Frontiers of CDR

Accelerating Underexplored Solutions to the Climate Crisis

December 10, 2020
1:30PM ET | 10:30AM PT

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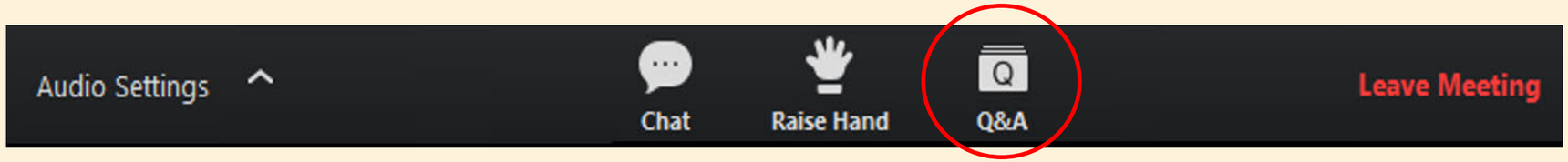
Housekeeping

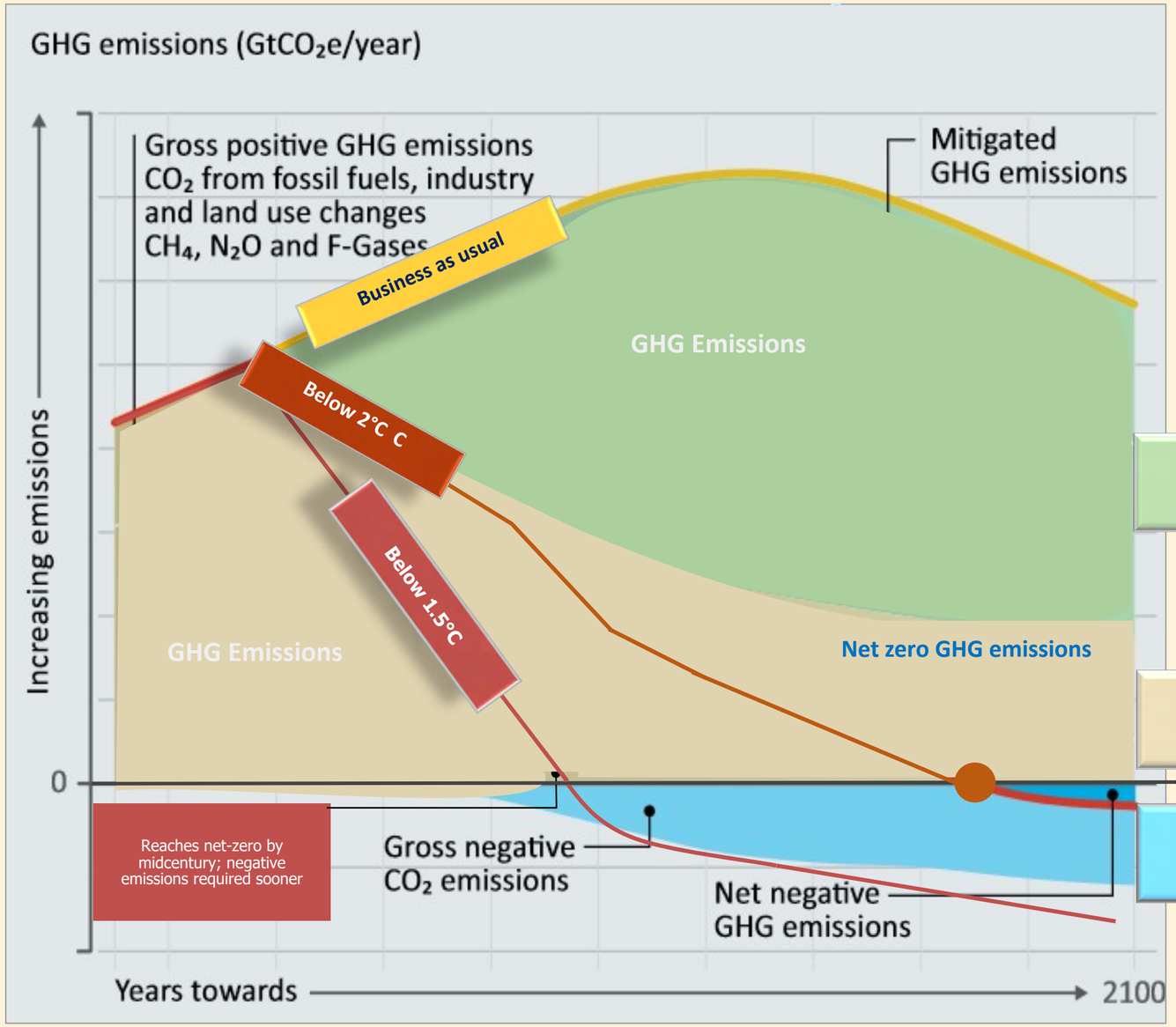
- Use the **Chat function** to engage with other participants and attendees throughout the event

- Use the **Q&A function** to submit questions to the panelists

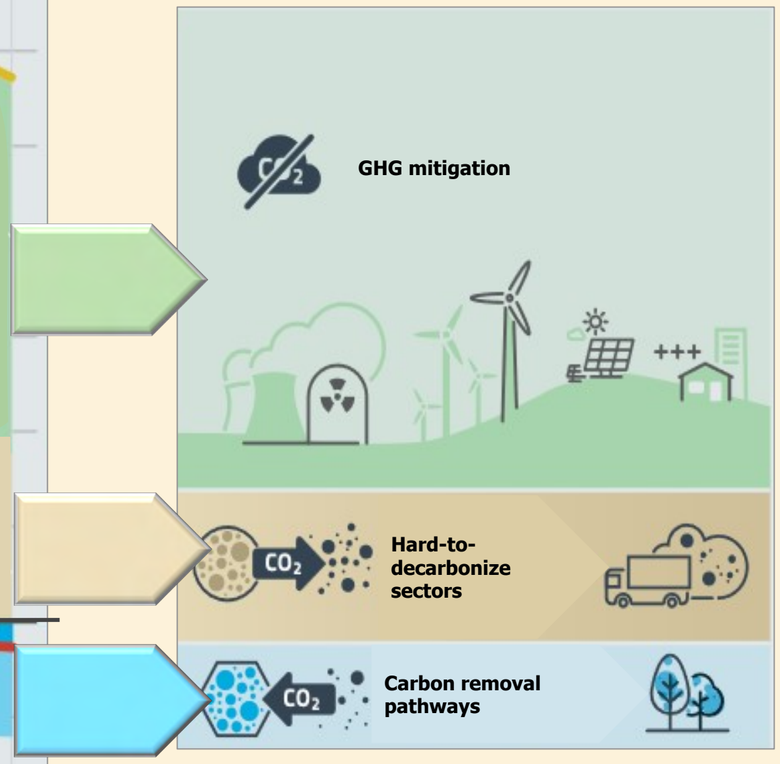


- Today's webinar will be recorded and posted to our website www.energyfuturesinitiative.org and YouTube

The Need for CDR



Examples of Associated Technologies



Note: This figure shows emission reductions from conventional mitigation technologies combined with carbon dioxide removal. This exemplary scenario is consistent with a 66 percent chance of keeping warming below 2°C relative to a baseline. Global net emissions levels turn to net negative towards the very end of the century, but carbon dioxide removal is already being deployed much earlier. Some residual carbon dioxide emissions remain throughout the scenario, as they are too difficult to mitigate in the model Source: Jérôme Hilaire (MCC)

Essential and Urgent Need: Goal, Structure, Funding, RD&D Portfolio of a Federal CDR Program

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Goal

Comprehensive 10-year RD&D initiative focused on multiple CDR technology pathways.
Capable of gigaton-scale deployment, at technology-specific cost targets, with minimal ecological impact

Organization

Federal Committee on Large-Scale Carbon Management. 12-agency, whole-of-government effort involving planning, budgeting, and coordination

Proposed Funding

Budget of $10.7B over 10 years, with $325M in the first full year. Funding distributed among 10 agencies in six separate appropriations bills

RD&D Portfolio

Capture Technology Pathways				CO_2 Disposition		Cross-Cutting	
Direct Air Capture	Terrestrial & Biological	Carbon Mineralization	Coastal & Oceans	Geologic Sequestration	CO_2 Utilization	Systems Analysis	Large-Scale Demonstration Projects

27 Individual Portfolio Elements

Source: EFI, 2019.

