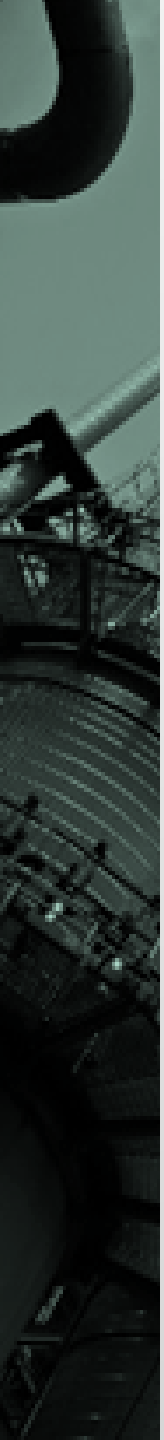
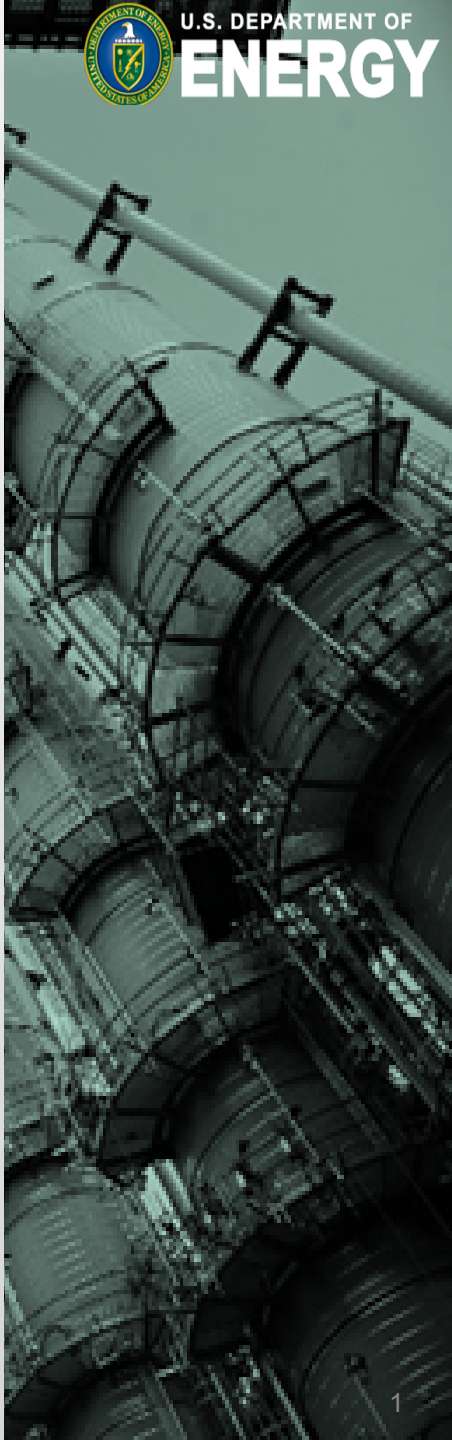




U.S. DEPARTMENT OF ENERGY

CARBON UTILIZATION

U.S. Department of Energy

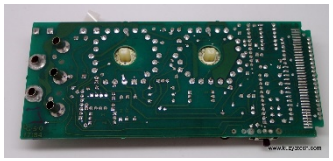
Office of Clean Coal & Carbon Management

Mark Ackiewicz | November 19th, 2019

HISTORY OF SOME CARBON/CO_2 UTILIZATION IN COMMERCIAL APPLICATIONS (NOT AN EXHAUSTIVE LIST)

1924: CO_2 fire suppression patented in US

1970s: enhanced oil recovery (EOR)



1990s: used as a precision cleaning solution for electronic surfaces

2014: Skyonic project

1922: Urea production using CO_2 and ammonia (NH_3) developed

1970s: Decaffeination of unroasted coffee beans

1990s: Use in polyurethane foam production (used in furniture, flooring, transportation)

