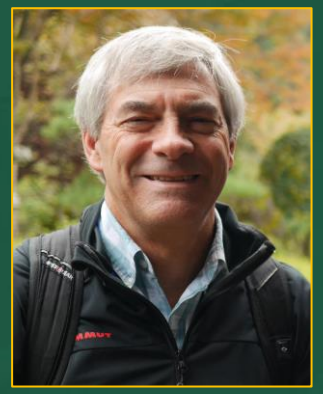
U.S. DEPARTMENT OF ENERGY | Office of Science

BES Virtual Roundtable on "Foundational Science for Carbon Dioxide Removal Technologies" March 2-4, 2022



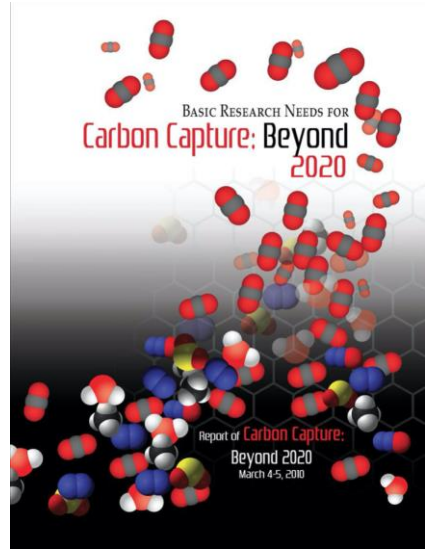
Co-Chair: Jim De Yoreo
Pacific Northwest National Laboratory

Co-Chair: Krista Walton
Georgia Institute of Technology

Briefing to the Basic Energy Sciences Advisory Committee
April 5, 2022

Previous DOE Reports and Initiatives

- **BES-Basic Research Needs for Carbon Capture: Beyond 2020**
  - March 4-5, 2010, Co-Chairs: Paul Alivisatos (LBNL) and Michelle Buchanan (ORNL)



- **DOE launched Carbon Negative Shot—the U.S. Government's first major effort in CDR, November 2021**
  - Carbon Negative Shot is the all-hands-on-deck call for innovation in technologies and approaches that will remove CO_2 from the atmosphere and durably store it at meaningful scales **for less than $100/net metric ton of CO_2-equivalent (CO_2e).**
  - This effort is being deployed to achieve a net-zero carbon economy and eventually remove legacy carbon pollution to help address the climate crisis, with dedicated focus on doing so in a just and sustainable manner.

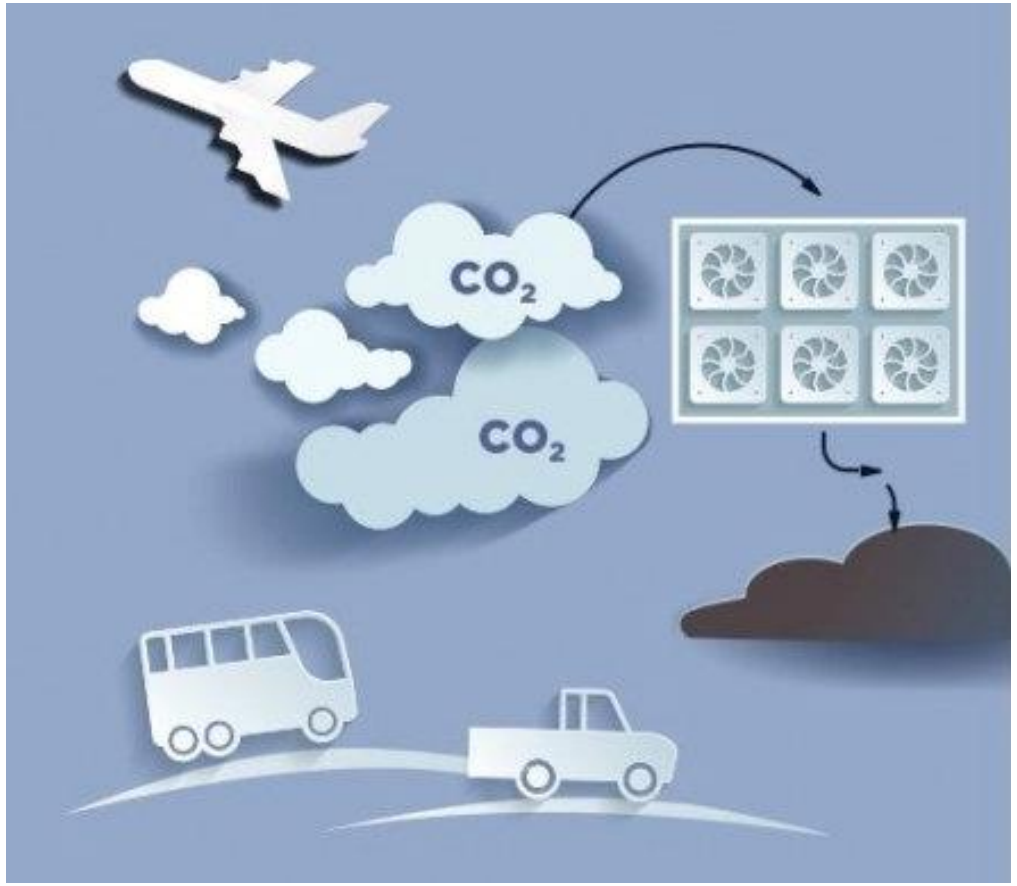
ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Carbon Negative™

