Carbon Conversion Program Overview

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National Energy Technology Laboratory (NETL)

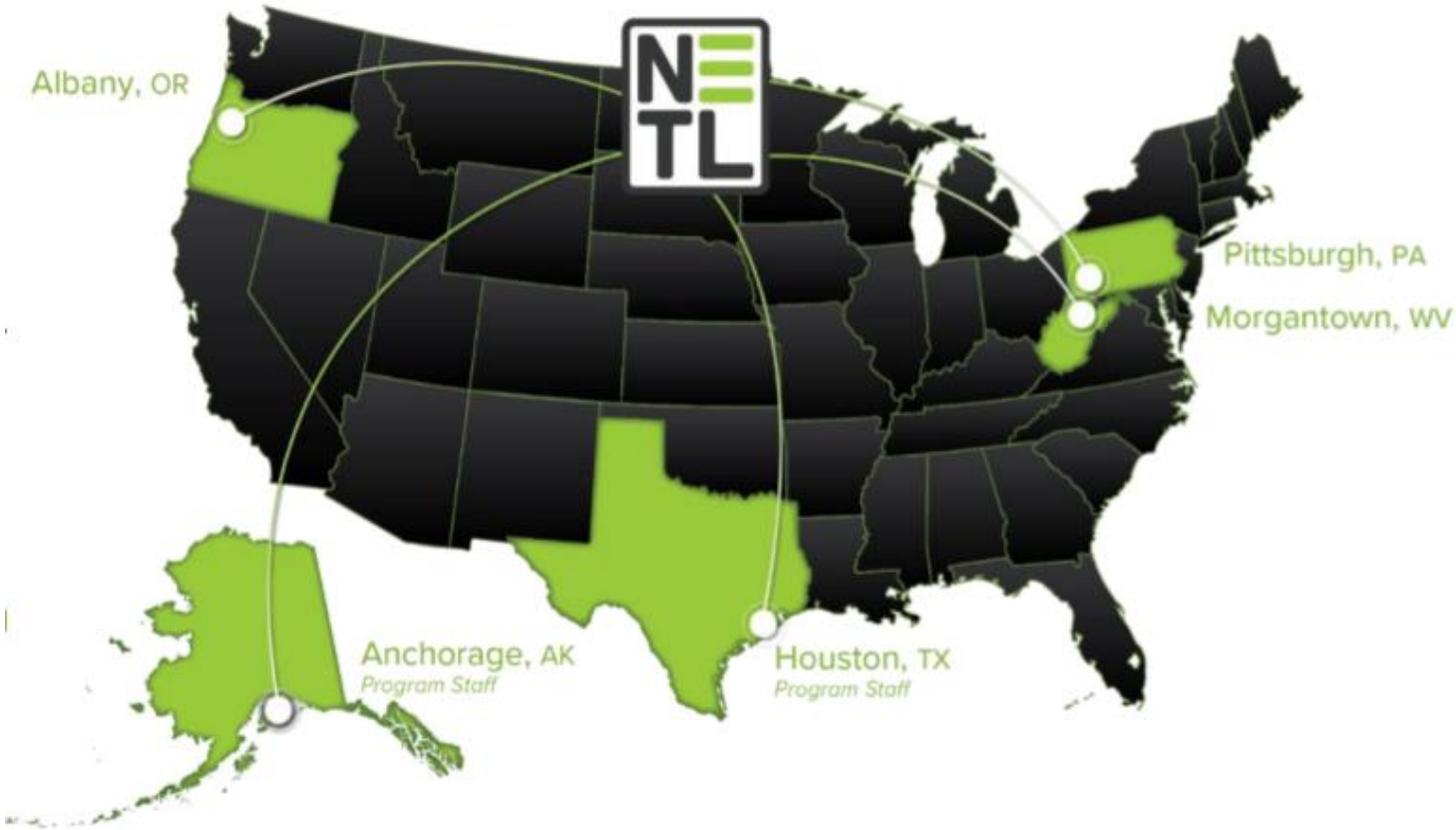
One of 17 U.S. Department of Energy (DOE) national laboratories; producing technological solutions to America's energy challenges.