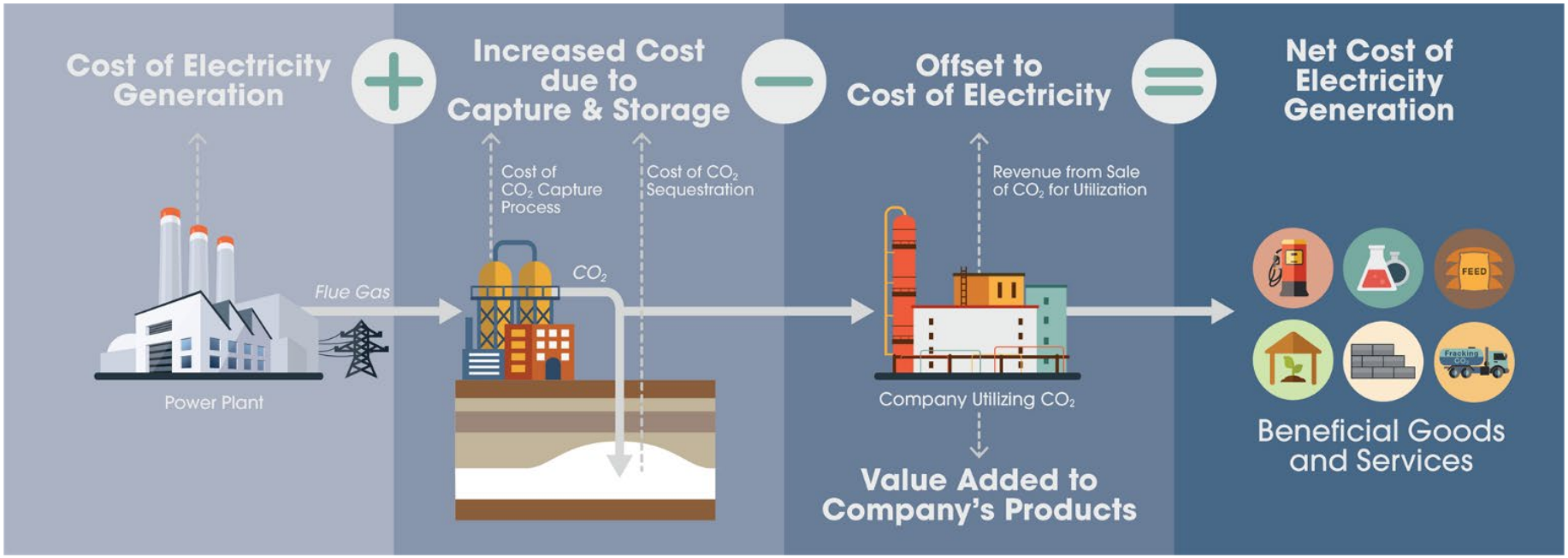
2015: SABIC Project in KSA recognized by CSLF

Photo of CO_2 capture and purification plant at SABIC's affiliate, UNITED, located in Jubail industrial city. courtesy of SABIC as presented at CSLF Ministerial meeting, November 2015.