Presentation

Key Findings and Recommendations: Frontiers of CDR

Brad Ack
Ocean Visions

Ari Patrinos
Novim

Sasha Wilson
University of Alberta

Frontiers of CDR

Uncharted Waters: Expanding the Options for Carbon Dioxide Removal in Coastal and Ocean Environments

Workshop Co-Leads

Brad Ack, Executive Director and Chief Innovation Officer, Ocean Visions
Greg Rau, Senior Research Scientist, Institute of Marine Sciences, University of California, Santa Cruz

Expert Panel

Jess Adkins – California Institute of Technology

Ken Buesseler – Woods Hole Oceanographic Institution

Wil Burns – American University

Elizabeth Canuel (observer) – Virginia Institute of Marine Science

John Crusius – US Geological Survey

Kevin Doran – University of Colorado

Matthew Eisaman – Stony Brook University

David Emerson- Bigelow Laboratory for Ocean Sciences

Antonius Gagern – CEA Consulting

Dwight Gledhill (observer) – NOAA

Charles H. Greene – Cornell University

Charles Hopkinson – University of Georgia

David Keller – GEOMAR Helmholtz Centre

David Koweek – Ocean Visions

Colin McCormick – Valence Strategic

Lizzie McLeod – The Nature Conservancy

Kelly Oskvig - NASEM

Phil Renforth – Heriot Watt University

Susan Roberts (observer) - NASEM

Celina Scott-Buechler – U.S. Senate

Brian Von Herzen – Climate Foundation

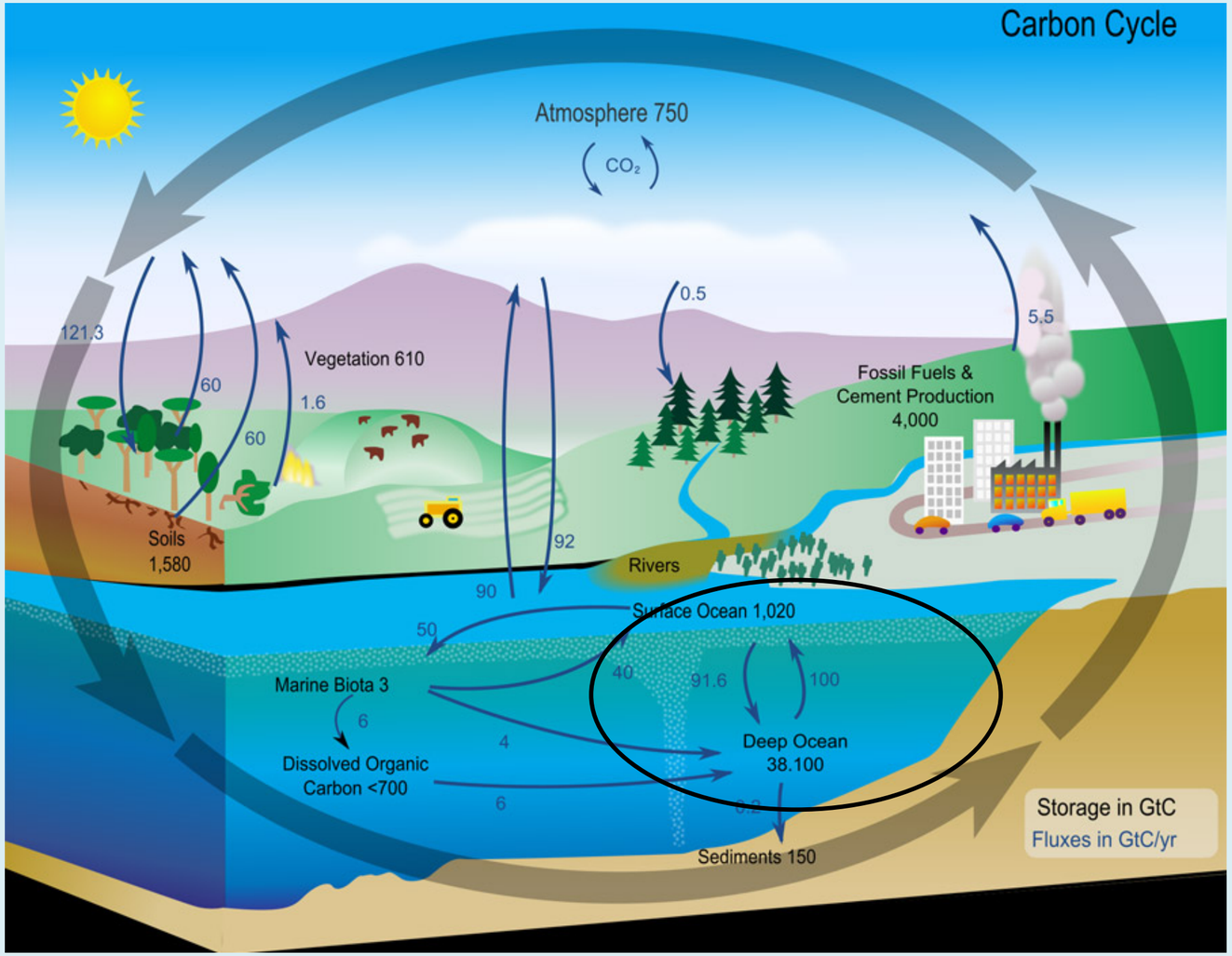
Marc von Keitz – ARPA-E

Heather Willauer – U.S. Naval Research Laboratory

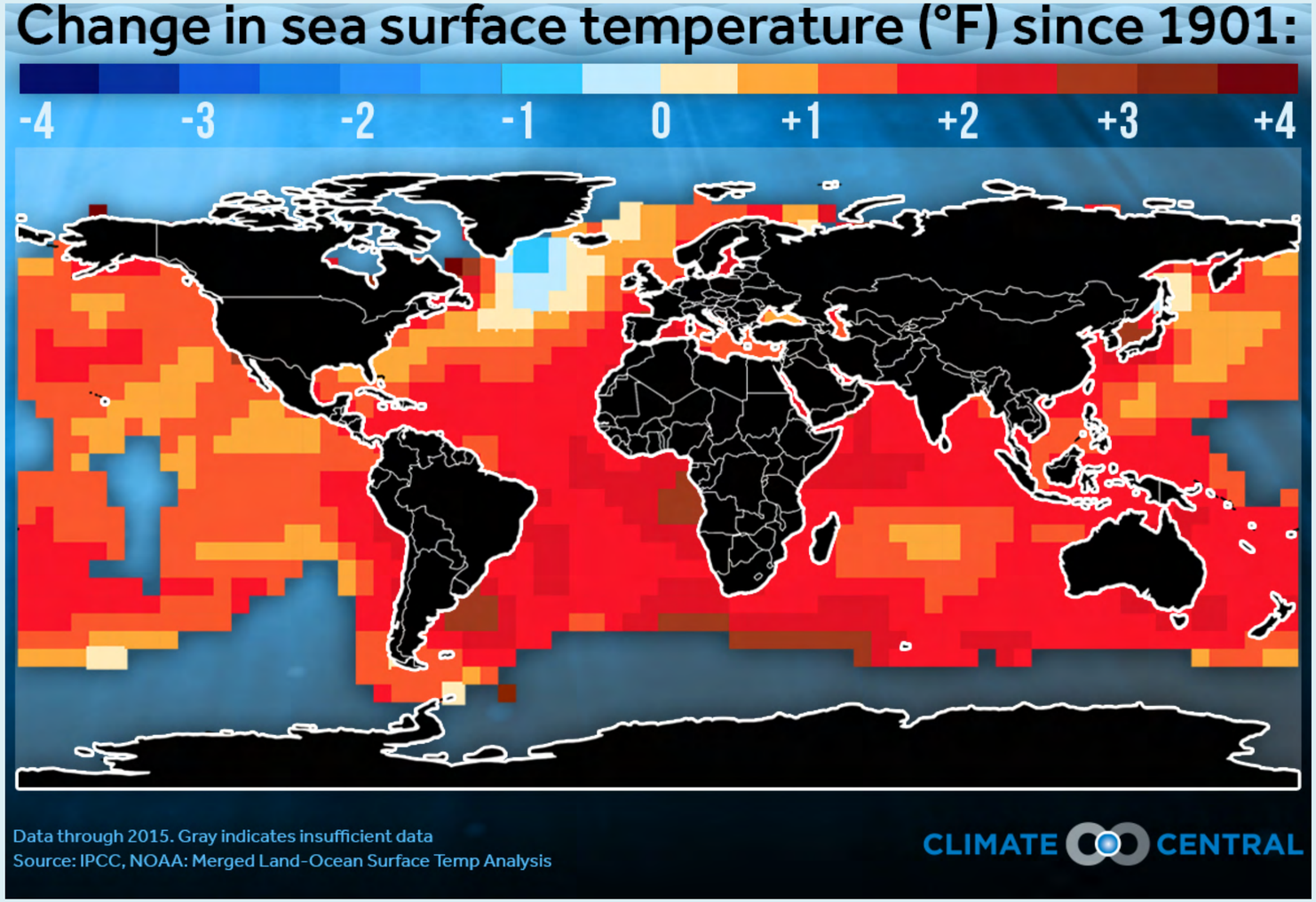
Why the Ocean?

The Ocean controls global carbon cycling through various biological and geological processes that exchange carbon between upper and lower layers of the ocean as well as between the atmosphere, land, and the ocean.

And, the ocean holds about 50 times more carbon than the atmosphere.



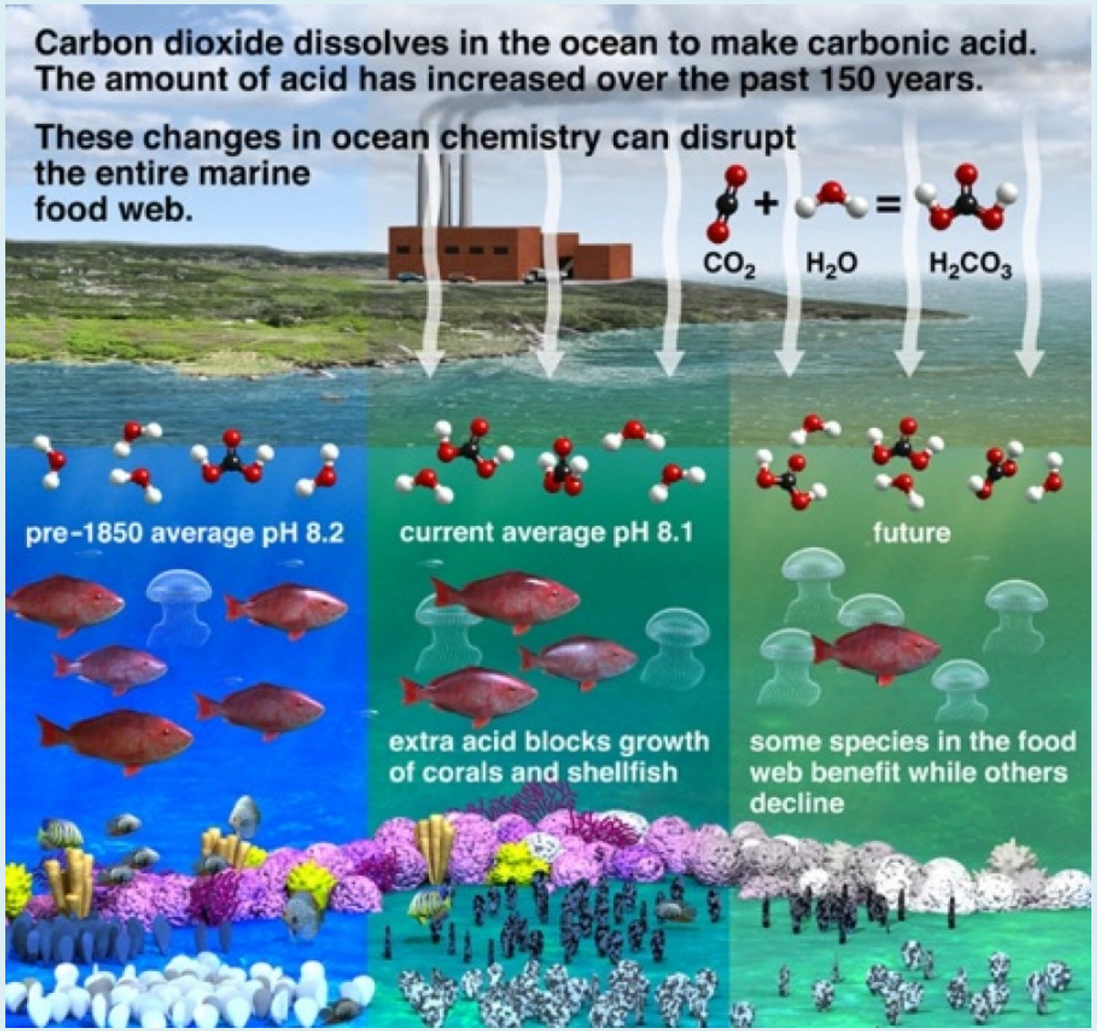
Ocean CDR Can Help Reduce Worst Threats to the Ocean



EFFECTS OF THERMAL STRESS

- Marine heatwaves
- Coral reefs dying
- Interrupted mixing
- Deoxygenation
- Accelerated sea level rise
- More powerful storms
- Increased melting of sea ice
- Changes to ocean currents
- Poleward species migration

