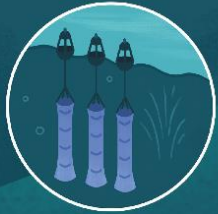
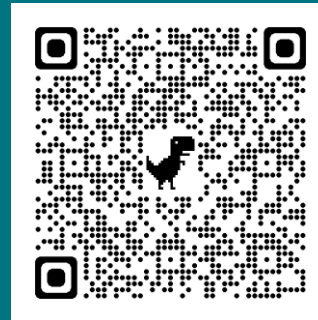


A Research Strategy for
**Ocean-based Carbon
Dioxide Removal**
and Sequestration



Thank you for joining,
we will be starting shortly.

Download the report!
www.nap.edu/26278



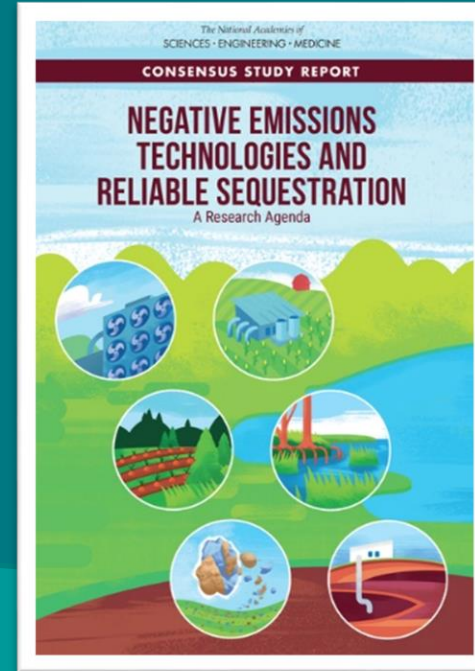
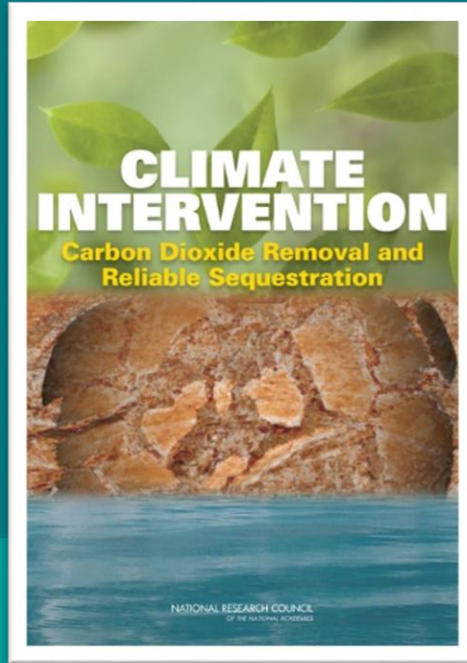
A Research Strategy for
**Ocean-based Carbon
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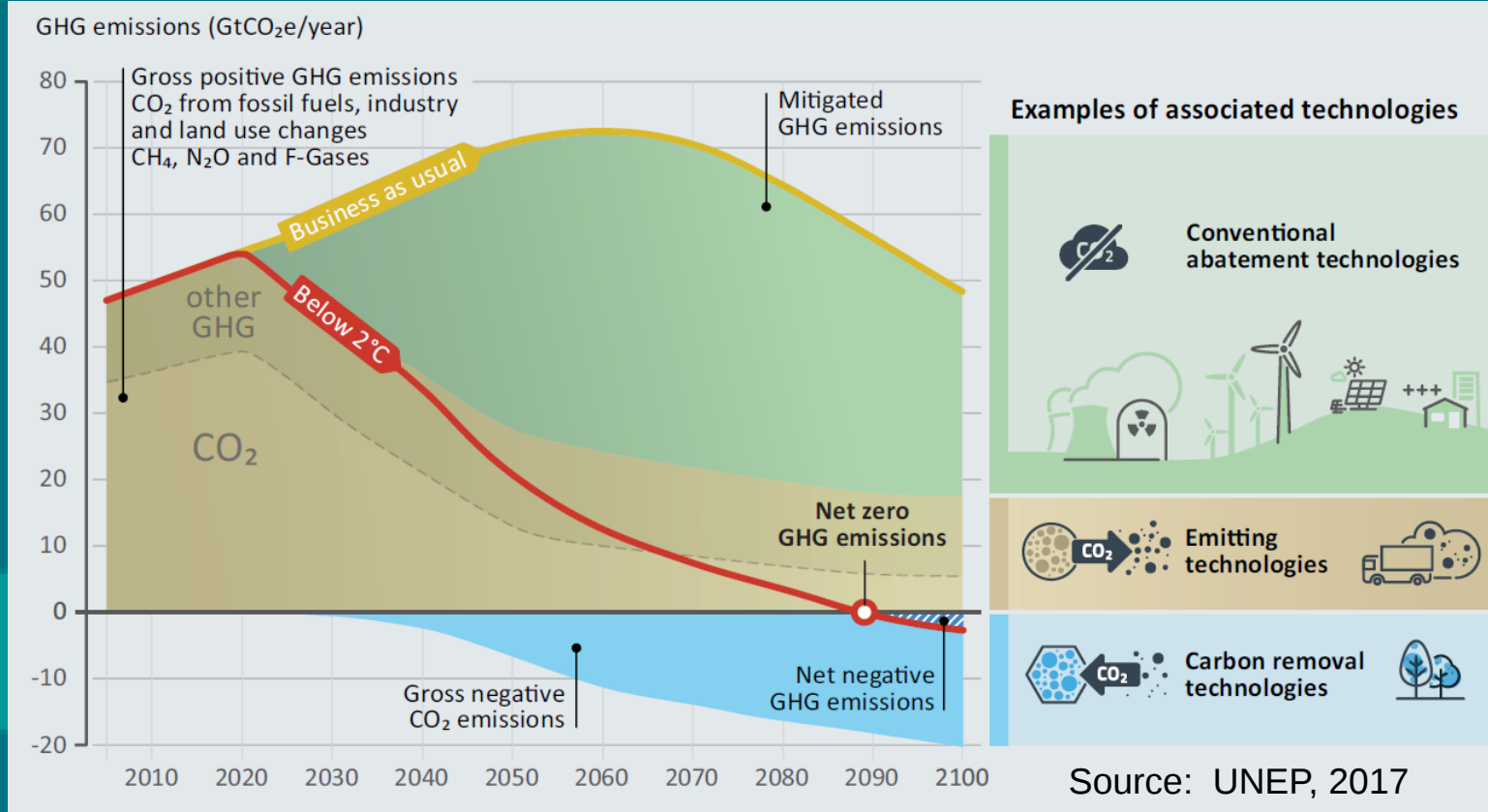
A Research Strategy for **Ocean-based Carbon Dioxide Removal** and Sequestration

