Carbon Conversion Program Overview and Wider Thoughts

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NATIONAL ENERGY TECHNOLOGY LABORATORY

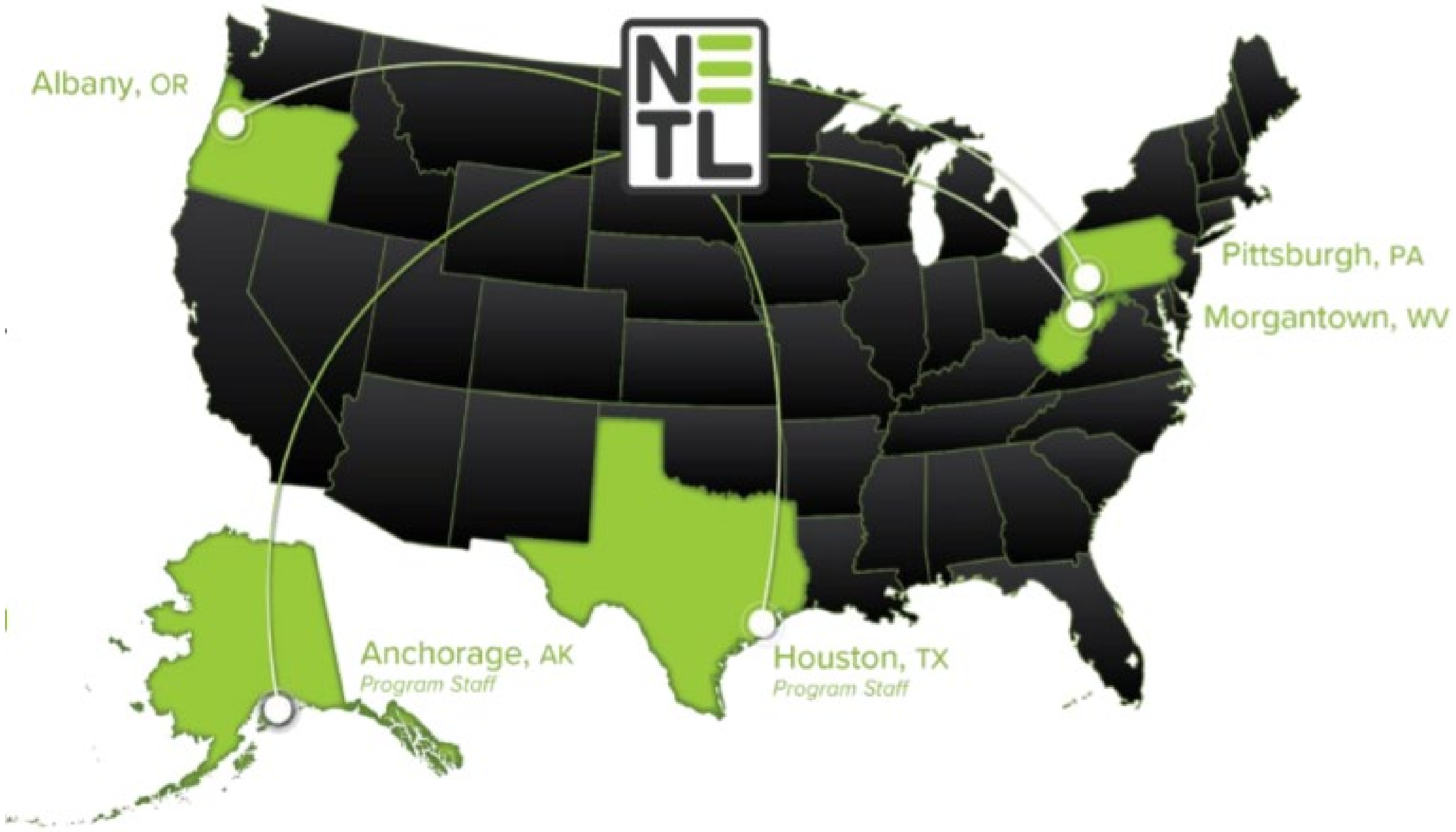
One of 17 U.S. Department of Energy (DOE) national laboratories; producing technological solutions to America's energy challenges.