BENEFITS OF CARBON UTILIZATION

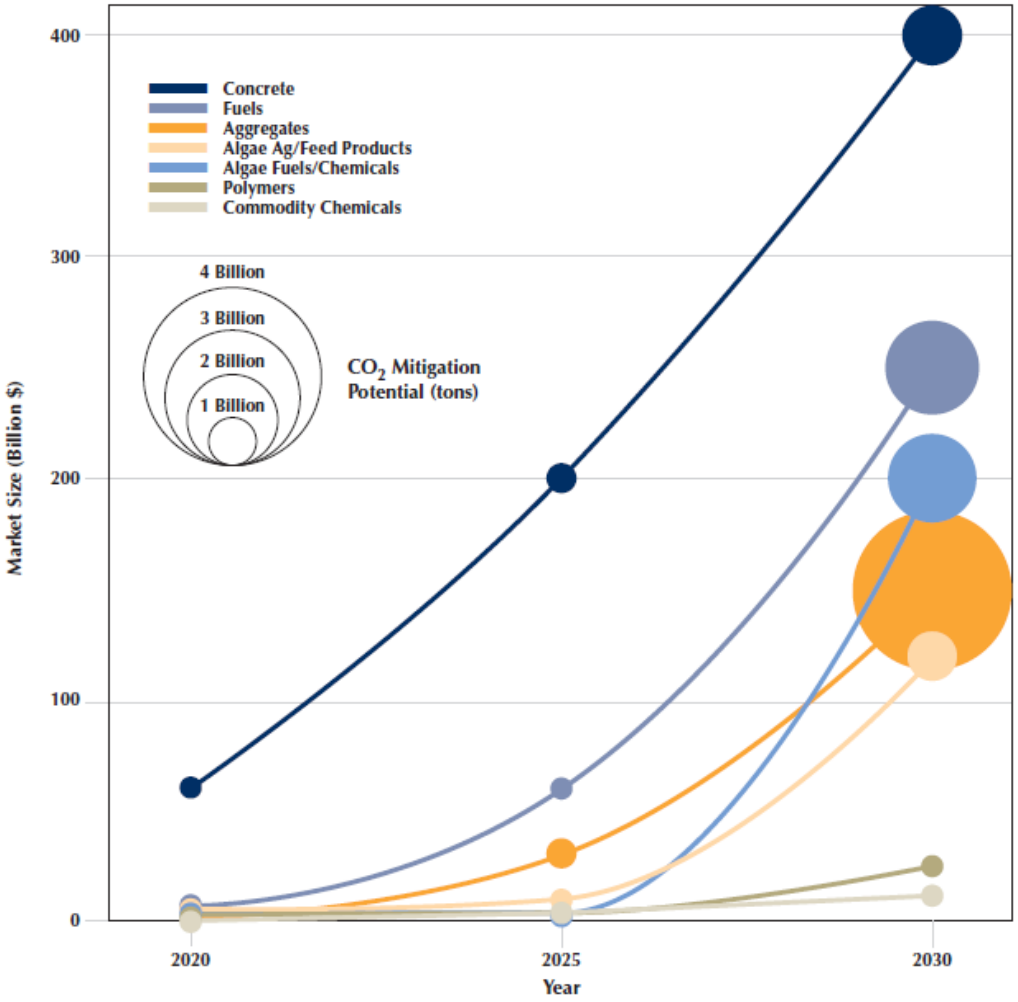
- Provides a means of generating revenue to partially offset cost of CO_2 capture.
- Potential for feedstock substitution and associated emissions reduction.
- Production of green products.
- Basis for claiming carbon credits/tax incentives.
- Development of markets for new materials.
- Creation of jobs as new processes are implemented.
- Technology Specific Benefits:
  - New uses for waste streams
  - Production of products with enhanced properties (e.g., strength, durability, weight, etc).
  - Less CO_2 that needs to be geologically stored – less wells, less land/surface area/pore space… which means equipment in the field

MARKET DRIVEN SOLUTION



MARKET POTENTIAL

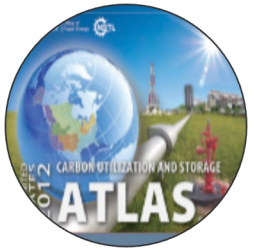
FIGURE 3: Market size and GHG mitigation potential of selected CCU sectors



Source: C2ES/Cogentiv Solutions analysis of market trends and potential greenhouse gas reduction capacity based on market projections from the Global CO_2 Initiative's Roadmap.