NASEM Briefing Presented by
Dr. Scott Doney, Committee Chair
December 8, 2021

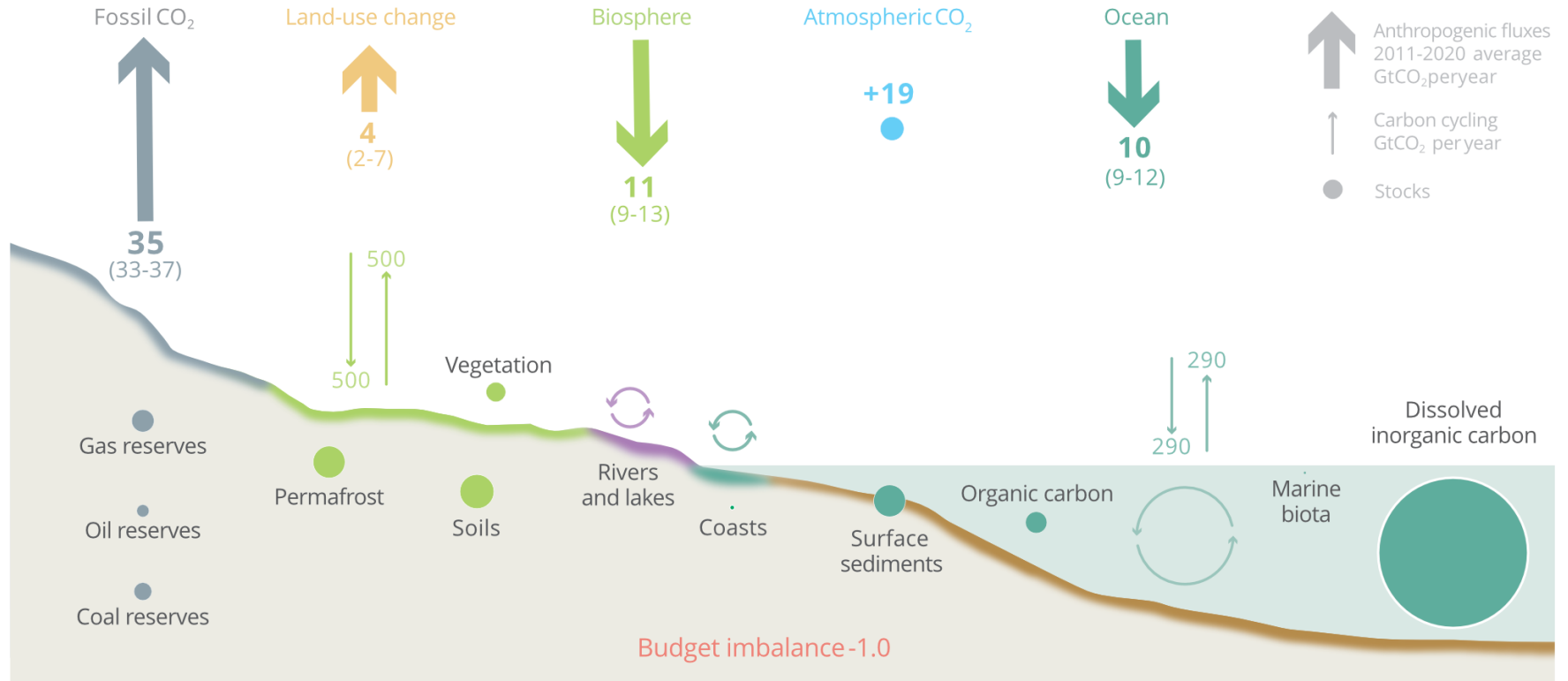
Study Context



Why we need CDR

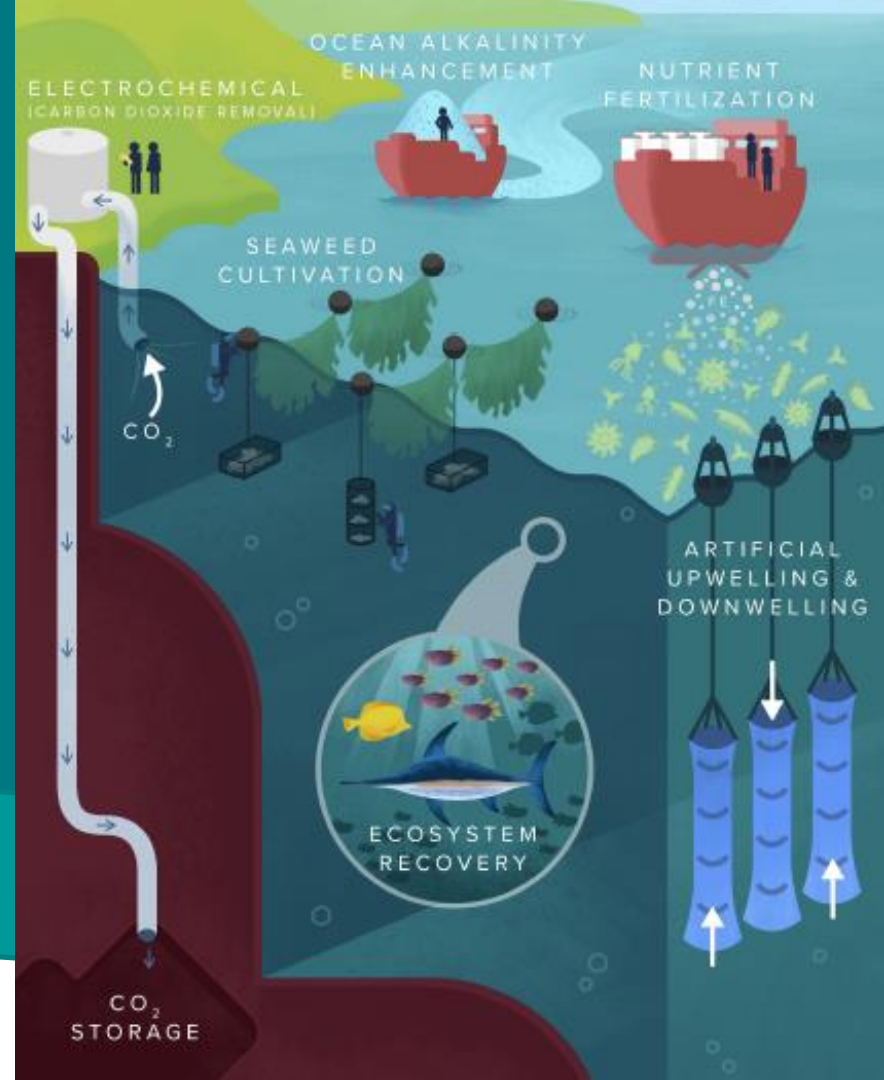


Why the Ocean?



Committee Charge

1. Identify the most urgent questions to better assess the benefits, risks, potential scale, and overall viability for ocean CDR
2. Define essential components of a R&D program
3. Estimate costs and potential environmental impacts of R&D program
4. Recommend ways to implement such a program



Study Overview

- 18-month Study
- Sponsored by ClimateWorks Foundation
- Public Workshops and Meetings - over 65 experts!
- Closed Meetings of Committee
- Review of Scientific Literature
- Development of Criteria for Assessment
- Report Writing and Response to External Peer Review



Committee

Scott Doney (Chair)

Ken Buesseler

Holly Buck

Debora Iglesias-Rodriguez

Kate Moran

Andreas Oschlies

Phil Renforth

Joe Roman

Gaurav Sant

David Siegel

Romany Webb

Angelicque White

University of Virginia

Woods Hole Oceanographic Institute

University of Buffalo

UC Santa Barbara

Ocean Networks Canada

GEOMAR Helmholtz Centre for Ocean Research

Heriot-Watt University

University of Vermont

UC Los Angeles

UC Santa Barbara

Columbia Law School

University of Hawai'i

Report Structure

- Summary
- Chapter 1 - Introduction
- Chapter 2 - Cross-cutting Considerations on Ocean CDR
- Chapter 3 - Nutrient Fertilization
- Chapter 4 - Artificial Upwelling and Downwelling
- Chapter 5 - Seaweed Cultivation
- Chapter 6 - Ecosystem Recovery
- Chapter 7 - Ocean Alkalinity Enhancement
- Chapter 8 - Electrochemical Approaches
- Chapter 9 - Synthesis and Research Strategy

Cross-cutting Considerations - Chapter 2

- Legal and Regulatory Landscape
- Social Dimensions and Justice Considerations
- Monitoring for Environmental Impacts
- Monitoring for Certification (Carbon Accounting)
- Policy Support For Ocean CDR