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 dioxide conversion

Goals

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

Drivers

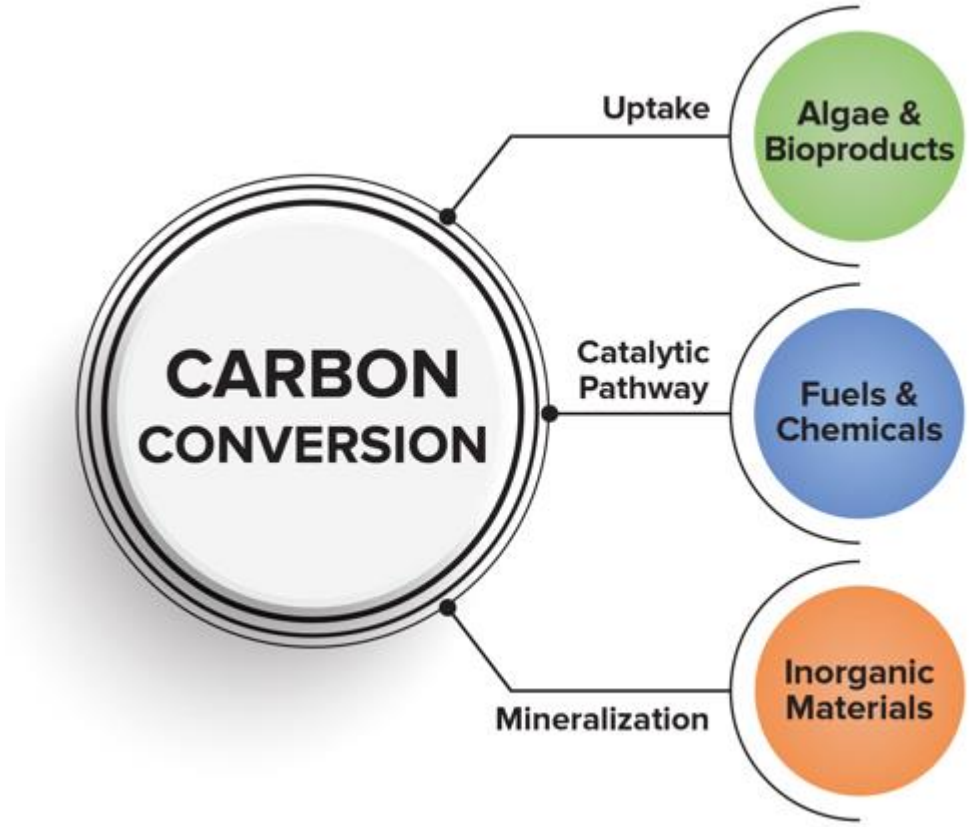
- United States 2020 CO_2 emissions ≈ 4.7 gigatonnes
  - Total global CO_2 emissions in 2021 ≈ 36.3 gigatonnes

