M GPY (campaign)	1–10 M GPY (extended campaign continuous)	50 M GPY (continuous)

Government Project Recipients and Partners Banks/Bonds/Institutional Investors

National Laboratories Process Development Units

Advanced Biofuels PDU
LBNL

Biomass Feedstock PDU
INL

Integrated Biorefinery PDU
NREL

Coupled Pyrolyzer - DCR NREL

Hydrothermal & Hydrotreating PDU
PNNL

SAF Pilot and Demonstration Projects

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Pilot

SAF

Stover

D3MAX

Woody

LanzaTech

Renewable Diesel

Algae

GLOBAL ALGAE

Wet Waste

μBIO MicroBio Engineering

ALOVIAM

E-Fuels

CO2

Marquis Energy

Demo

SAF

Woody

AVAPCO

ALDER FUELS

Ethanol

LanzaJet

RNG

SkyNRG

Renewable Diesel

Biogas

Trash 2 Cash

MSW

Fulcrum BioEnergy

Scale	Count
Pilot Phase 1	4
Pilot Phase 2	1
Demo Phase 1	3
Demo Phase 2	2

Technology	Count
Alcohol to Jet*	5
Fischer-Tropsh	2
Pyrolysis	1
Gasification	2
Biochemical Conversion	2
Hydrothermal Liquifaction	2
Power to Liquids	1

* Counts projects using other technologies to first produce Ethanol

Fulcrum not currently funded under SDI, but is demonstrating Gasification of MSW to SAF at 11mgy facility in Reno, NV

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Industrial Efficiency and Decarbonization Office (IEDO)

Dr. Felicia Lucci

Technology Manager

IEDO Technology Scaling Mechanisms

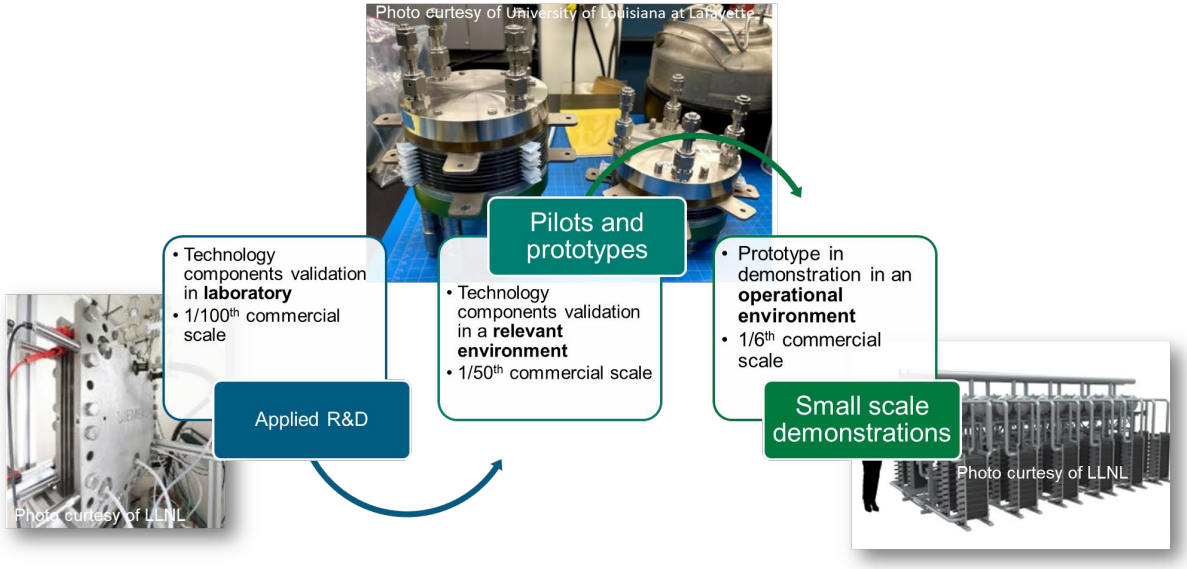
Manufacturing USA Institutes

Public-private partnerships to address major collaborative projects
Address gaps between research and commercialization in the advanced manufacturing sector through collaboration, Shared Resources, and workforce pipeline

Tiered R&D Projects

Targeted RD&D investments to advance technologies from applied R&D to pilots to site specific assessments

- Tier 0 projects validate technologies in a laboratory
- Tier 1 validate technologies in relevant environment
- Tier 2 pilot-scale technology validation in a relevant or operational environment.
- Preliminary Front-End Engineering Design (pre-FEED) initial site-specific detailed design



Manufacturing USA Institute – Rapid Advancement in Process Intensification Deployment (RAPID)

- **5-year, $40 million** investment to drive RD&D of advanced process technologies to enable **more resilient, lower cost, and reduced energy and carbon footprint manufacturing** in the process industries.
- Includes a focus on converting **sustainable feedstocks** to chemical products
- Continued work to modularize/distribute chemicals manufacturing strongly **aligns with sustainable chemistry principles,** including environmental justice.