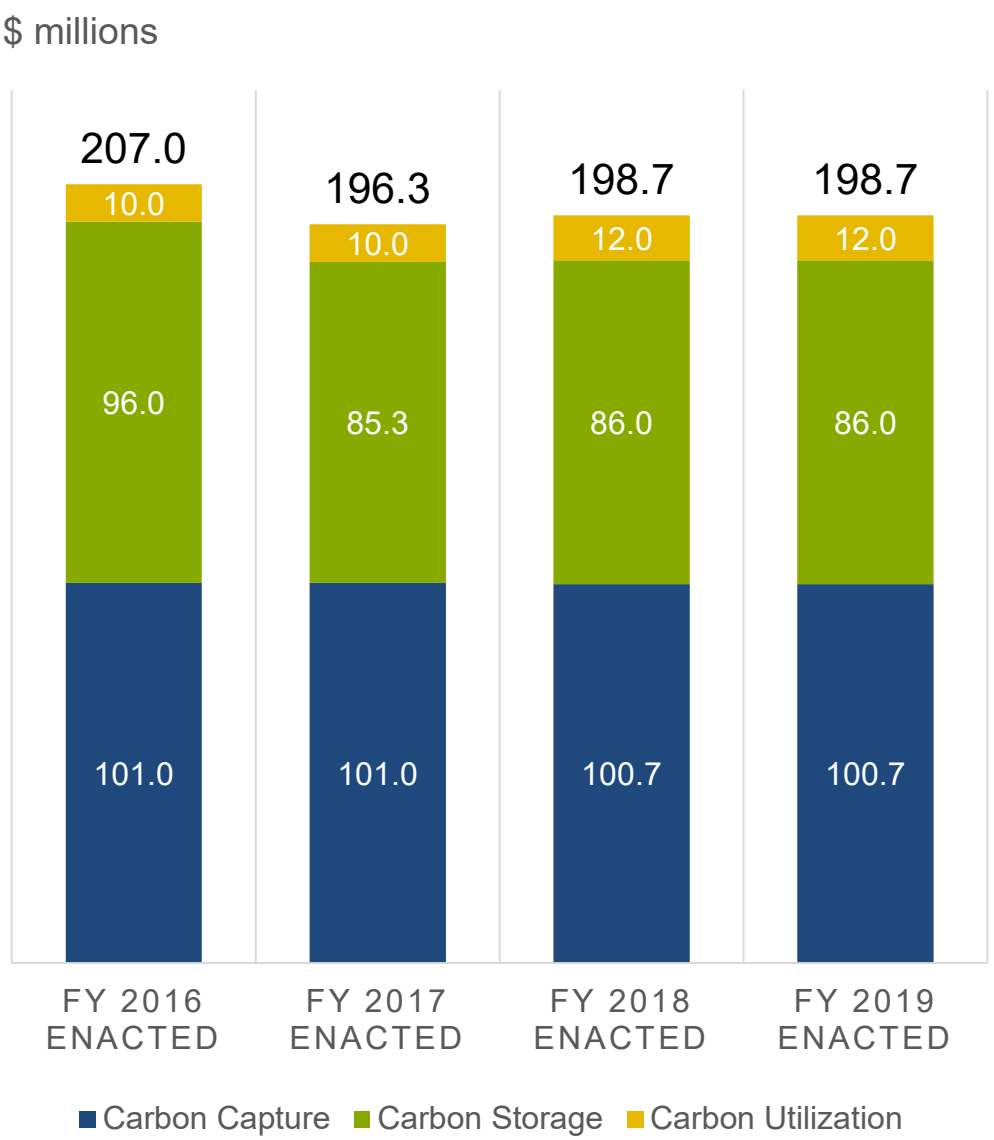
FEDERAL INVESTMENT

Carbon Utilization
R&D and technologies to convert CO_2 to value-added products



Carbon Storage
Safe, cost- effective, and permanent geologic storage of CO_2

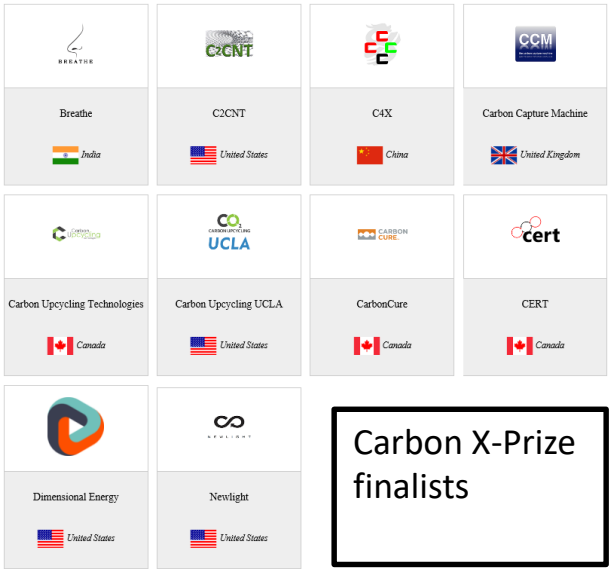
Carbon Capture
R&D and scale-up technologies for capturing CO_2 from new and existing industrial and power plants



SOME GLOBAL INITIATIVES

Carbon X-Prize:

- launched in September 2015
- $20 million available
- 10 finalists
- Winners announced March 1, 2020