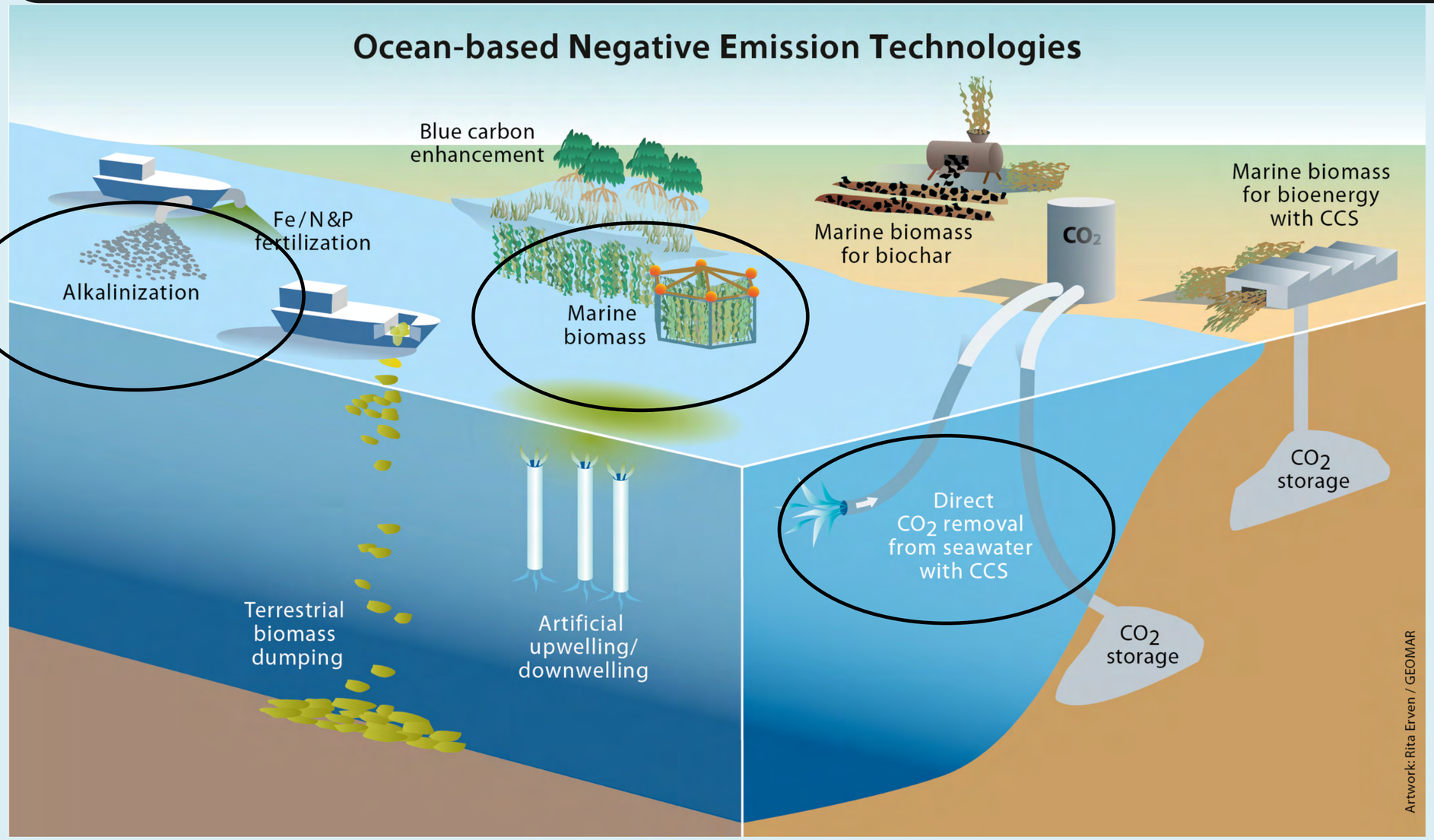
Ocean CDR Can Help Reverse Worst Threats to the Ocean



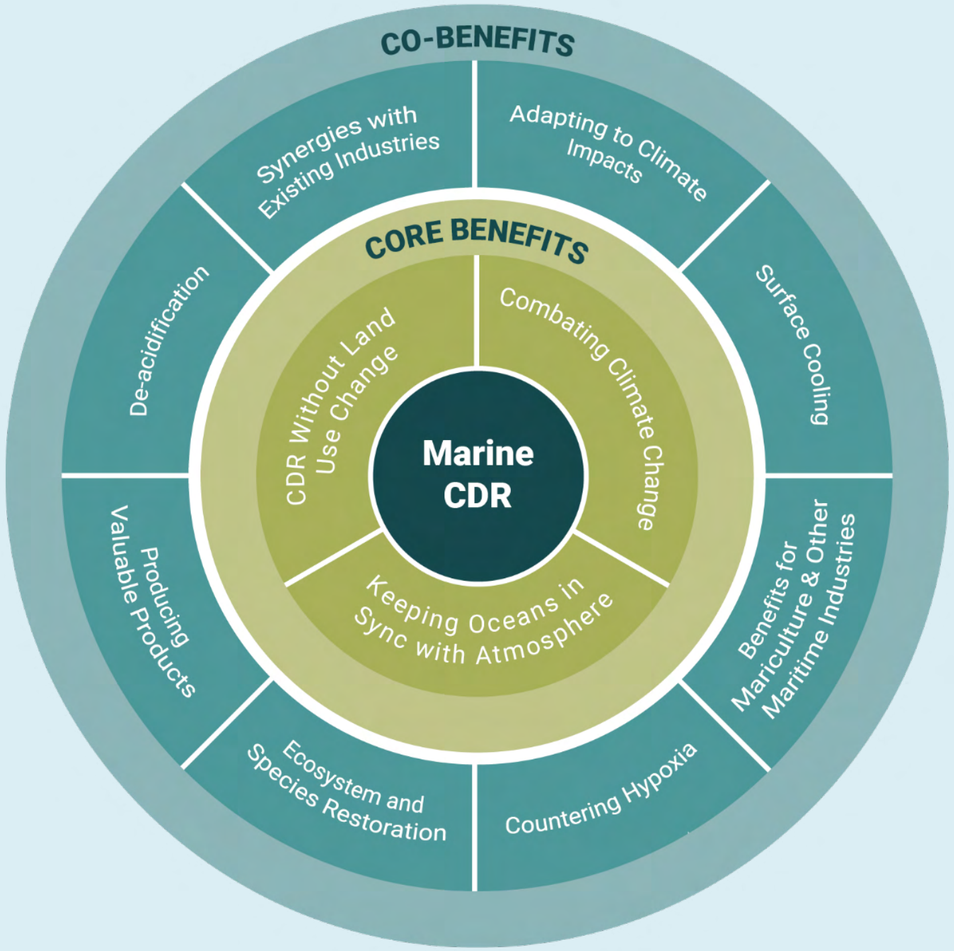
EFFECTS OF CHEMICAL STRESS

- Ocean are 30% more acidic than pre-industrial era
- This threatens the base of the food chain
- In turn, human wellbeing and economies

There Are Multiple Ocean CDR Approaches: Biomimicry and "Geo-mimicry"



Ocean CDR Offers Numerous Potential Co-benefits



Production of carbon neutral or negative food, fiber and energy resources
Potential benefits to corollary production of food (shellfish, finfish)
Improved habitat for marine biodiversity
Localized amelioration of ocean acidification
Localized amelioration of thermal stress
Nutrient remediation – reduce hypoxia
And more!

Recommendations

Federal funding of $2 billion over the next decade for an *interagency* federal RD&D initiative on Ocean CDR. Specifically:

1. RD&D on a variety of Ocean CDR pathways, for technology development, optimization, field testing and scalability. Many tests in many places.
2. Improving methods for measuring and verifying CDR benefits, ecosystem effects, lifecycle impacts
3. Improving predictive modeling tools for ocean-CDR siting and operation
4. Enhancing markets for co-products from ocean CDR pathways and integration into carbon markets
5. Enhancing public engagement and building support
6. Creating enabling national and international governance frameworks

Concluding Thoughts

CDR is an imperative

It needs to be 10x'ed and 10x'ed again

Ocean pathways have great promise and merit greatly increased attention

U.S. Government leadership can do a great deal to bolster and accelerate the field

We have to not just stabilize but reverse the climate damage we have wrought!

If we don't do it, who will?
If not now, when?