Stakeholder Engagement

Institute Roadmapping

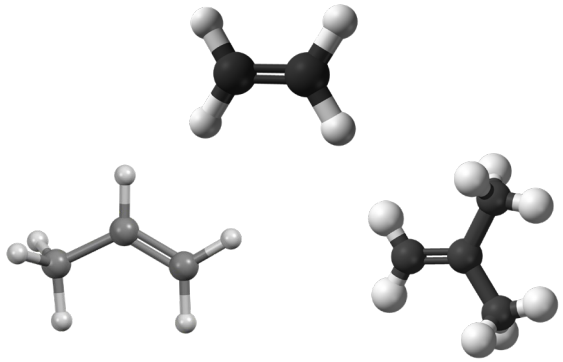
Technology Valuation

- May 14 – 15, 2024 Golden, CO
- RAPID Roadmap Workshop: Technology Valuation | AIChE

Technical Levers for Process Intensification Including Education, Workforce Development, and DEI

- June 3 – 5, 2024 Houston, TX
- International Congress on Sustainability Science & Engineering (ICOSSE '24) | AIChE

Scaling Technologies



RAPID Manufacturing Institute

- Scaling electromagnetic reactors to product light olefins from waste plastics
- Potential for 50 -70 % reduction in carbon intensity from conventional processes

Bridgestone Americas Tire Operations, LLC.

- Scaling ethanol to butadiene process for circular tire economy
- 85% reduction in carbon intensity in carbon intensity from conventional process

ReSource Chemical

- Scaling FDCA, a sustainable alternative to fossil-derived terephthalic acid (PTA)
- Potential for >100% reduction in carbon intensity from conventional process

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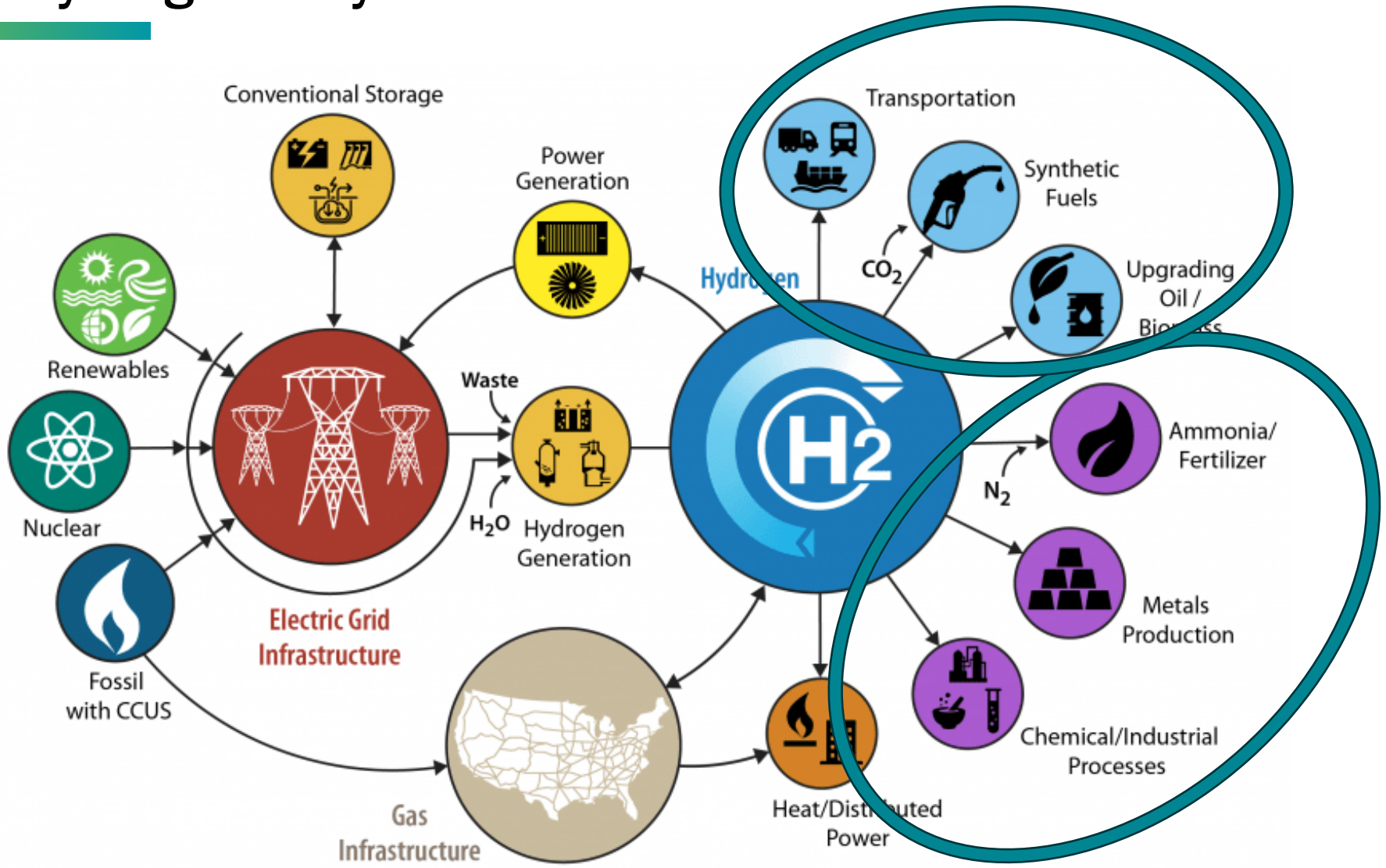
Hydrogen and Fuel Cell Technologies Office (HFTO)