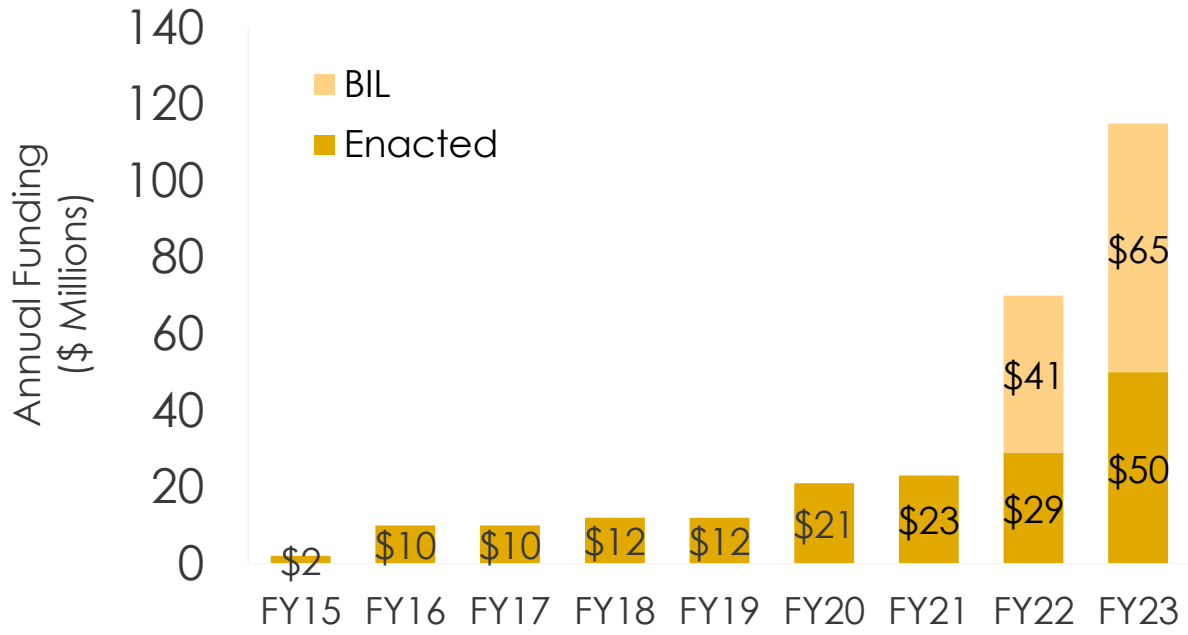
Challenges

- Scale of CO_2 emissions relative to CO_2 consumption
- Qualifying economic viability and environmental impact requires significant resources
- Electricity prices rarely negative/free
- "Prototypes are easy, production is hard"

Carbon Conversion Program Structure

Carbon Conversion Program R&D Areas





Carbon Conversion Within NETL

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
- Not as straightforward to qualify as technical viability

Carbon Conversion 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, catalytic pathway, and biological uptake

Carbon Conversion Through NETL via BIL

BIL represents ~$310MM investment over five year

One aspect is "Utilization Procurement Grants," aka UPGrants

https://netl.doe.gov/upgrants

Demonstration Grants

- **50% cost share**

To Eligible Entities

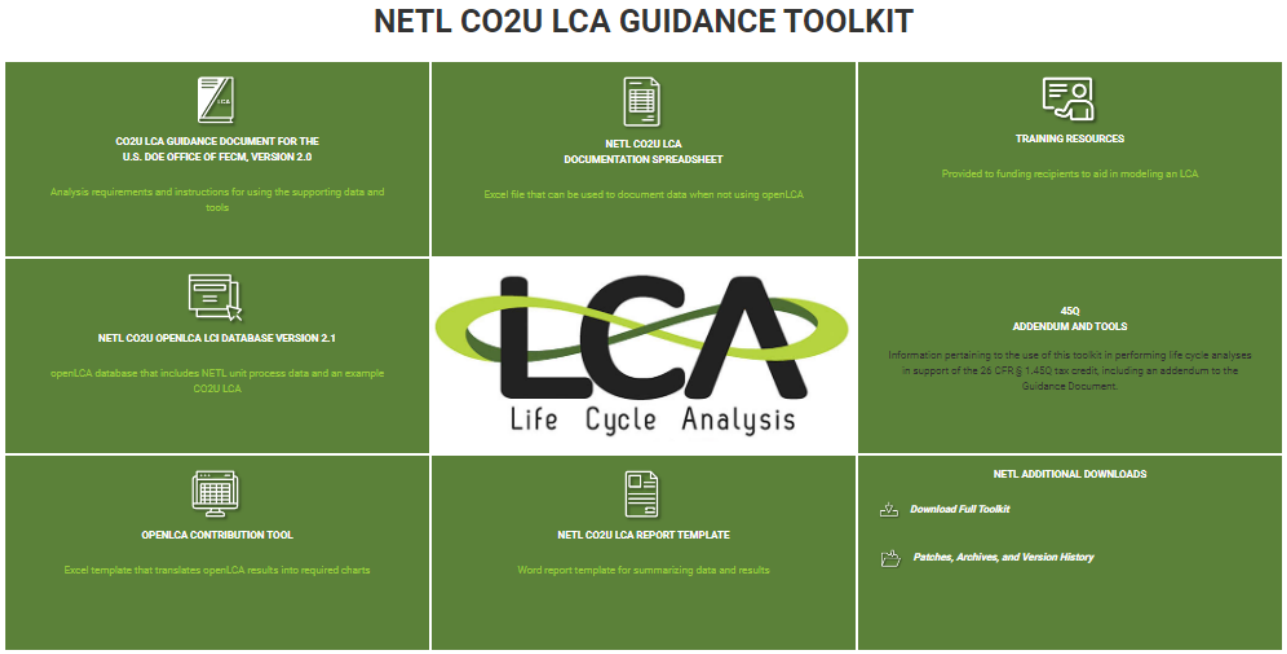
- **States, local gov, public utility/agency**