Carbon X-Prize finalists

Oil and Gas Climate Initiative (OGCI) investments:

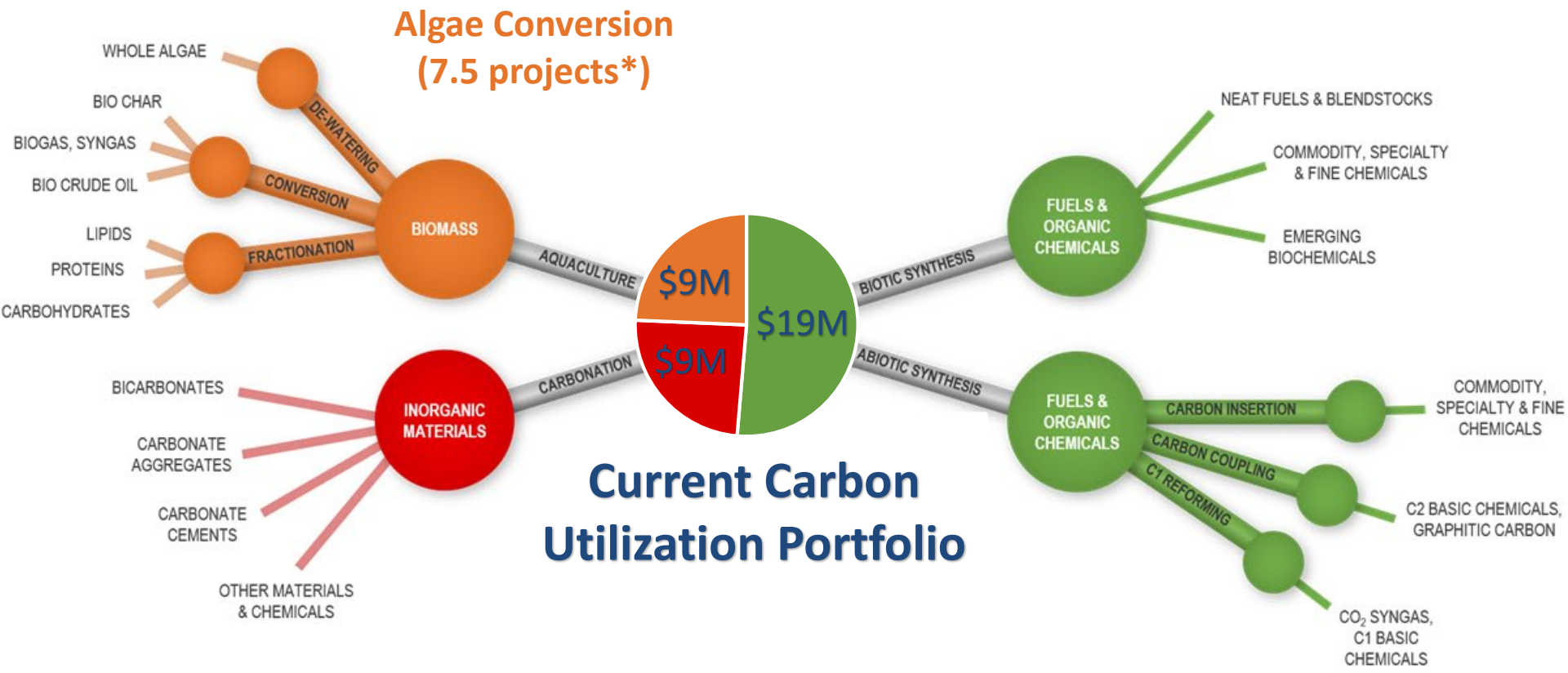
- Solidia Technologies – CO_2 utilization in concrete (October 2017)
- Econic – CO_2 into polyols (September 2018)

Policies:

- US: 45Q tax credit revision (2018). $35/ton for converting into fuels, chemicals, or other useful products (e.g., cement).