Assessment Criteria

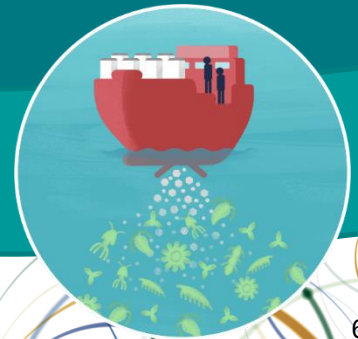
- Knowledge Base
- Efficacy
- Durability
- Scale
- Monitoring & Verification
- Viability and Barriers including Environmental & Social Impacts
- Governance and Social Dimensions
- R&D Opportunities



Nutrient Fertilization

Example from Chapter 3

- Medium to High Confidence that iron fertilization will work
- CDR durability for 10-100 years, maybe more
- Potential to remove 0.1 - 1.0 Gt CO₂/yr, maybe more
- Concern for undesirable geochemical and ecological consequences
- Negative social considerations - history, “dumping”, use conflicts
- Co-benefits largely unknown
- Carbon accounting likely challenging
- Cost <\$50/t CO₂ (excluding monitoring & verification)



	Ocean Nutrient Fertilization	Artificial Upwelling/ Downwelling	Seaweed Cultivation	Ecosystem Recovery	Ocean Alkalinity Enhancement	Electrochemical processes
Knowledge Base	Medium-High	Low-Medium	Medium-High	Low-Medium	Low-Medium	Low-Medium
Efficacy	Medium-High	Low	Medium	Low	High	High
Durability	Medium	Low-Medium	Medium-High	Medium	Medium-High	Medium-High
Scalability	Medium-High	Medium	Medium	Low-Medium	Medium-High	Medium-High
Environmental Risk	Medium	Medium-High	Medium-High	Low	Medium	Medium-High
Social Considerations	Challenging	Challenging	Challenging + Positive Impacts	Less Challenging + Positive Impacts	Challenging	Challenging
Co-benefits	Medium	Medium-High	Medium-High	High	Medium	Medium-High

Durability: <10, 10-100, >100 yr
 Scale: <0.1, 0.1-1.0, >1.0 Gt CO₂/yr

Summary Table S.1 & 9.1

	Ocean Nutrient Fertilization	Artificial Upwelling/ Downwelling	Seaweed Cultivation	Ecosystem Recovery	Ocean Alkalinity Enhancement	Electrochemical processes
Cost of scale-up	Low	Medium-High	Medium	Low	Medium-High	High
Costs and challenges of C accounting	Medium	High	Low-Medium	High	Low-Medium	Low-Medium
Cost of environmental monitoring	Medium					
Additional resources needed	Low-Medium	Medium-High	Medium	Low	Medium-High	Medium-High

Cost of scale-up: <\$50, \$50-100, >\$100 or 150 \$/t CO₂

Summary Table S.1 & 9.1



Common Challenges to Ocean CDR

- Knowledge Base
- Governance
- Intended & Unintended Environmental and Social Impacts
- Monitoring and Verification
- Cost

Overall Recommendation

To inform future societal decisions on climate response mitigation, **a research program for ocean CDR should be implemented**, in parallel across multiple approaches, to address current knowledge gaps. The research program should not advocate for or lock in future ocean CDR deployments but rather **provide an improved and unbiased knowledge base** for the public, stakeholders, and policy makers. Funding for this research could come from both the public and private sectors, and collaboration between the two is encouraged.

Research Agenda

Foundational Research (over 10 years)