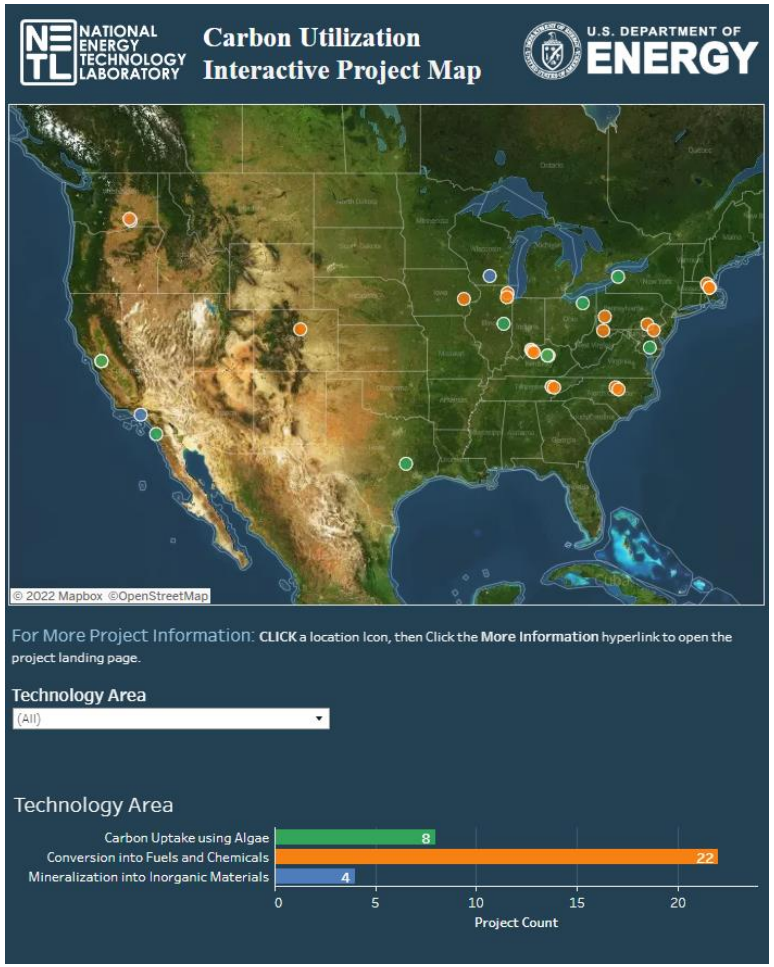
Procure and use commercial or industrial products

- **Derived from anthropogenic carbon oxides**
- **Less GHG emissions than incumbent**
- **Vendor must pass critical review**

Carbon Conversion Program Tools

https://netl.doe.gov/carbon-management/carbon-conversion





Carbon Conversion via Biological Uptake

A range of products are possible

- Animal feeds
- Nutraceuticals
- Dyes/colorants
- Polymers
- Soil amendments
- Fuels
  - Specific to the mission of DOE EERE's BETO (BioEnergy Technologies Office)