<100 Dollars | 1 Ton | 1 Decade

Carbon Dioxide Removal (CDR):
A Necessary Part of Achieving Net-Zero Emissions

What is CDR?

- CDR encompasses a wide array of approaches that capture CO_2 directly from the atmosphere and durably store it in geological, biobased, and ocean reservoirs or in value-added products – like low-carbon concrete – to create negative emissions (i.e., when more carbon is removed from the atmosphere than is being generated)



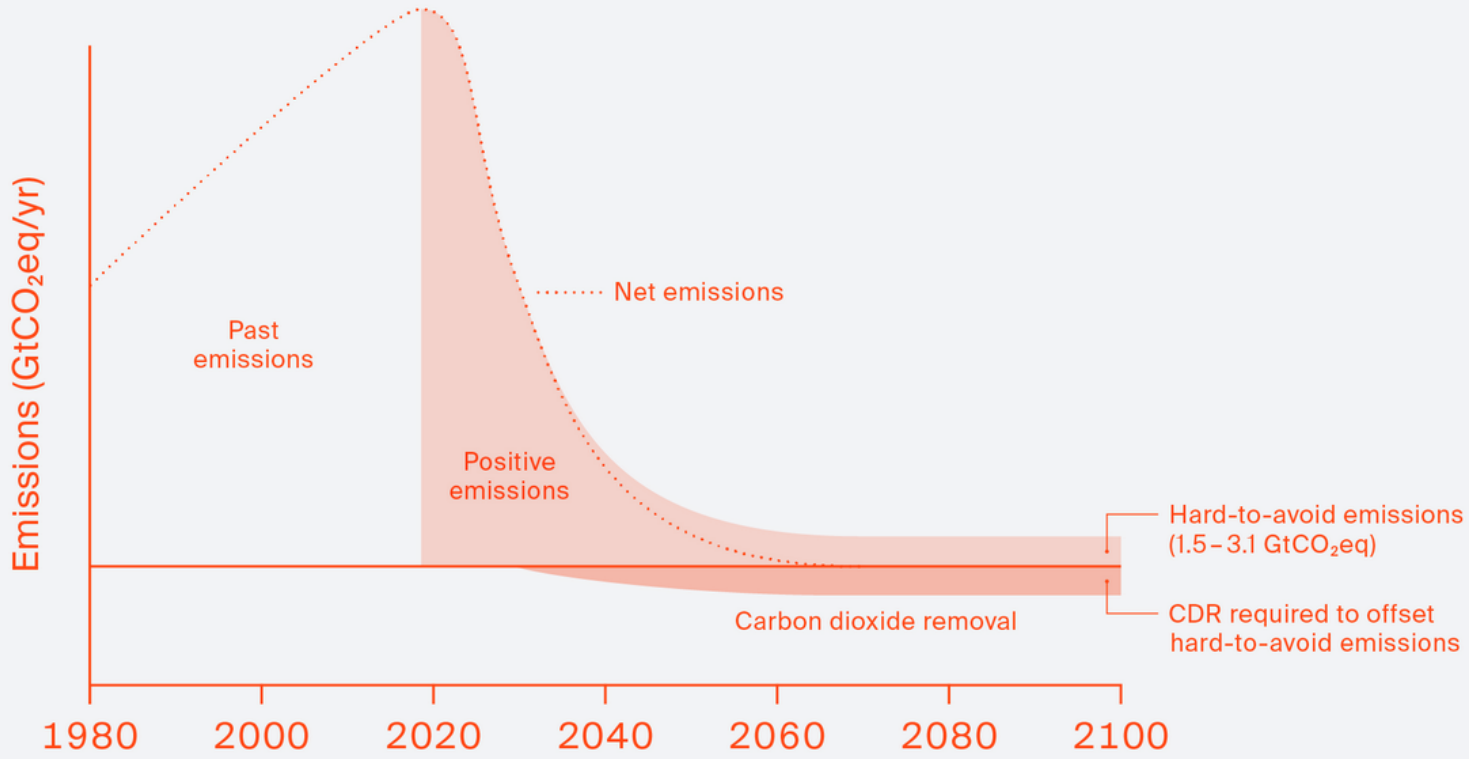
- CDR is distinct from point-source carbon capture from fossil power sector and heavy-duty industry

