Carbon Conversion Program Overview and Wider Thoughts

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One of 17 U.S. Department of Energy (DOE) national laboratories; producing technological solutions to America’s energy challenges.

Mission
- Ensuring affordable, abundant and reliable energy that drives a robust economy and national security, while
- Developing technologies to manage carbon across the full life cycle, and
- Enabling environmental sustainability for all Americans.

Vision
To be the nation’s premier energy technology laboratory, delivering integrated solutions to enable transformation to a sustainable energy future.
Mission

• Advance carbon management through carbon conversion
• Minimize the climate and environmental impacts of fossil energy

Goals

• Support R&D that can convert CO₂ into products
  • Conversion must be environmentally and economically attractive
• Support scaling (demonstration) of products where appropriate

Drivers

• United States 2020 CO₂ emissions ≈ 4.7 gigatonnes
  • Total global CO₂ emissions in 2021 ≈ 36.3 gigatonnes

Challenges

• Scale of CO₂ emissions relative to CO₂ consumption
• Qualifying economic viability and environmental impact requires significant resources
• Electricity prices rarely negative/free
• “It’s tough to make predictions, especially about the future”
Carbon Conversion Program Structure

Carbon Conversion Program R&D Areas

Focus of other programs

Annual Funding ($ Millions)

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R&D through Research and Innovation Center
- Majority focus on conversion into chemicals
- Activity in catalyst design, microwave reformation, reactive capture, and more

Life Cycle Analysis through Energy Systems Analysis Team
- Vital to determining economic viability and environmental impact
- Active in Global CO₂ initiative
- Challenges
  - Working to harmonize LCA methodology with other groups
  - Requires collaboration across multiple offices, departments, and external entities

Techno-Economic Analysis through Energy Process Analysis Team
- All successful technologies must add value
- Sensitivity analysis dependent upon many unknowns
- Challenges
  - Not as straightforward to qualify as technical viability
Extramural research outside of NETL

Various Funding Mechanisms Employed
- Field Work Proposals with other national laboratories
- Funding Opportunity Announcements
  - Majority of funding is competitively awarded
- Grant Programs
  - SBIR and STTR for small businesses and institutions of higher education
  - Other mechanisms including TCF, ACT, EPSCoR

Robust Project Portfolio
- Thirty-five active projects within the portfolio and growing quickly
  - Mineralization, conversion, and biological uptake
(D) USE OF FUNDS.—An eligible entity shall use a grant received under this paragraph to **procure and use** commercial or industrial products that—

‘‘(i) use or are derived from anthropogenic carbon oxides; and

‘‘(ii) demonstrate significant net reductions in lifecycle greenhouse gas emissions compared to incumbent technologies, processes, and products.’’
Carbon Conversion via Biological Uptake

A range of products are possible
- Animal/fish feed, nutraceuticals, dyes/colorants, polymers, soil amendments, etc...
  - Fuels are specific to the mission of DOE EERE’s BETO (BioEnergy Technologies Office)

Advantages and challenges
- Uses well understood processes (10,000+ years of human agricultural experience)
- Mostly enabled with catalog engineering (uses COTS equipment)
- Biological processes well suited to creating many complex carbon molecules
- Large areas required to achieve gigatonne scale
  - Kinetically slower than higher temp/pressure processes

There are many variables manufacturers must consider
- What is the source of the CO₂?
  - Concentration, temperature, pressure, contaminants
- What inputs are required?
  - Heat, nutrients, photons
- Where is the customer and what are their requirements?
  - Price, quantity, quality, availability
- What is the process?
  - Open ponds, photo bio-reactors, columns
Supporting R&D for Biological Uptake

DE-FOA-0002654 – Carbon Utilization Technology: Improving Efficient Systems for Algae
• Issued by EERE BETO
• Topic Area 2: Algae-based technology to utilize anthropogenic CO₂ from utility and industrial sources
  • Up to five awards at $2MM each

DE-FOA-0002403 – Engineering-Scale Testing and Validation of Algae-Based Technologies and Bioproducts
• Four selections at ~$2MM DOE share each
• Support for R&D to develop and test technologies that can utilize carbon dioxide from power systems or other industrial sources for bio-mediated uptake by algal systems to create valuable products and services.
• Scale of ~1000 liters
Carbon Conversion via Thermo/Electro Chemistry

A wide range of products are possible
- Fuels, polymers, solid carbons, alcohols

Advantages and challenges
- Pathways to gigatonne scale exist
- Almost any molecule can be synthesized
  - Including those currently derived from fossil fuels
- Value of products must outweigh cost of energy inputs
- Breakthroughs may require significant funding (e.g. electrochemistry and catalysts)