Frontiers of CDR

Rock Solid: Harnessing Mineralization for Large-Scale Carbon Management

Workshop Co-Leads

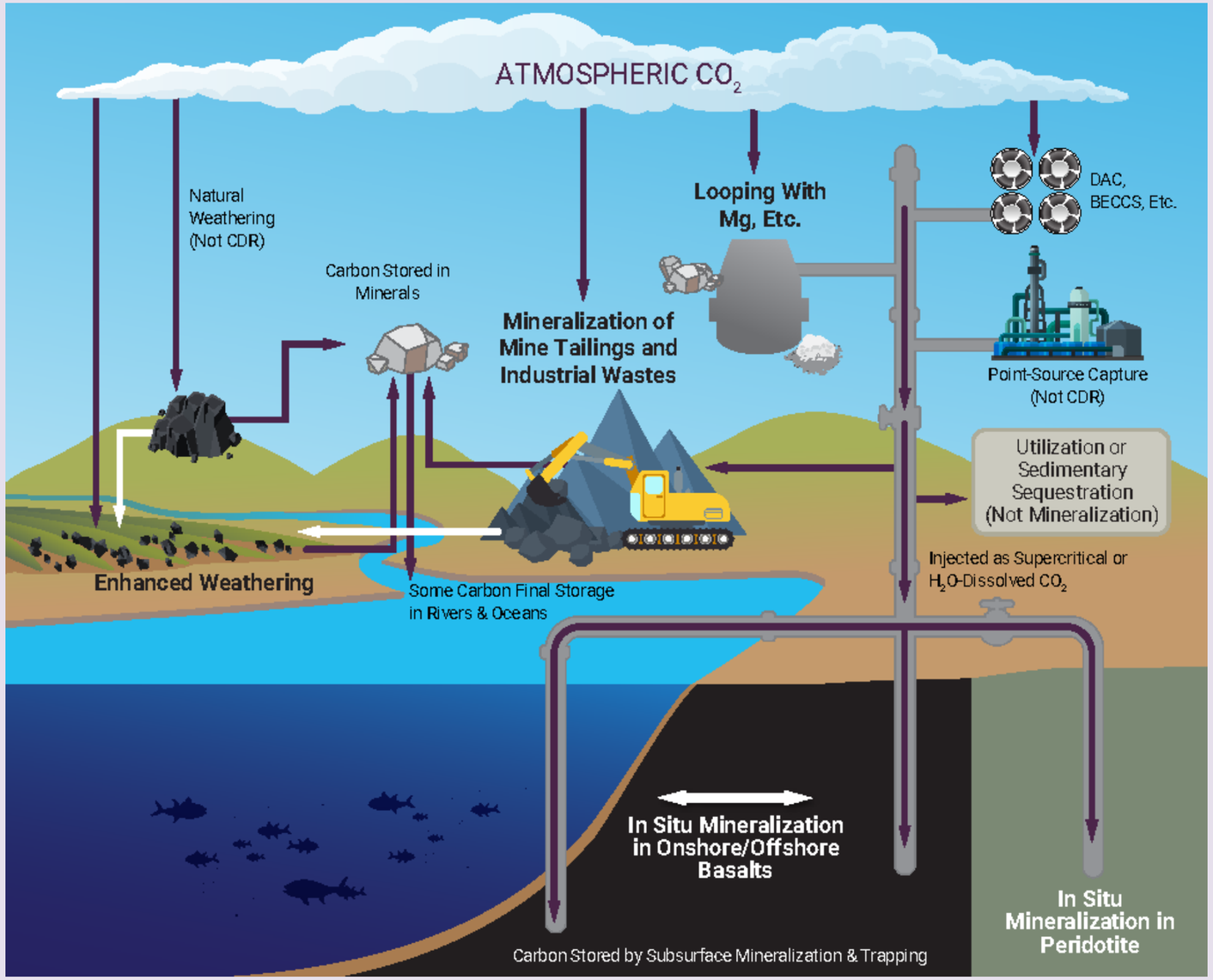
Donald DePaolo, Senior Advisor for Energy Sciences, Lawrence Berkeley National Laboratory
Sasha Wilson, Associate Professor - Faculty of Science, University of Alberta

Technical Workshops and Expert Panel

August 5–6, 2020; 24 participants from diverse agencies, national laboratories, universities, and the minerals and energy industry

Discussion Topics	Presenters and Discussion Leaders
Foundational Science & Technology	Anna Harrison (Queen's Univ.), Katharine Maher (Stanford Univ.), Carl Steefel (LBNL)
Ex situ Mineralization (Mineral Wastes, ERWC in Soils, Oxide Looping)	Emily Chiang (Guelph Univ.), Gregory Dipple (Univ. British Columbia), Anna Harrison (Queen's Univ.), Rachael James (Univ. Southampton), Peter Kelemen (Columbia Univ.), Evelyn Mervine (Anglo American / Univ. Queensland), Ian Power (Trent Univ.), Phil Renforth (Heriot-Watt Univ.)
In situ Mineralization (Basalt on Land and at Sea, Peridotite)	Edda Sif Aradóttir (Carbfix), David Goldberg (Columbia Univ.), Peter Kelemen (Columbia Univ.), Peter McGrail (PNNL), Benjamin Tutolo (Univ. Calgary)
Challenges and Opportunities of Large-Scale Deployment	Sally Benson (Stanford Univ.), Julio Friedmann (Columbia Univ.), George Guthrie (LANL)
LCA, TEA and Regulatory	Sally Benson (Stanford Univ.), Sean McCoy (Univ. Calgary), Jennifer Wilcox (Univ. Pennsylvania)
Governance and Legal	Kevin Doran (Univ. Colorado), Julio Friedmann (Columbia Univ.), Romany Webb (Columbia Univ.)

Pathways for Carbon Mineralization

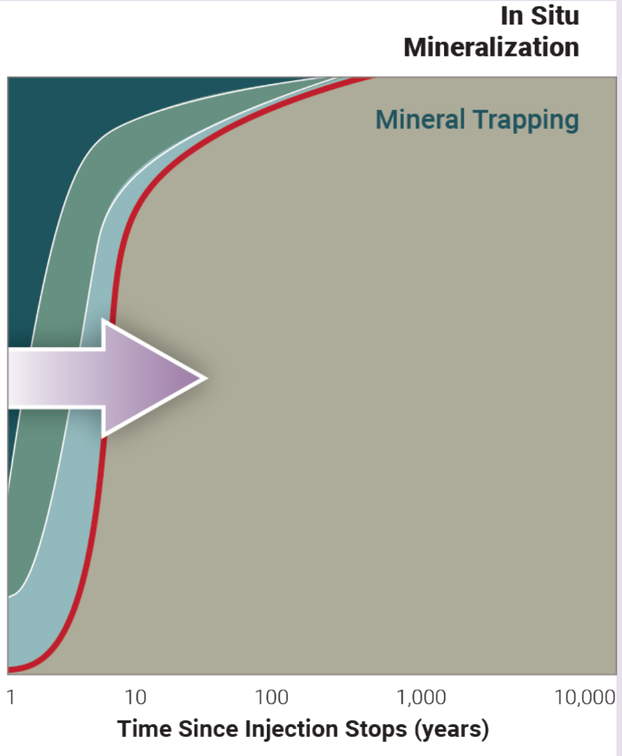


Key Findings

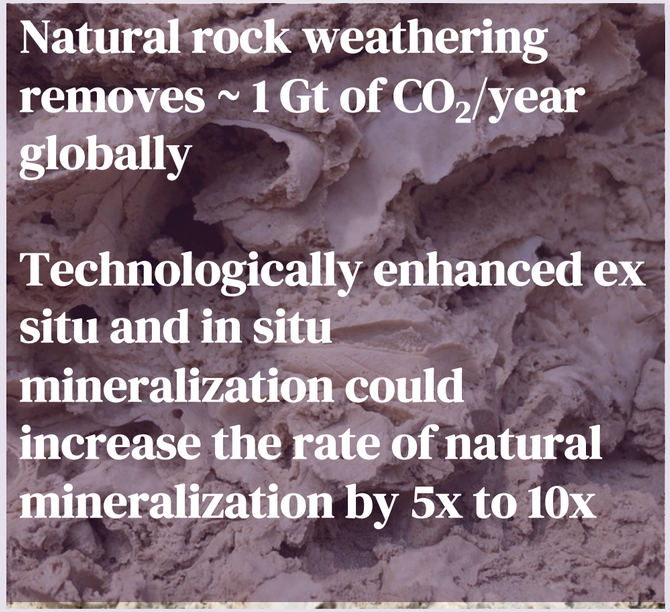
Carbon mineralization provides a pathway to permanent isolation of CO_2 from the environment