https://www.energy.gov/fecm/articles/infographic-carbon-dioxide-removal

Net-Zero and Role of Carbon Dioxide Removal

Figure 1.1 →

Schematic of hard-to-avoid emissions and the CDR needed to offset them. Adapted from a figure produced by Glen Peters (2020)



Reference: CDR Primer, 2021

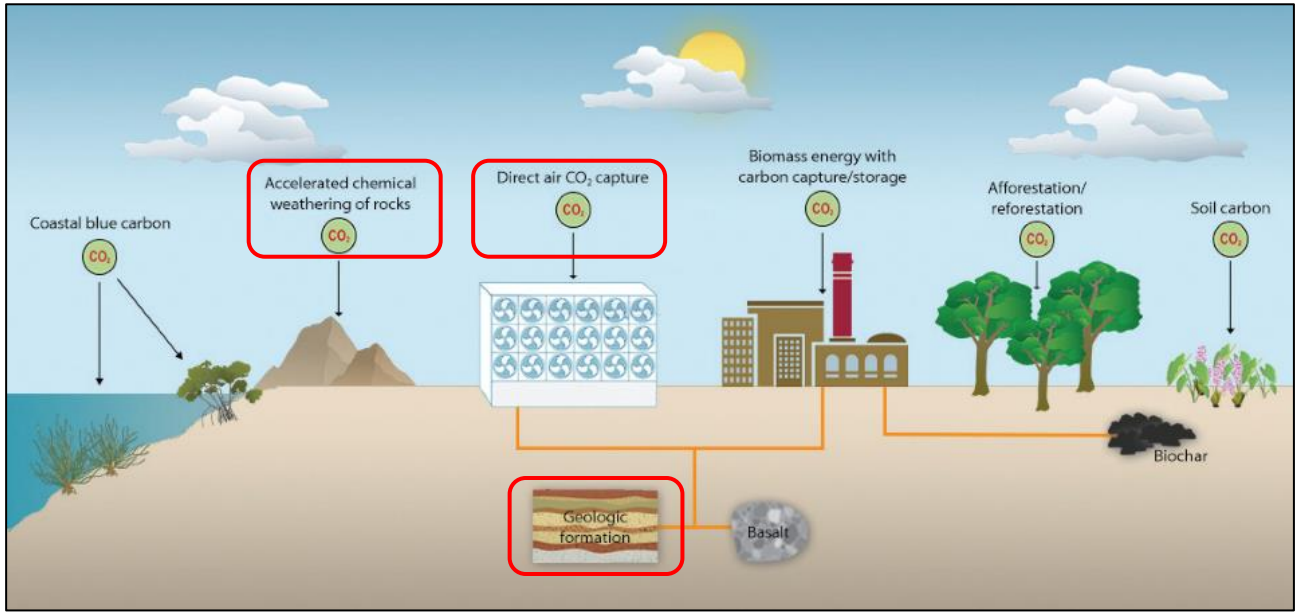
Roundtable on Foundational Science for Carbon Dioxide Removal (CDR) Technologies

Organized by SC-BES (lead), FECM, EERE, and ARPA-E

Goal: Identify the key underpinning science needs and priority research opportunities that will accelerate research, development, and deployment of CDR technologies

Roundtable Scope: Consider areas for BES research to enable future, as well as advance current, CDR technologies:

- CO_2 capture from dilute sources
- Durable CO_2 in minerals and materials
- Geological sequestration

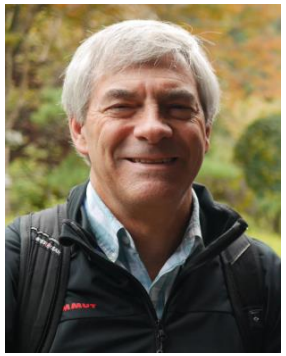


Participants: A diverse group of up to 30 participants representing labs, universities, industry, and other stakeholders

* https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda

Virtual Roundtable Charge

Co-Chairs: Jim De Yoreo (PNNL)
Krista Walton (Georgia Tech)
Date: Virtual, March 2-4, 2022



Virtual Roundtable led by SC-BES
With participation by:

- Fossil Energy and Carbon Management (FECM)
- Energy Efficiency and Renewable Energy (EERE)
- Advanced Research Projects Agency-Energy (ARPA-E)

Charge:

- Determine scientific and technical barriers that limit CDR technologies and expand beyond ambient air to consider other dilute sources such as large bodies of water
- Identify Priority Research Opportunities (PROs) for fundamental science that will accelerate progress in developing current CDR technologies, as well as to reveal opportunities for novel technologies with improved functionality
- PROs will describe the most important research directions that will form the basis for a coordinated, long-term strategy and provide guidance to the research community over the next decade

Roundtable Panels

- **Carbon Capture from Dilute Sources**
  - Panel Lead: Jeff Long, UC Berkeley

- **Durable Carbon Storage**
  - Panel Lead: Jose Rodriguez, BNL

- **Sequestration**
  - Panel Lead: Laura Pyrak-Nolte, Purdue

- **Cross-cutting**
  - Panel Co-Leads: James Kubicki, UTEP

    May Nyman, Oregon State

*Roundtable participants represented Universities (19), Industry (1), and National Laboratories (6)