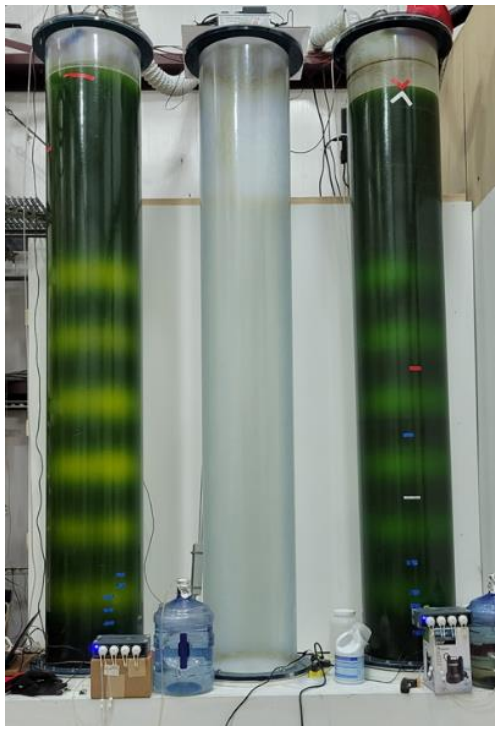
Advantages and challenges

- 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

Carbon Conversion via Biological Uptake

Pictures courtesy of
University of Illinois
Urbana-Champaign

Picture courtesy of
Global Algae Innovations



Picture courtesy of
University of Maryland Center
for Environmental Science

Carbon Conversion via Catalytic Pathway

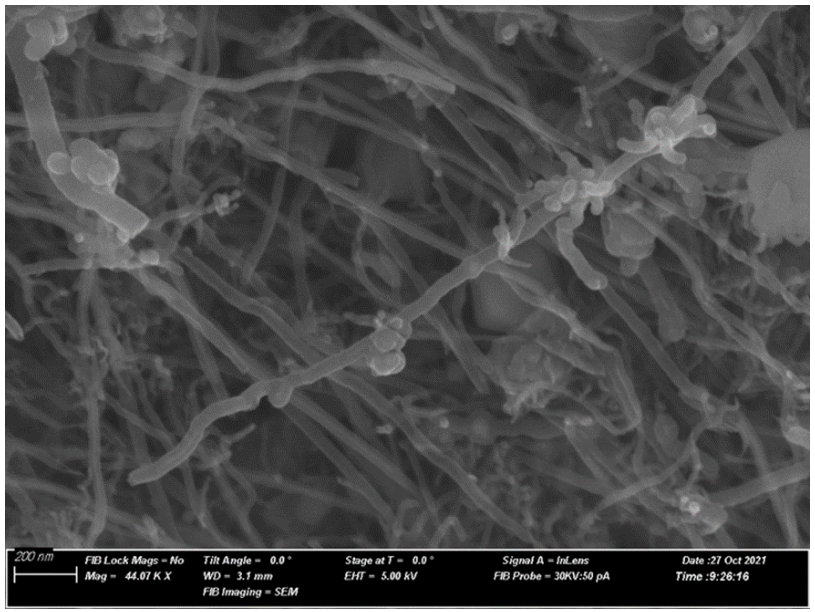
A wide range of products are possible

- Fuels
- Polymers
- Solid carbons
- Alcohols
- C2-C4 products (ethane, propane, butane, etc…)
- Methanol and Methane

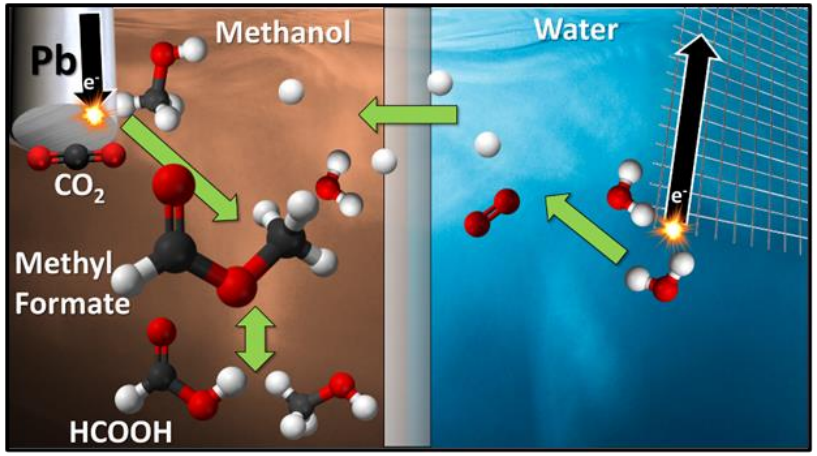
Advantages and challenges

- 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)