CARBON UTILIZATION R&D

U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy



Production of Inorganic Materials (9.5 projects*)

Synthesis of Fuels and Organic Chemicals (30 projects)

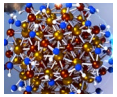
***Some projects incorporate multiple conversion pathways**

CARBON UTILIZATION CHALLENGES

U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy

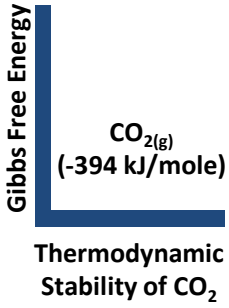
Thermochemical Challenges

Reliable, inexpensive carbon-lean energy

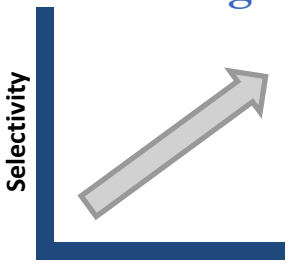


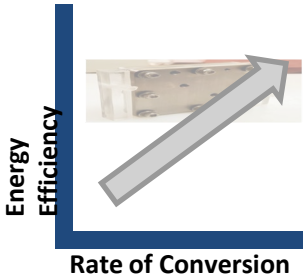
Catalysts

High Energy Reactants



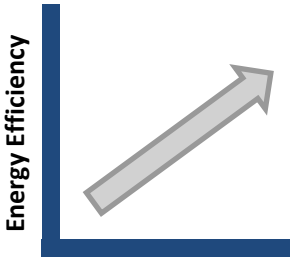
Electrochemical & Photochemical Challenges





Limited utilization of the solar spectrum by photocatalysts

Mineral Carbonation



Availability of Alkaline Industrial Wastes

Biological Capture

Efficient land use
Algae processing

Efficient capture of total solar radiation

EARLY UTILIZATION PROGRAM SUCCESSES

MCGILL UNIVERSITY → CARBON CURE™

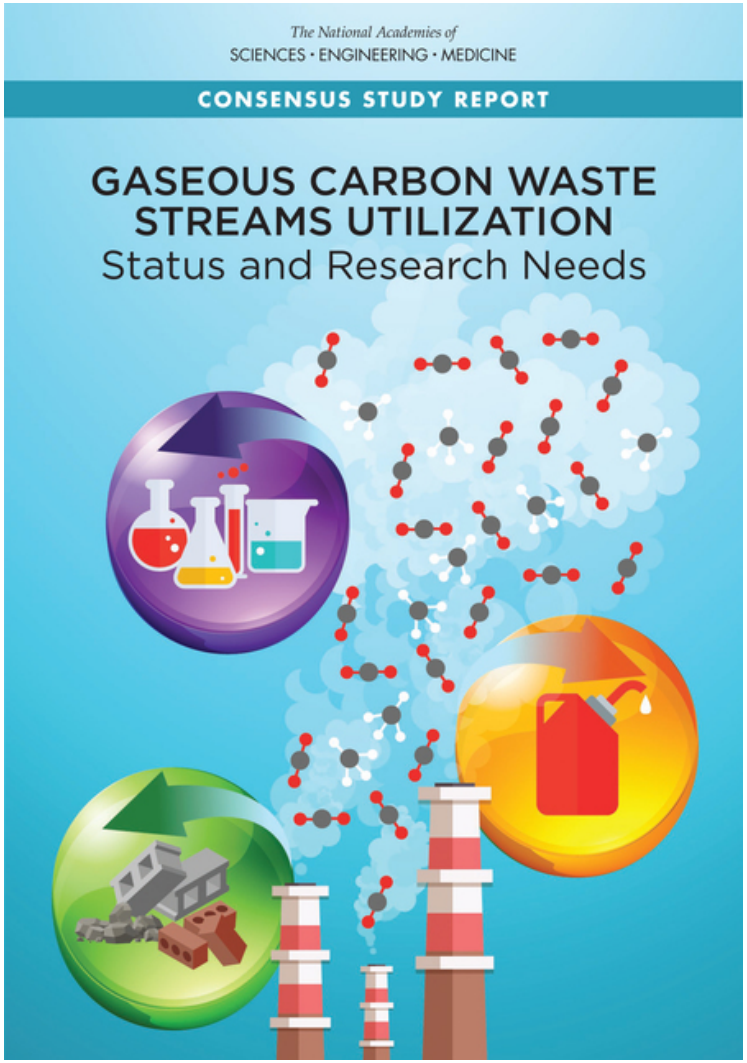
RUTGERS UNIVERSITY → Solidia Technologies