Tomas Green

Technology Manager

Clean Hydrogen Plays Role as Feedstock in Decarbonization



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Cross-Office Funding Opportunity (HFTO/IEDO)

DE-FOA-0003219 FY24 Energy and Emissions Intensive Industries FOA

- Topic Area 6: Innovative Industrial Pre-FEED Studies
  - AOI 1: Integration of Clean Hydrogen in the Industrial Sector
  - AOI 2: Carbon Capture for the Industrial Sector
  - AOI 3: Integrated Process Pre-FEED

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Understanding Deployment Potential: Green HEART

Funded by HFTO and WETO
NREL (lead) + ANL, LBNL, ORNL, and SNL

Novelty and Advantages:

- **Optimized** hydrogen cost delivered for specific end use
- **Holistic** approach, increased efficiency, and reduced capital costs
- **Independence** from natural gas price volatility, grid connection permits, and large-scale transmission buildouts.

End uses:

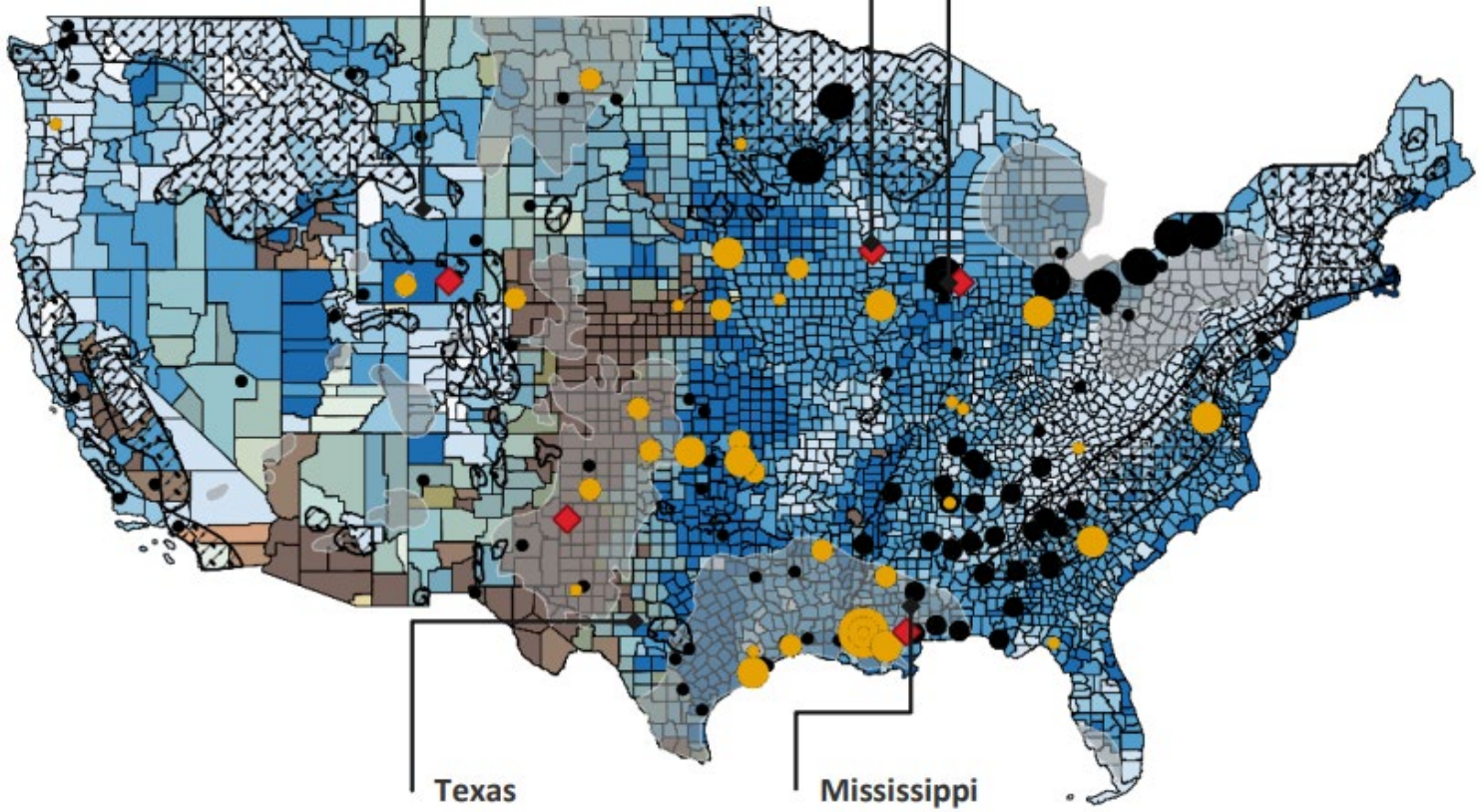
- Steel, Ammonia, SAF

Understanding Deployment Potential: Green HEART

Wyoming
- Best wind resource in the country
- Ammonia production nearby

Iowa
- Existing ammonia pipeline
- Close to ammonia and steel demand centers
- No geologic storage

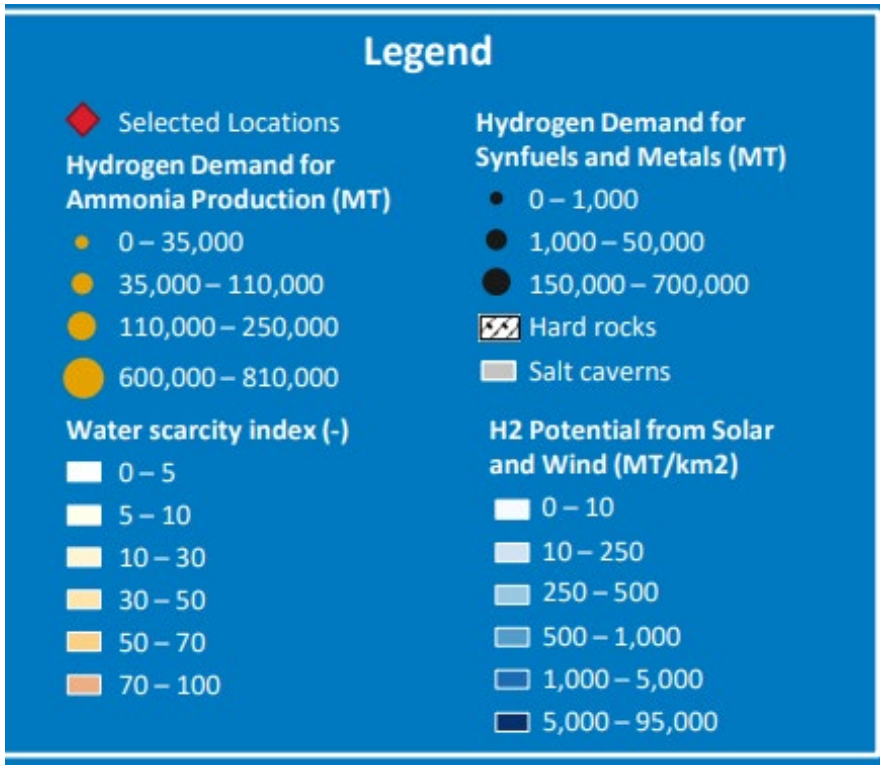
Indiana
- Largest steel mill in the U.S. with 8.2 MMT steel/year capacity
- No geologic storage



Texas
- Salt caverns and water stress region
- Excellent wind resources

Mississippi
- Close to existing demand
- Salt caverns

Preliminary Analysis



https://www.energy.gov/sites/default/files/2024-02/h2-infrastructure-strategies-workshop-hammond.pdf