Carbon Conversion via Catalytic Pathway



Picture courtesy of SkyNano



Picture courtesy of University of Louisville

Carbon Conversion via Mineralization

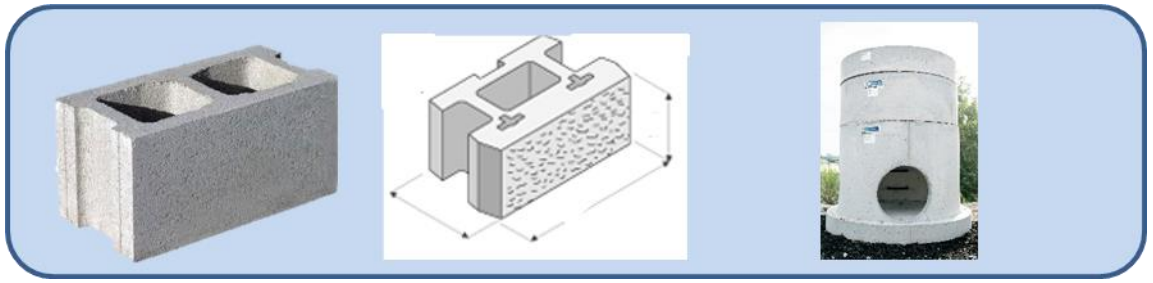
A limited range of products are possible

- Cured concrete blocks (CMU)
- Synthetic aggregates
- Suboxides
- Other building materials

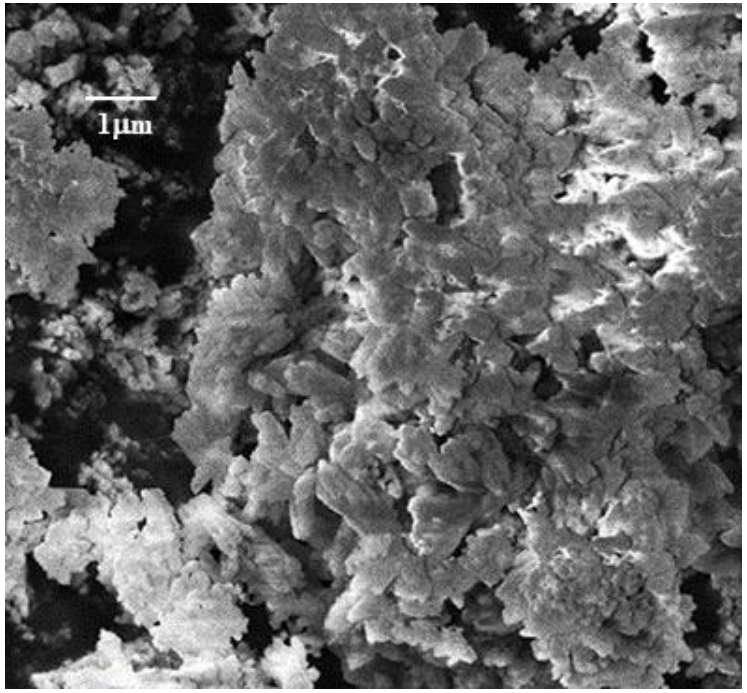
Advantages and challenges

- 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)

Carbon Conversion via Mineralization



Pictures courtesy of UCLA



Picture courtesy of University of Wisconsin Madison

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

Expanding the program

- Funding for program is increasing quickly
- Interest is increasing even more quickly than funding

Collaboration with multiple stakeholders

- Necessary due to the scale and breadth of the challenge
- It's not just FECM; lots of other DOE Offices, USG Departments, and NGOs involved

Program supports capabilities to test technologies at scale

- National Carbon Capture Center (NCCC)
- First USG funding source to support UCLA CarbonBuilt technology
  - One of two winners of prestigious NRG COSIA XPRIZE

Supporting R&D across multiple pathways

- Biological, thermos/electro chemical, mineralization, and reactive capture

TEA and LCA are vital for an effective program

- "It's tough to make predictions, especially about the future"

Carbon Conversion Contacts and Resources

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https://netl.doe.gov/carbon-management/carbon-conversion