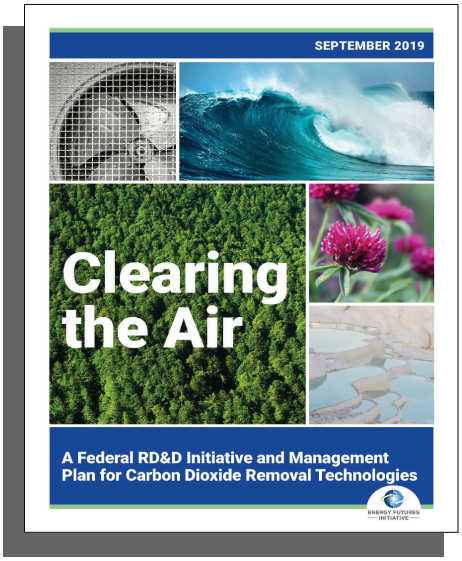
Clearing the Air

"Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies," is a 12-month study of innovative technologies for carbon dioxide removal (CDR).

CDR is a broad set of pathways to a) remove CO_2 that is already in the environment (principally in the atmosphere) and b) store it in soil, plant matter, surface minerals, geological reservoirs, ocean waters, or ocean sediments, or convert it into products or materials that isolate CO_2 from the environment. Specific CDR pathways include natural processes (e.g., planting trees), technologically-enhanced natural processes (e.g., ex situ carbon mineralization), and technological processes (e.g., direct air capture, or DAC).

The report outlines a 10-year RD&D initiative to bring to commercial readiness innovative CDR technologies at gigaton scale, at technology-specific cost targets, with minimal ecological impacts. The report reflects independent analysis by the Energy Futures Initiative and was sponsored by the Linden Trust for Conservation and ClimateWorks Foundation.



Key Takeaways from *Clearing the Air*

- A comprehensive CDR RD&D innovation portfolio is needed to address all major technology pathways (DAC, terrestrial and biological, carbon mineralization, coastal and oceans). It also includes two CO_2 disposition pathways (geologic sequestration, CO_2 utilization) necessary for CO_2 once captured, and two cross-cutting programs (systems analysis, large-scale demonstration projects).
- A 10-year focused RD&D effort is estimated at $10.7 billion, allocated among 10 federal agencies and 27 offices or organizations within those agencies.
- The CDR RD&D initiative will require a whole-of-government effort combining new high-level coordination processes and organizational and management changes at federal agencies.
- CDR will be an essential complement to strategies for reducing future CO_2 emissions as net-zero emissions goals become more widespread. CDR provides optionality and flexibility to compensate for difficult-to-decarbonize sectors and can reduce atmospheric CO_2 concentrations from past emissions.

Why Technological CDR is Essential

As of 2018, two-thirds of the major carbon emitting countries were not on track to meet their Paris targets, and the U.S. is no exception: in 2018, its CO_2 emissions rose 2.7 percent. The Intergovernmental Panel on Climate Change (IPCC) recently highlighted the dramatic differences in impact on the planet's ecosystems between a 1.5°and 2° Centigrade global temperature increase—every tenth of a degree matters—and yet

the U.S. government Fourth Climate Assessment concluded that without significant reductions in emissions, average temperatures could rise by 5 degrees Centigrade by the end of the century.

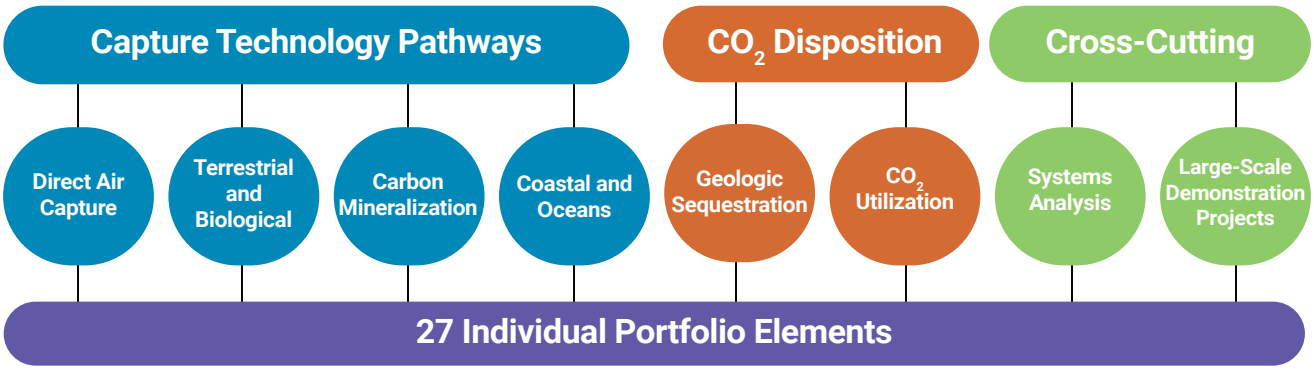
Concerns about the inadequacy of collective efforts, a growing body of scientific evidence, and current emissions trajectories are reflected in the actions of many national and subnational governments to adopt "net-zero" emissions targets by mid-century, defined as "balancing the amount of emitted greenhouse gases with the equivalent emissions that are either offset or sequestered." This calls for technology innovation that goes beyond the scope of conventional mitigation options.