Roundtable – Plenary Speakers

Deep Decarbonization and Environmental Justice

Jennifer Wilcox

Principal Deputy Assistant Secretary, FECM

Challenges in Achieving Net-CO_2 Reduction via Catalytic Conversion of CO_2

Jingguang Chen

Columbia University

Issues and Research Needs for Geologic CDR and Sequestration of CO_2

Don DePaoulo

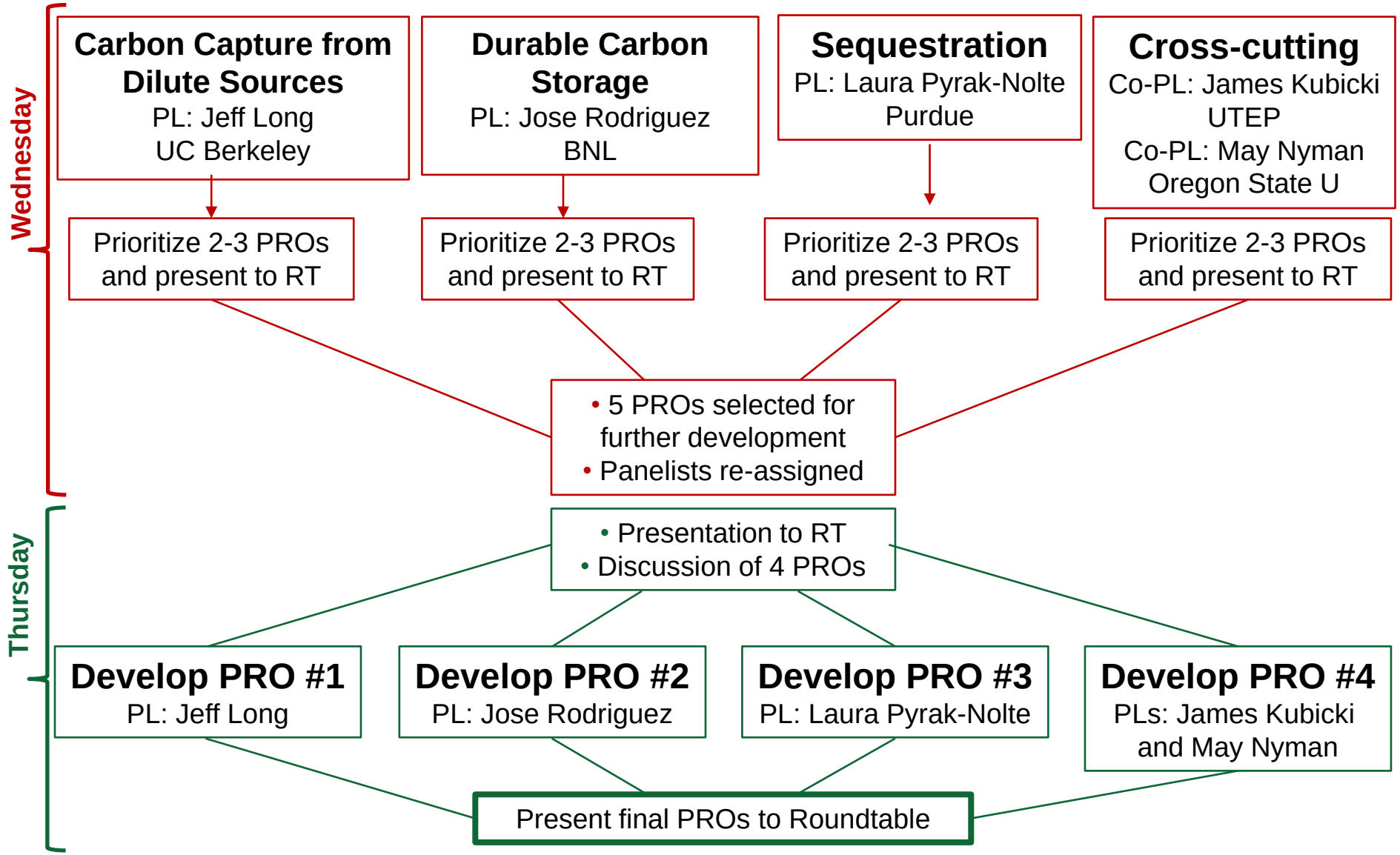
LBNL

Goal of Four Panels: Identify Candidate PROs

PROs describe the most important BES research directions that will form the basis for coordinated, long-term, impactful research in carbon dioxide removal technolog*ies*

- PROs will provide guidance to the research community for at least the next decade
  - Should represent "**stretch**" goals
  - ***Scientific Challenges**:* A high level, compelling summary of why this research area is important. This summary should explain the inspiration for the science. Include 1-2 short, key scientific questions that the PRO will answer.
  - ***Summary of Research Directions:*** More specific description of the research goals and approach, including schemes, figures, and papers with accompanying text.
  - ***Potential Scientific Impact**:* An overview of how the PRO could impact science. What is the potential scientific impact if new understanding and CDR approaches are successful?
  - ***Potential Impact on CDR Technologies**:* Describe the expected impact on CDR technologies from this research

Path to define Priority Research Opportunities (PROs)



Panelists Re-Aligned to Finalize Five PROs

PRO #1
Interfacial processes of CO_2 transport and reactivity
CO-LEADS: Nyman/Kubicki

PRO #2
Novel materials for CO_2 capture/ conversion
LEAD: Long

PRO #3
Unconventional pathways for capture, release, conversion
CO-LEADS: Atwater/Park

Harry Atwater
CalTech

A.-H. Alissa Park
Columbia

PRO #4
CO_2 conversion
LEAD: Rodriguez

PRO #5
Secure carbon storage
LEAD: Pyrak-Nolte

Priority Research Opportunities to Advance Foundational Science for Carbon Dioxide Removal Technologies

PRO 1: Master Interfacial Processes of CO_2 Transport and Reactivity Across Multiple Length and Time Scales