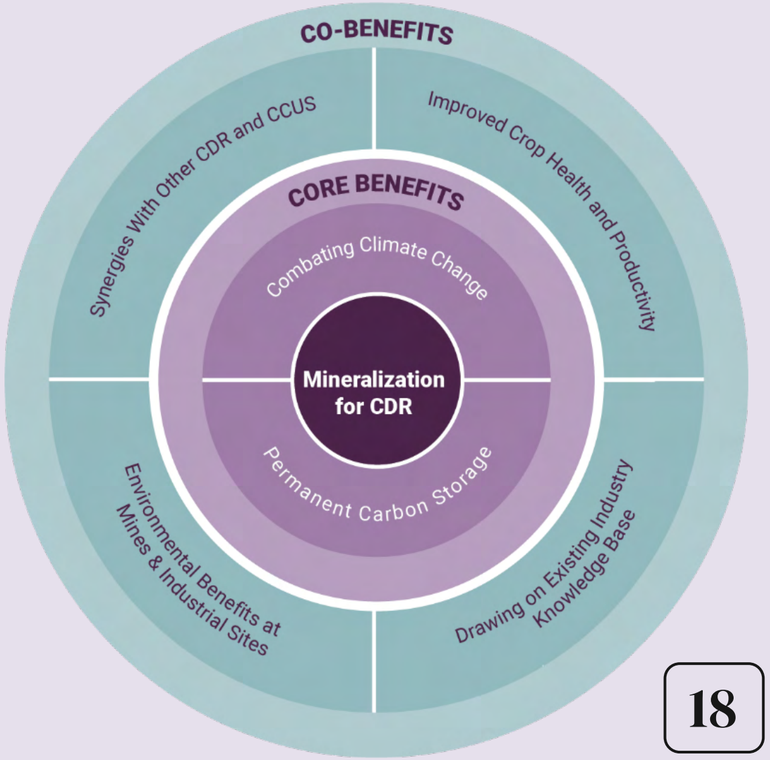
Technological enhancements can expand and accelerate natural carbon mineralization, making it feasible to achieve Gt scale CDR

Carbon mineralization has important co-benefits that enhance its attractiveness



NASEM & Kelemen (2018) after Benson et al. (2005) & Krevor et al. (2015)

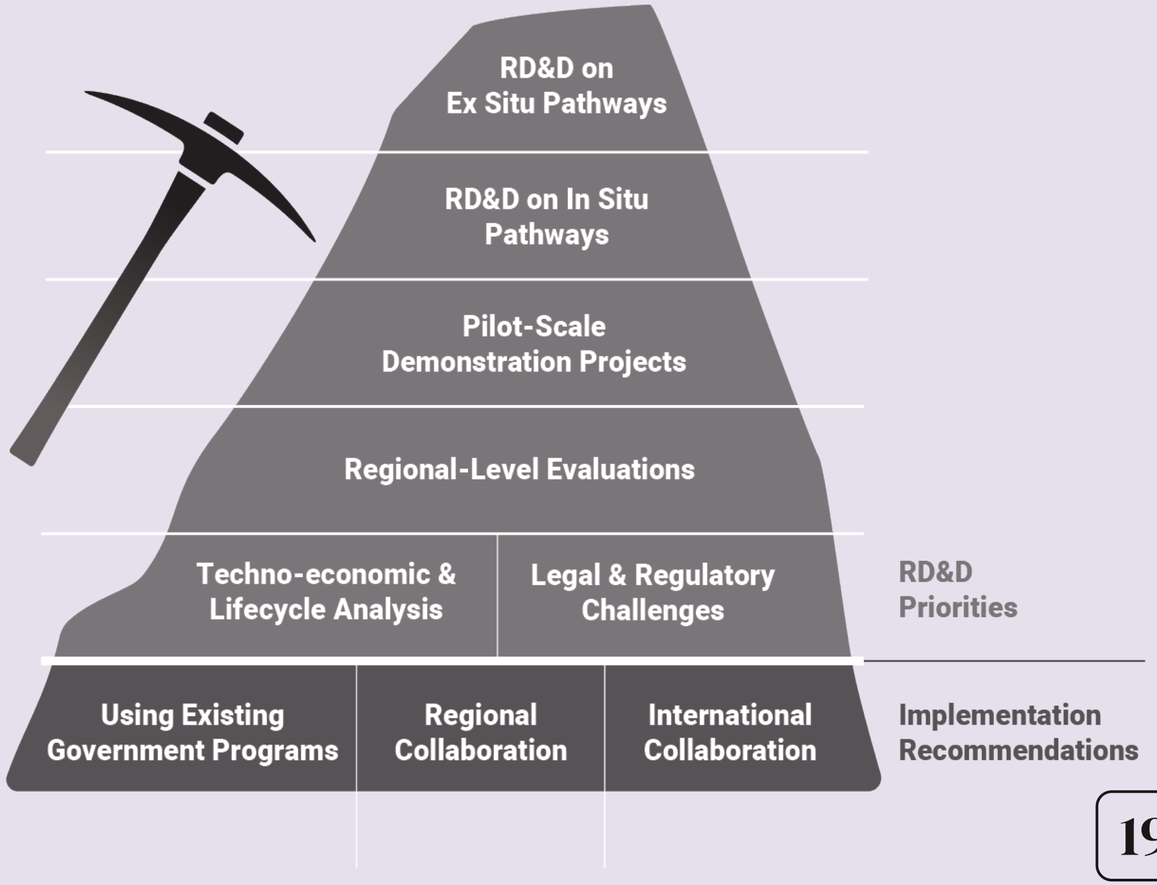




Recommendations

Increased Federal Investment in Carbon Mineralization Research Development and Demonstration (RD&D) should include a portfolio of 5 major mineralization pathways that encompass both ex situ and in situ pathways. Each pathway has potential to reach Gt-scale CDR within a cost range of < \$100/ton of CO_2.

1. Surface (i.e. ex situ) carbonization of mineral wastes from mining and materials processing;
2. Enhanced rock weathering and carbonation in soils on agricultural fields, forest soils, riverbanks, and coastal areas;
3. Surface capture of CO_2 via calcium and magnesium oxide carbonation and subsequent "looping" or recycling of capture materials;
4. Subsurface (i.e. in situ) injection of CO_2 (either as supercritical, liquid-like CO_2 or CO_2 dissolved in water) into mineral formations (basalt and ultramafic rocks); and
5. Hybrid approaches, such as combining direct air capture with subsurface injection.