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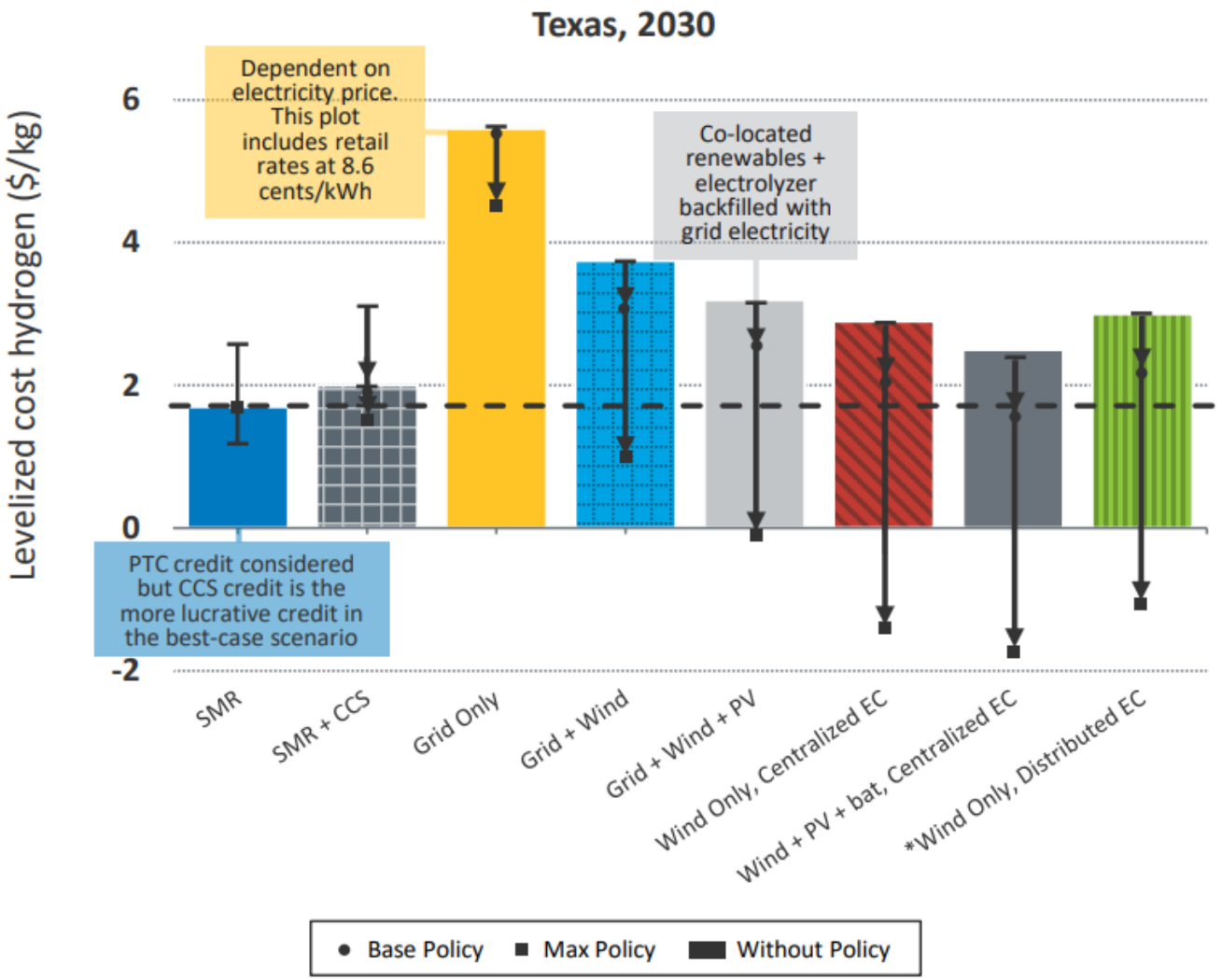
Understanding Deployment Potential: Green HEART



Preliminary Analysis

Off-grid costs less than on-grid:

- Reduced electricity costs (retail vs. dedicated PPA results in decrease)
- Dynamic operation of H2 allowed (and accounted for in increased replacement costs)
- Low-cost hydrogen storage (salt caverns)

*Made conservative assumptions.

*Distributed includes electrical efficiency gains ~4%

*Potential conversion efficiencies are not included

Key Insight: With max policy, all locations compete with SMR

Notes:

- Technology year (TY) 2030 corresponds to operational year 2035
- CCS credit considered for over 12 years
- H2/wind PTC applied over 10 years
- Model does not account for RECs

LCOE for TX 2030

- Off-grid: 1.3 cents/kWh with PTC
- On-grid: 8.6 cents/kWh (retail rates), 4.1 cents/kWh (wholesale rates)

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https://www.energy.gov/sites/default/files/2024-02/h2-infrastructure-strategies-workshop-hammond.pdf

Office of Clean Energy Demonstrations (OCED)