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, Goals, Drivers, Challenges

Mission

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

Goals

- Support R&D that can convert CO_2 into products
  - Conversion must be environmentally and economically attractive
- Support scaling (demonstration) of products where appropriate

Drivers

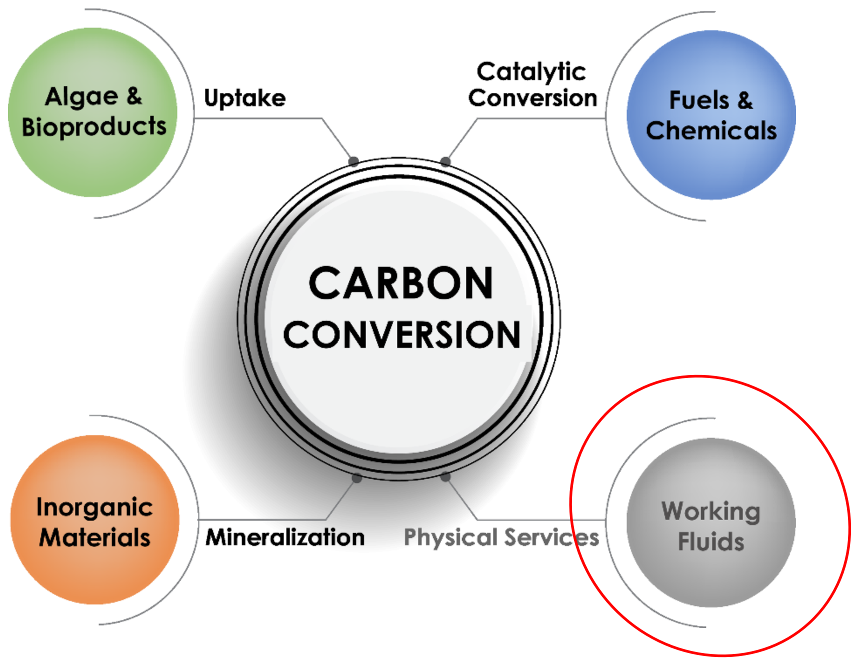
- United States 2020 CO_2 emissions ≈ 4.7 gigatonnes
  - Total global CO_2 emissions in 2021 ≈ 36.3 gigatonnes

Challenges

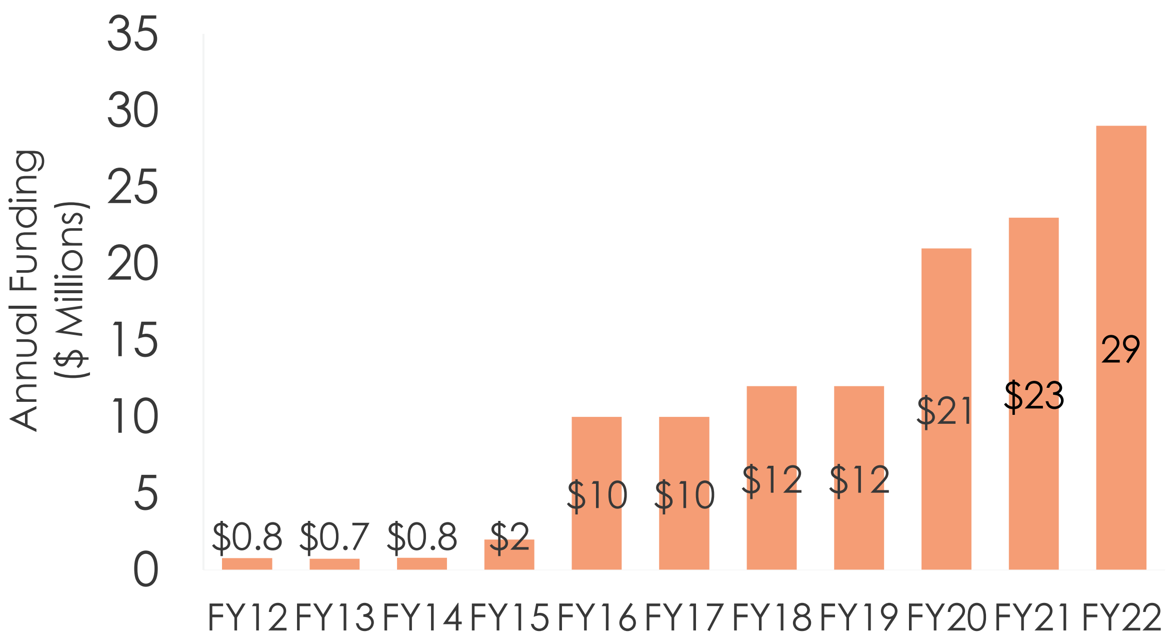
- Scale of CO_2 emissions relative to CO_2 consumption
- Qualifying economic viability and environmental impact requires significant resources
- Electricity prices rarely negative/free
- "It's tough to make predictions, especially about the future"

Carbon Conversion Program Structure

Carbon Conversion Program R&D Areas



Focus of other programs



Carbon Conversion Program Within NETL

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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 CO_2 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

Carbon Conversion Program Through NETL

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

Carbon Conversion Program Through NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

Public Law 117-58 – Nov 15, 2021

PP 988 of text

(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 CO_2?
  - 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

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DE-FOA-0002654 – Carbon Utilization Technology: Improving Efficient Systems for Algae

- Issued by EERE BETO
- Topic Area 2: Algae-based technology to utilize anthropogenic CO_2 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

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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 CO_2?
  - 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

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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/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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CARBON UTILIZATION

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