Recommendations

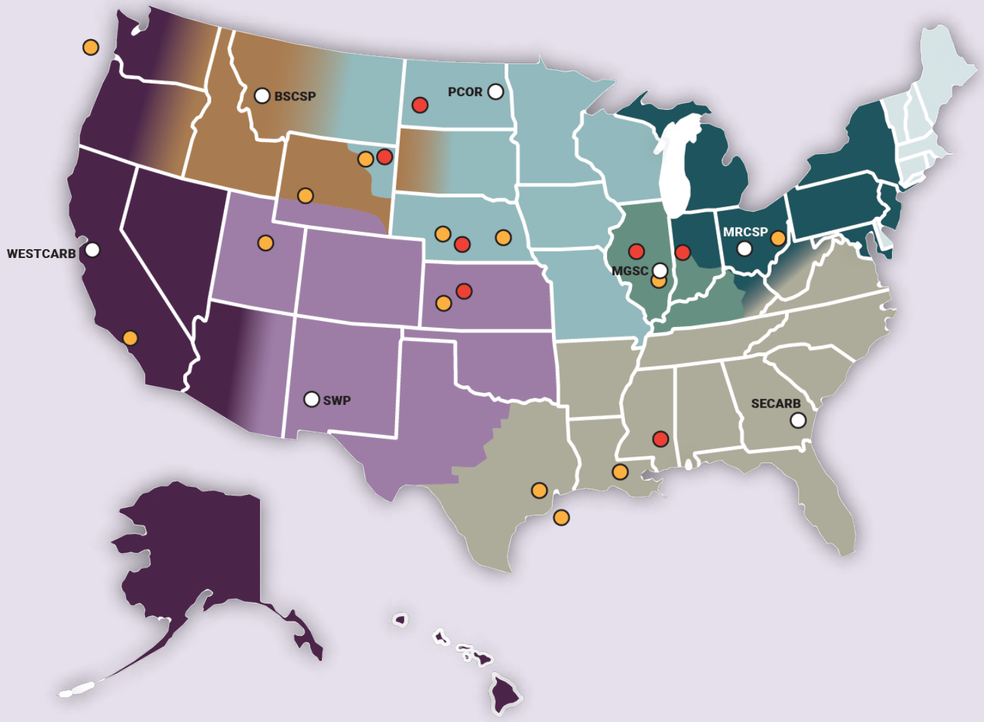
Larger-scale pilot projects: test the technical and economic feasibility of ex situ and in situ carbon mineralization pathways that have shown promising results in small scale experiments.

Regional carbon mineralization testing sites with government-industry-university partnerships: adopt the model from the DOE Regional Carbon Sequestration Partnerships and the CarbonSAFE programs.

Co-benefits of carbon mineralization: Emphasize for example, enhanced soil productivity from use ex situ mineralization; and use of mine tailings and industrial wastes

New methodologies: Techno-economic analysis (TEA), Life cycle assessments (LCA) and Monitoring, Reporting and Verification (MRV) standards to enable large scale deployment

Policy Alignment for Gt-scale deployment: clarification of permitting requirements and eligibility for the 45Q tax credit.



DOE RCSP and CarbonSAFE

Frontiers of CDR

From the Ground Up: Cutting-Edge Approaches for Land-Based Carbon Dioxide Removal

Workshop Co-Leads

Aristides Patrinos, Chief Scientist and Director of Research, NOVIM
Stan Wullschleger, Interim Associate Laboratory Director, Oak Ridge National Laboratory

Technical Workshops and Expert Panel

April 16-17, 2020; 23 participants from diverse agencies, universities, and institutions
Plant Cultivars and Technology-Driven Approaches for Biological CDR
Forestry and Technology-Driven Approaches for Biological CDR

Roger Aines – Lawrence Livermore National Laboratory
David Babson– Advanced Research Project Agency—Energy
Wolfgang Busch – Salk Institute for Biological Studies
Kate Calvin– Pacific Northwest National Laboratory
Joanne Chory – Salk Institute for Biological Studies
Timothy Donahue – University of Wisconsin
Kevin Doran – University of Colorado Boulder
Chris Field– Stanford University
Benjamin Z. Houlton – Cornell University
Rattan Lal – The Ohio State University
Connor Nolan– Stanford University
Keith Paustian – Colorado State University
Jennifer Pett-Ridge – Lawrence Livermore National Laboratory
G. Phillip Robertson – Michigan State University
Patrick S. Schnable – Iowa State University
Whendee Silver – University of California, Berkeley
Anthony M. Stiegler – Salk Institute for Biological Studies
Gerald A. Tuskan – Oak Ridge National Laboratory
Catherine Woteki – Iowa State University

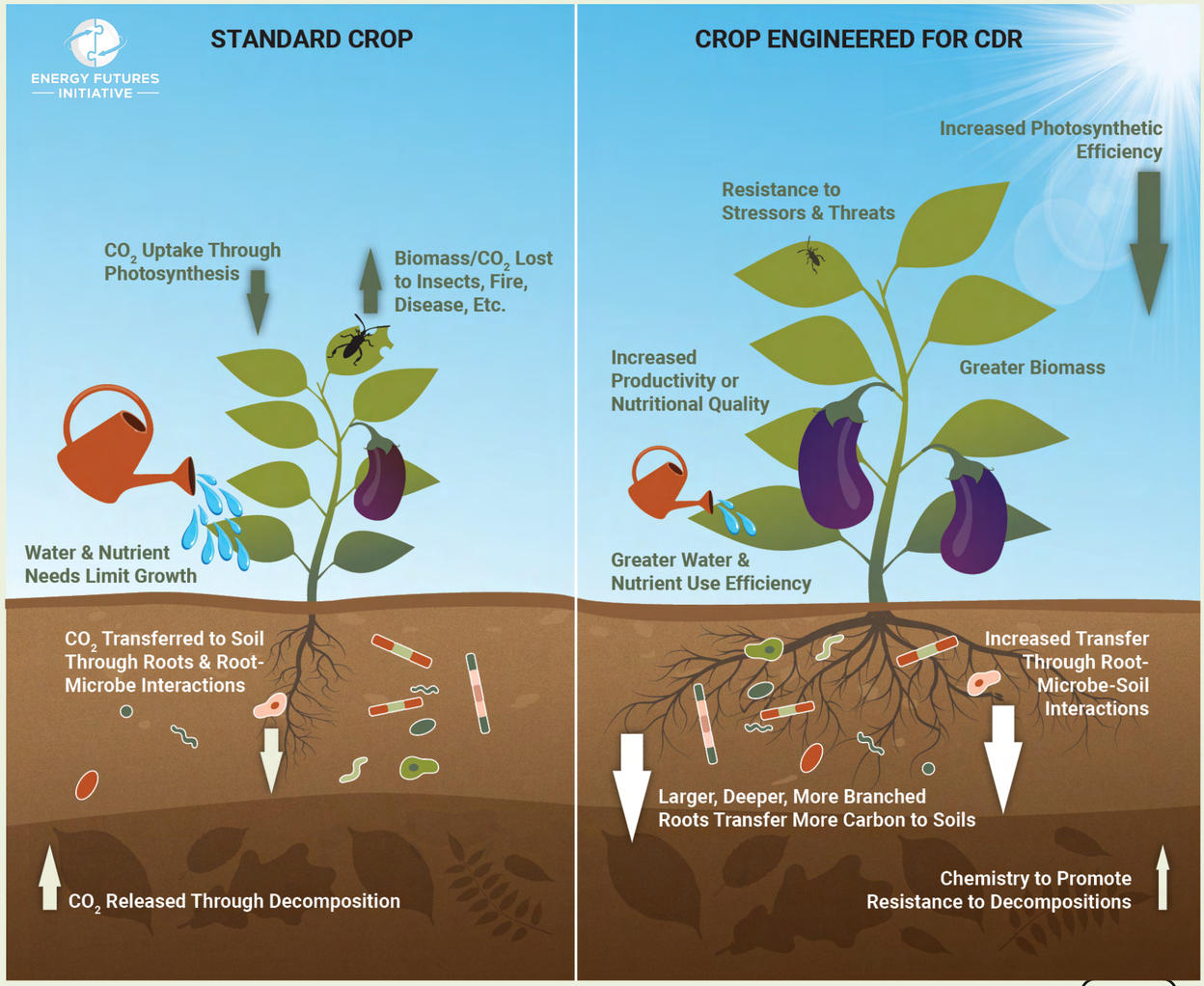
Key Findings

Innovations across several areas of science and technology open the door to new pathways for biological and terrestrial CDR

- Innovations in biotechnology, large-scale data management, and artificial intelligence have the potential to supercharge the amount of CDR from agricultural and forestry lands

Biological and terrestrial CDR portfolio should emphasize soil organic carbon replenishment and storage and development of new strains of plants and trees with greater carbon absorption ability

- R&D is needed on gene identification, targeted trait improvement, and biotechnologies that can accelerate these breakthroughs.