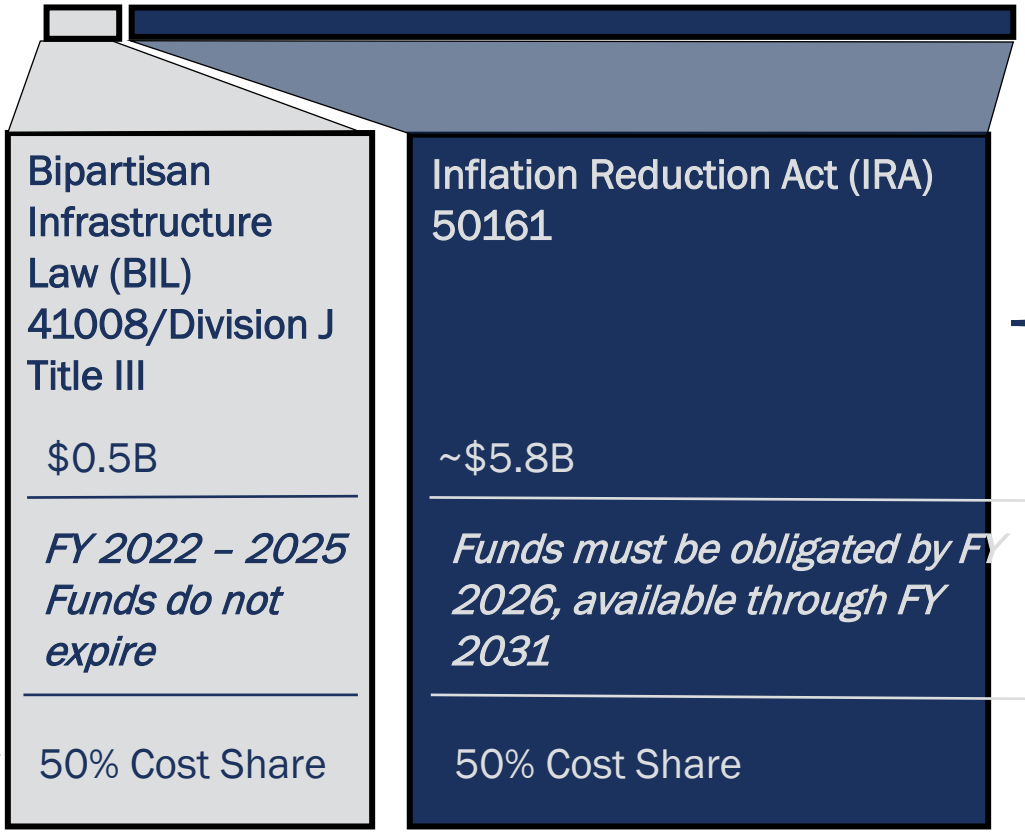
Dr. Andrew Sumner

Project Manager

Industrial Demonstrations Program
Selection Announcements

Industrial Demonstrations Program (IDP)

$6.3B for industrial emissions demonstration and deployment projects



DE-FOA-0002936: Up to $6B

Topic Area 1: BIL: Near-Net-Zero Facility Build Projects

Topic Area 2: IRA: Facility-Level Large Installations and Overhaul Retrofit Demonstrations

Topic Area 3: IRA: System Upgrades and Retrofits for Critical Unit Operations or Single Process Lines Within Existing Facilities

33 Selected Projects:

- 3 TA1 / 18 TA2 / 12 TA3
- $20.88B in Total Project Costs
- At least 25 states represented

OCED Office of Clean Energy Demonstrations
MESC Office of Manufacturing and Energy Supply Chains
LPO Loan Programs Office

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CHEMICALS & REFINING

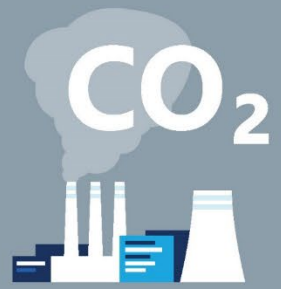
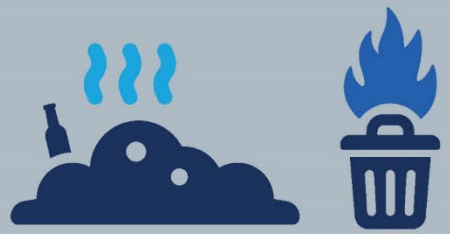
& SEPARATIONS PROCESSES FOR PULP & PAPER

8
projects

$1.3B
federal investment

3M
metric tons CO_2 avoided annually

Note: Anticipated based on information provided to the Department of Energy as of March 2024

	Traditional Production	Demonstrations	Real World Impact
Carbon Capture and Utilization	 Carbon process emissions released to the atmosphere	 Carbon captured and routed to a new process for upcycling	 Fuels for marine transport Polymers for apparel Electrolytes for lithium ion batteries
Value-Added Recycling	 Waste landfilled or incinerated	 Chemical byproducts and textiles recycled	 High-quality plastics for food and medical applications Decarbonized fuels
Process Heat	 Fossil-based high-temperature heat	 Specialized, decarbonized burners Thermal batteries powered by renewables Membrane separation	 Major CO_2 emissions reductions and improved air quality for communities