Novomer
Catalyzing Green Chemistry

Gaseous Carbon Waste Streams Utilization: Status and Research Needs

Released October 18, 2018

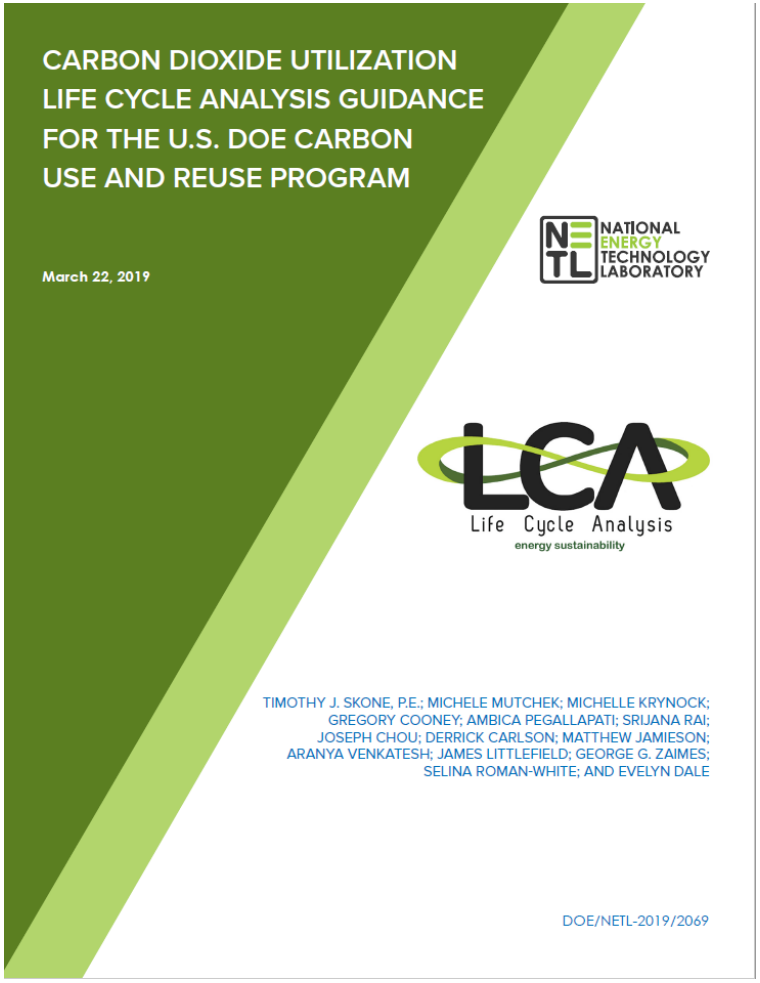
- Research Agenda and Challenges
- Improvements Needed
- Research Needs
- Market Opportunities
- Commercialization Opportunities
- LCA Requirements



https://www.nap.edu/catalog/25232/gaseous-carbon-waste-streams-utilization-status-and-research-needs

LIFE CYCLE ANALYSIS PROJECT GUIDELINES

- DOE FE/NETL Life Cycle Analyses work and templates, best practices, baseline studies



A comprehensive form of analysis that evaluates the environmental, economic, and social attributes of energy systems ranging from the extraction of raw materials from the ground to the use of the energy carrier to perform work.

NETL CO_2U LCA Toolkit is now available at netl.doe.gov/LCA/CO2U

SOME OVERALL THEMES

- **Carbon utilization technologies have a role to play in future carbon management and the circular carbon economy.**
- **Number of CO_2 utilization options available - mechanism for deployment and commercialization.**
- **Needs to be done at scale.**
    - Need high-volume and high-value products
    - Dependent upon the pace of technology development and future energy, market, and regulatory landscapes
    - Leverage regional and temporal resources, infrastructure and feedstocks
- **EOR is the most near-term utilization option.**
- **Non-EOR CO_2 utilization options are at varying degrees of commercial readiness and technical maturity.**
    - Research needs to be multifaceted and multiscale
    - More detailed, transparent, and consistent technical, economic, and environmental analyses should be conducted

CARBON UTILIZATION

Thanks for your attention. Questions?

Contact: Amishi.kumar@hq.doe.gov