Key Findings

CDR can also produce co-benefits

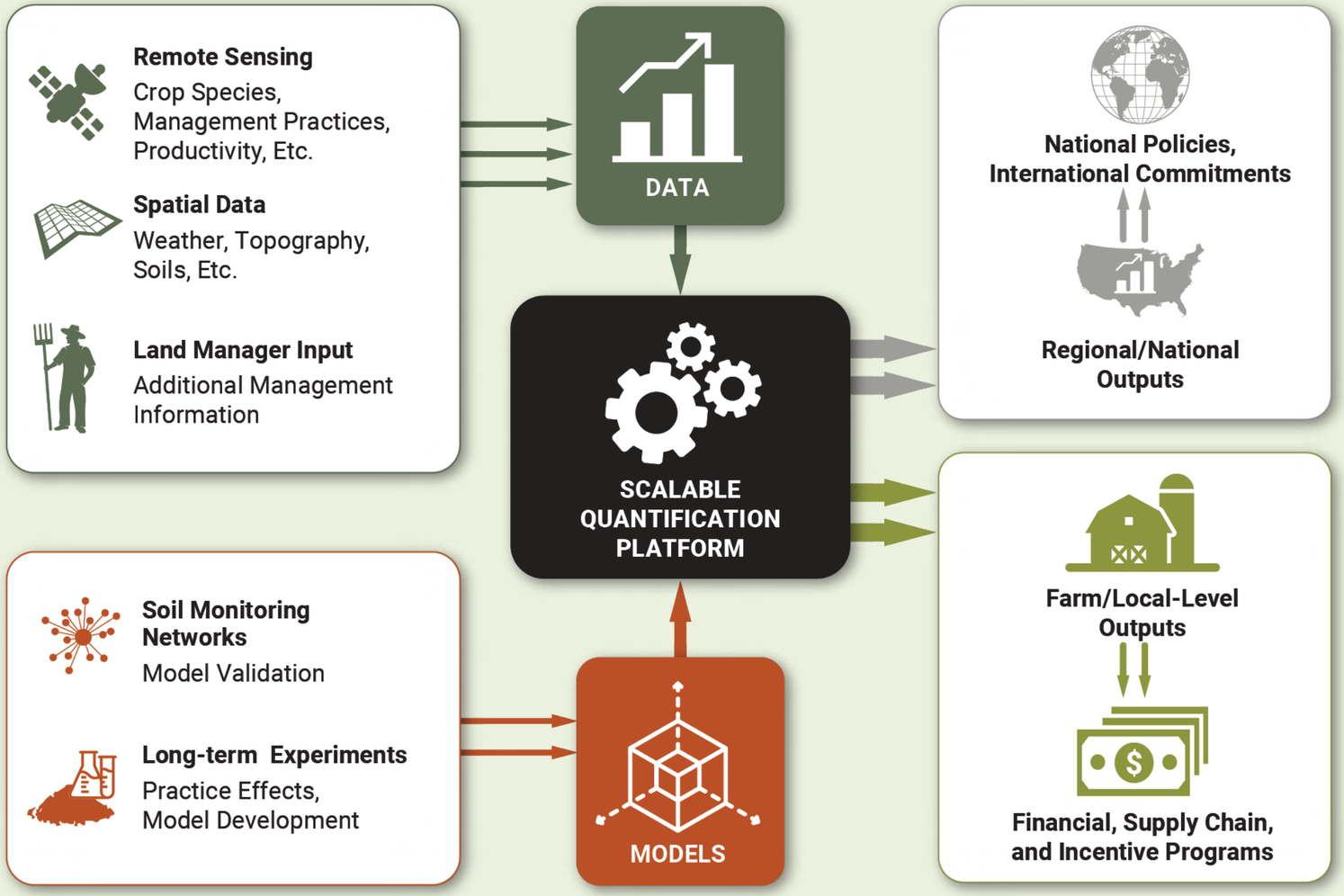
- Biological and terrestrial CDR complements other agriculture objectives such as improved soil health and yields, reduced resource needs, and new revenue streams for farmers.

Biological and terrestrial CDR should proactively address the ethical, legal, and social challenges associated with biotechnology innovation

- Compliance with current federal and international regulations should adequately address these concerns

Key Findings

Policy actions will be needed to address cross-cutting challenges facing soil-based CDR



Modeling and monitoring tools will be crucial to the scale-up of soil-based CDR methods.
Source: EFI, 2020. Adapted from NASEM, 2018.

Conclusions

Scientific advances in biotechnology for terrestrial CDR comparable to clean energy contributions can be achieved in the coming decade.

Significant investments in trait identification and improvement; biotechnology; and scale-up experiments in both agricultural and forestry lands will be necessary.

Substantive multidisciplinary and international collaborations should be pursued.

In the U.S. significant interagency coordination, with USDA in a central role, would accelerate reaching the CDR goals.

Panel Discussion

The Future of CDR in a Biden-Harris Administration

Moderator

Michael Coren
Quartz

Scott Doney
University of Virginia

Lesley Jantarasami
Bipartisan Policy Center

Colin McCormick
Georgetown University

Jennifer Wilcox
University of Pennsylvania

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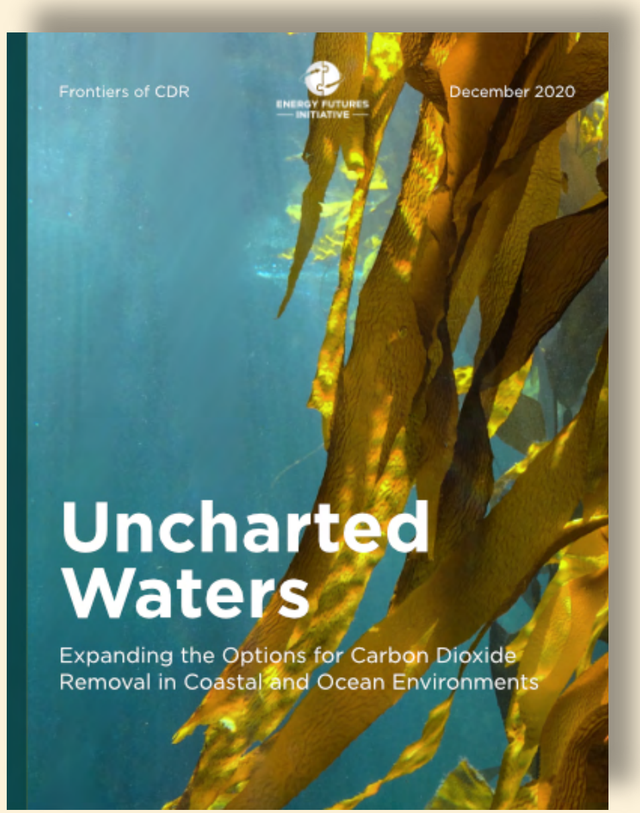

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Thank You!