There are many variables manufacturers must consider
- What is the source of the CO₂?
  - Concentration, temperature, pressure, contaminants
- What inputs are required?
  - Electricity, hydrogen
- Where is the customer and what are their requirements?
  - Price, quality
- What is the process?
  - Electrochemical cells, thermochemical reactors, microwave/plasma reactors, etc…
Supporting R&D for Catalytic CO$_2$ Conversion

Largest project count within our portfolio
- The majority of active projects
- Focusing mostly on high volume with some support of R&D into high-value

Several conversion technologies under consideration
- Thermochemical, electrochemical, membrane, molten salt, plasma, microwave
  - Optimal route heavily dependent on CO$_2$ source, raw material costs, and geography

A range of liquid, gas, and solid products
- Formic acid, polymers, ethylene, aromatics, acetic acid, methanol, dimethyl carbonate, propane, propylene, carbon monoxide, nanotubes, graphene, etc…
  - Ensure that we minimize duplication across DOE offices
  - Fundamental tradeoff between high-volume and high-value

Challenges
- Scale of CO$_2$ emissions relative to CO$_2$ consumption
Carbon Conversion via Mineralization

A limited range of products are possible
- Cured concrete, synthetic aggregates, suboxides, other building materials

Advantages and challenges
- Can be energetically downhill
- Can apply at gigatonne scale
- Mostly enabled with catalog engineering (uses COTS equipment)
- Can address other waste streams (e.g. produced water or mine tailings)
- Products often have a low specific value (i.e. $/tonne requires large scale)

There are many variables manufacturers must consider
- What is the source of the CO$_2$?
  - Concentration, temperature, pressure
- What inputs are required?
  - Raw minerals, electricity/heat
- Where is the customer?
  - Transportation is a significant proportion of the product cost
Supporting R&D for Mineralization Technologies

DE-FOA-0002614 – Carbon Management

- FOA released 05/05/2022
- Applications received 07/22/2022
- Multi-program FOA
  - Carbon Conversion
  - Carbon Dioxide Removal
  - Point Source Carbon Capture Technology
  - Carbon Storage Technology
- AOI-1A. Lab-Scale Testing of Mineralization Systems to Generate Commercial Products
Reactive Capture and Conversion (RCC)

Newer area of focus within the program

- Published RFI seeking input on RCC in 2019
- RCC is distinct from other capture technologies
- CO$_2$ becomes incorporated into the final product and is neither regenerated, transported for further use, nor stored as pure CO$_2$
- Avoids energy intensive regeneration
  - Adsorption towers are also a relatively expensive component
- [https://www.nrel.gov/docs/fy21osti/78466.pdf](https://www.nrel.gov/docs/fy21osti/78466.pdf)
- [https://www.nrel.gov/bioenergy/workshop-reactive-co2-capture-2020-proceedings.html](https://www.nrel.gov/bioenergy/workshop-reactive-co2-capture-2020-proceedings.html)

Targeted lab call

- Focus on conversion or mineralization

Five national nab projects

- LLNL – Direct Air Reactive Capture and Conversion for Utility-Scale Energy Storage
- NETL – Integrating CO$_2$-Selective Polymer Layers and Electrocatalytic Conversion
- NREL – A Pressure-Swing Process for Reactive CO$_2$ Capture and Conversion to Methanol through Precise Control of Co-Located Active Sites in Dual Functional Materials
- ORNL – Porous Catalytic Polymers for Simultaneous CO$_2$ Capture and Conversion to Value-added Chemicals
- PNNL Integrated Capture and Conversion of CO$_2$ into Materials: Pathways for Producing CO$_2$-Negative Building Composites
Necessity of TEA/LCA for an Uncertain Future

**Tomorrow will look a lot like today**
- Mix of fossil, renewable, and nuclear resources
  - Abundant waste heat integration opportunities
  - Industrial electricity prices of $60 - $80 / MWh

**Inexpensive and Abundant Hydrogen**
- $1/kg Hydrogen
  - Thermochemical conversion of CO\(_2\) into chemicals and plastics
  - Industry widely decarbonized (e.g. steel, cement, fertilizer)

**Techno-Cornucopian worldview**
- Inexpensive electricity at $20 - $30 / MWh
  - Widescale electrification
  - Favorable for electrochemical approaches

**Other Unknowns**
- Carbon prices/credits, DAC costs, energy breakthroughs, etc…
High-Profile Discussion Items

Supporting R&D in new and existing areas
• Reactive Capture and Conversion (RCC)
  • Avoid energetically costly regeneration step
  • Disadvantage is that sorbent/solvent is consumed

Collaboration with multiple stakeholders
• Necessary due to the scale and breadth of the challenge
• Interest in carbon conversion has increased drastically within the last six months

Expanding the program quickly
• Funding for and interest in the program are increasing quickly
Carbon Conversion Contacts and Resources

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https://netl.doe.gov/coal/carbon-utilization