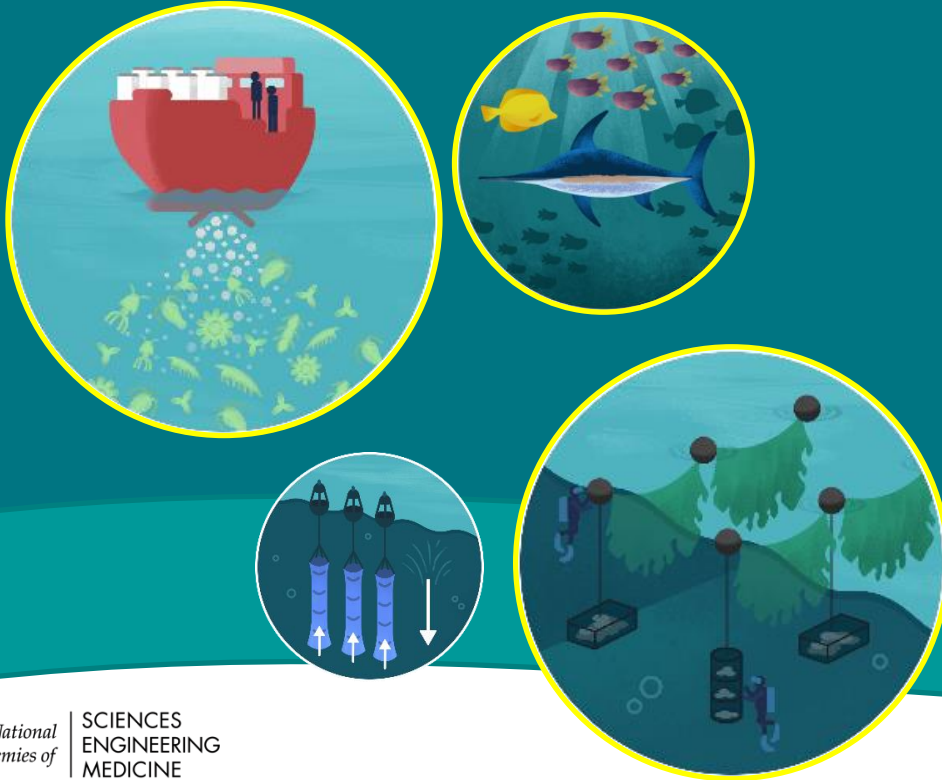
\$125M

- Legal & Regulatory Framework
- Code of Conduct
- Monitoring and Accounting
- Social Dimensions
- Policy Support
- Capacity Building

Summary Table S.2 & 9.2

Prioritization

Biotic CDR Approaches



Abiotic CDR Approaches



Nutrient Fertilization - Research Priorities

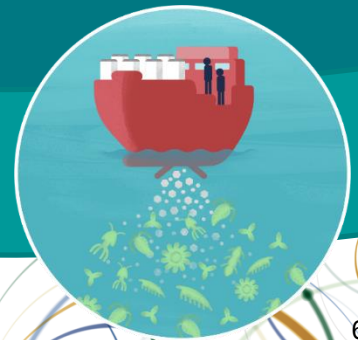
Example from Chapter 3

Priorities next ~5 years

- Carbon sequestration efficiency, e.g., carbon export to depth; iron (Fe) bioavailability
- Tracking of sequestered carbon
- In field experiments- >100 t Fe and $>1,000$ km² initial patch size followed over annual cycles

Additional research elements on 5-10 year time periods

Summary Table S.3 & 9.3



Research Agenda

Approach-specific Priorities (over 5 yrs)

\$850M

Nutrient Fertilization

\$165M

Artificial Upwelling and Downwelling

\$25M

Seaweed Cultivation

\$130M

Ecosystem Recovery

\$130M

Ocean Alkalinity Enhancement

\$125M

Electrochemical Processes

\$275M

Recommendations for an Ocean-CDR Research Program:

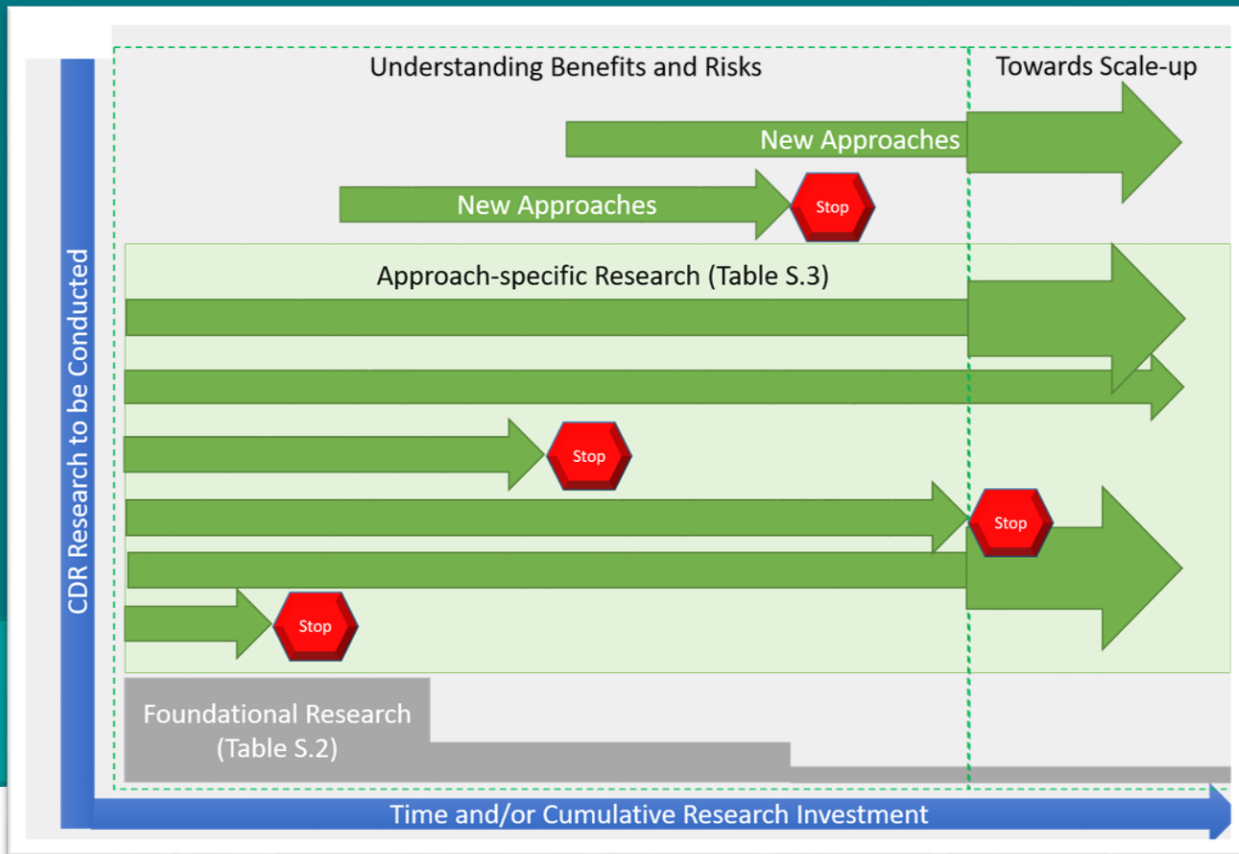
(1)Goals

(2)Common Components

(3)Research Priorities



Implementation

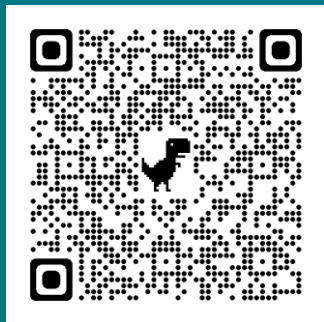


Key Takeaways

- Emission reduction is most important but is NOT ENOUGH- terrestrial CDR is NOT ENOUGH; ocean CDR could play a role, as part of a portfolio of approaches
- An ocean CDR research program should be implemented to understand “will it work?” and “what are the consequences?” - “are any of the six approaches feasible”?
- Foundational research to lay the framework for any ocean CDR should start now
- Research agenda is to inform decision makers; it is not an endorsement
- Technical feasibility is not enough; need policy support; need social support; need accounting and verification of C removal; need to understand co-benefits, environmental & social impacts

Thank you

The report is available for
download at nap.edu



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