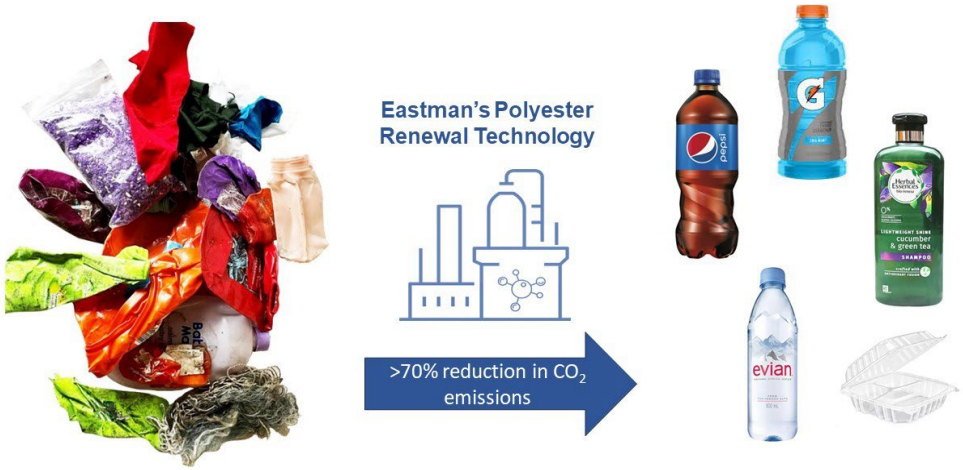
OCED
Office of Clean Energy Demonstrations

Polyethylene Terephthalate Recycling Decarbonization Project

Selectee: Eastman Chemical Company

Location: Longview, Texas

Federal Cost Share: Up to $375 million



Illustrative of future opportunities

Image credit: Eastman Chemical Company LLC

Proposed Activities:

- Construct a first-of-a-kind plastic molecular recycling facility integrated with low-carbon renewable energy, capable of taking waste streams that are typically landfill or incinerated and turning them into virgin-quality polyethylene terephthalate (PET)
- Use thermal energy storage combined with on-site solar power to decarbonize process heating operations
- Create product with 70% lower carbon intensity compared to fossil virgin PET and approximately 90% reduction when including avoided incineration emissions
- Create 200 permanent jobs and 1,000 construction jobs
- Support the renovation of the Paula Martin Jones Recreation Center and turn it into a hub for community outreach, workforce training, and more

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Syngas Production From Recycled Chemical Byproduct Streams

Selectee: BASF Corporation

Location: Freeport, Texas

Federal Cost Share: Up to $75 million

Image credit: BASF Corporation

Proposed Activities:

- Recycle liquid byproducts into syngas, which will be used as a low-carbon feedstock for BASF's Freeport operations
- Use plasma gasification and renewable power to replace targeted natural gas-fired incineration, decreasing carbon dioxide emissions by up to an estimated 90% at the BASF Freeport site
- Enable uptake for a technology that is widely able to recycle liquid byproducts into additional production feedstock like syngas or hydrogen
- Improve local air quality
- Create additional permanent jobs

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Sustainable Ethylene From CO_2 Utilization with Renewable Energy

Selectee: T.EN Stone & Webster Process Technology, Inc.

Location: U.S. Gulf Coast

Federal Cost Share: Up to $200 million

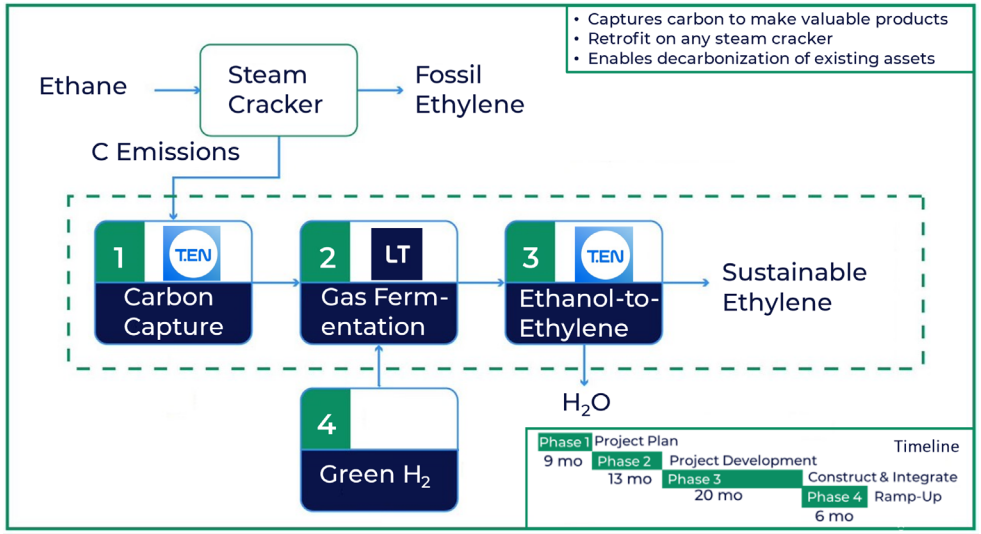

Image credit: T.EN Stone & Webster Process Technology, Inc.