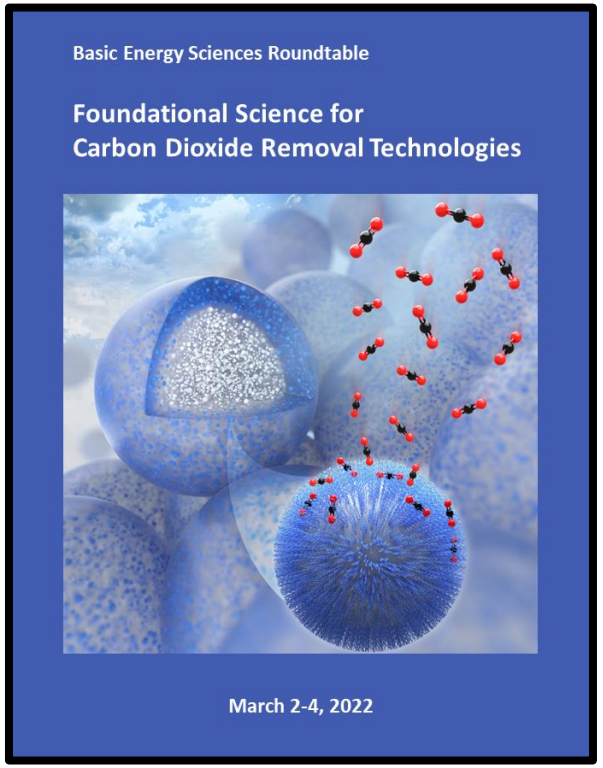
- **Key question:** How does the coupling across interfaces between disparate phases influence mass and energy transfer, and reactivity? How can these processes be controlled to enhance CO_2 reactivity and transport?

PRO 2: Design and Synthesize Materials that Simultaneously Achieve Multiple Functions for CO_2 Capture and Conversion

- **Key question:** What are the design principles for materials that simultaneously exhibit high binding affinity, low energy barrier for release, and durability? How can CO_2 capture be coupled to conversion in a single material?

PRO 3: Discover Unconventional Pathways and Materials for Energy-Efficient CO_2 Capture, Release and Conversion

- **Key question:** How can unconventional thermodynamics and kinetics be exploited to drive capture, release, and convert with low-energy consumption? How can these principles be incorporated into novel materials design of composites or multi-functional materials with tailored morphologies?



Roundtable held virtually March 2-4

Chairs:

- Krista Walton (Georgia Tech)
- James De Yoreo (PNNL)

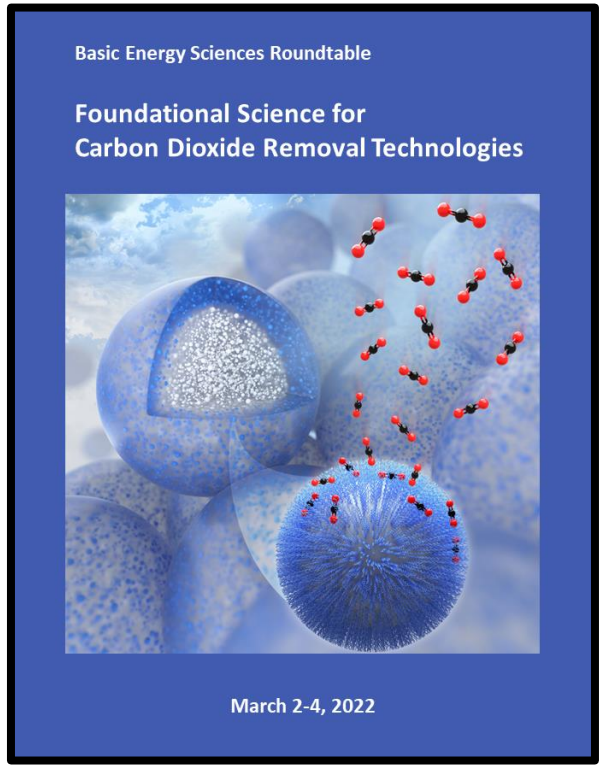
Priority Research Opportunities to Advance Foundational Science for Carbon Dioxide Removal Technologies

PRO 4: Control Multiphase Interactions Required for CO_2 Conversion into Molecules, Minerals, and Materials

- **Key question:** What are the key multiphase interfacial structures, chemistries, and phenomena that control kinetics and mechanisms of CO_2 transformation into minerals and materials?

PRO 5: Achieve Predictive Understanding of Complex Subsurface Geologic Processes to Enable Secure Carbon Storage

- **Key question:** How can we integrate processes, data, and modeling across time and length scales to bridge the gap between idealized laboratory models and complex subsurface structures to create predictive models for long-term CO_2 storage security?



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Roundtable Status

Target brochure date: by May

Target report date: late July or early August

Output: A public report describing Priority Research Opportunities that identify fundamental science needs to overcome technological barriers in areas outlined in National Academics Negatives Emissions Technology consensus study* and other studies

* https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda

Acknowledgements

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Nichole Fitzgerald (EERE-BETO)
Kate Peretti (EERE-AMO)

ORISE

Linda Severs

Questions?