Proposed Activities:

- Utilize captured carbon dioxide from ethylene production by applying a biotech-based process and green hydrogen to create ethanol and ethylene
- Deploy LanzaTech's Gas Fermentation technology, previously supported by ARPA-E, to demonstrate the ability to capture and upcycle carbon dioxide to ethanol in any industry with carbon dioxide emissions. The ethanol is then converted to ethylene using Technip Energies' proprietary Hummingbird® technology
- Create 200 construction jobs and 40 permanent jobs
- Hire locally and approach unions, community groups, and labor groups once site is finalized to negotiate, review, and update agreements for quality jobs and community collaboration

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Star E-Methanol

Selectee: Orsted P2X US Holding LLC

Location: Texas Gulf Coast

Federal Cost Share: Up to $100 million

Image credit: Orsted P2X US Holding LLC

Proposed Activities:

- Capture biogenic carbon dioxide from a local industrial facility and synthesize with clean hydrogen to produce up to 300,000 metric tons of e-methanol per year
- Reduce carbon footprint of the methanol production process by more than 80% compared to traditional methods
- Prove out supply and demand for renewable hydrogen-derived alternative fuels for the marine shipping and transportation sector
- Create 50 permanent jobs and 300 construction jobs
- Work with the University of Houston to develop a curriculum around zero-carbon fuels and the hydrogen economy to equip workers with skills to take part in the new energy economy

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Novel CO_2 Utilization For Electric Vehicle Battery Chemical Production

Selectee: The Dow Chemical Company

Location: Freeport, Texas

Federal Cost Share: Up to $95 million

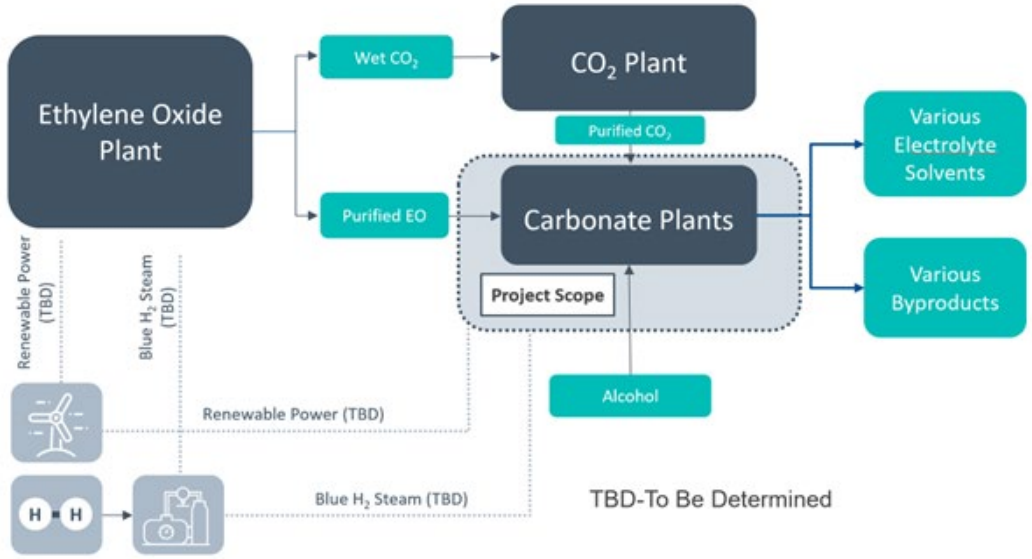

Image credit: The Dow Chemical Company

Proposed Activities:

- Design and construct facility with the intent to capture and utilize approximately 100,000 tons of carbon dioxide per year
- Produce essential components of electrolyte solutions needed for domestic lithium-ion batteries
- Provide supply chain resilience by establishing a domestic manufacturing base for the U.S. electric vehicle and power storage markets
- Create roughly 50 permanent manufacturing jobs and roughly 600 construction jobs
- Partner with diverse manufacturers, educational institutions, accelerators, and more

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Office of Clean Energy Demonstrations (OCED)

Maressa Brennan

Pathway to liftoff: Decarbonizing chemicals & refining

THANK YOU!

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Closing Comments – Day 2

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Adjourn

Thank you!