This is where carbon dioxide removal comes in: *achieving global net-zero emissions is simply not credible without major carbon-negative contributions at considerable scale.* It is also a pathway for reducing greenhouse gas concentrations in the atmosphere, and mitigating the impact of past emissions. Investment in CDR is essential.

The National Academies of Science, Engineering, and Medicine reported the potential scale for global CDR deployment needed by mid-century to be 10 $GtCO_2$ per year, and 20 $GtCO_2$ per year by the end of the century. The IPCC projected a cumulative need for CDR of 100 to 1,000 $GtCO_2$ by 2100 to limit warming to 1.5 degrees Centigrade.

Technological CDR RD&D Portfolio

The RD&D portfolio framework is organized according to the four major capture technology pathways (DAC, terrestrial and biological, carbon mineralization, and coastal and oceans), two CO_2 disposition pathways (geologic sequestration and CO_2 utilization), and two cross-cutting programs (systems analysis and large-scale demonstration projects).



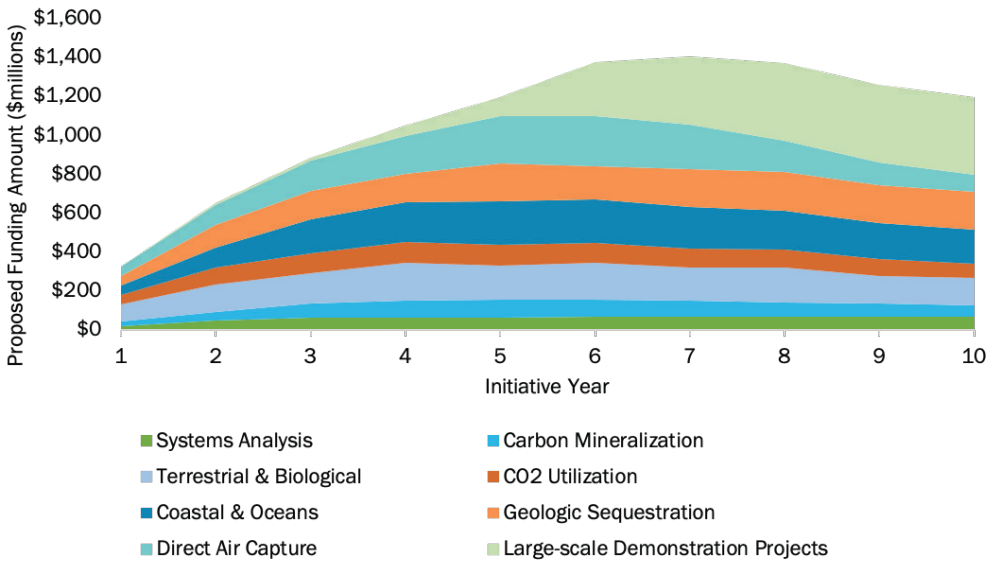
Work performance of the RD&D portfolio would be divided among 10 agencies: the Department of Energy (DOE), the National Science Foundation (NSF), the Department of Agriculture (USDA), the National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) within the Department of Commerce (DOC), the Department of Defense (DOD), the Environmental Protection Agency (EPA), the Department of the Interior (DOI), the Department of Transportation (DOT), and the National Aeronautics and Space Administration (NASA). High-level interagency planning and budget coordination would be provided by the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB).

The participating 10 federal departments and agencies would be funded through six appropriations bills: Agriculture; Commerce, Justice, and Science; Defense; Energy and Water; Interior and Environment; and Transportation, Housing, and Urban Development.

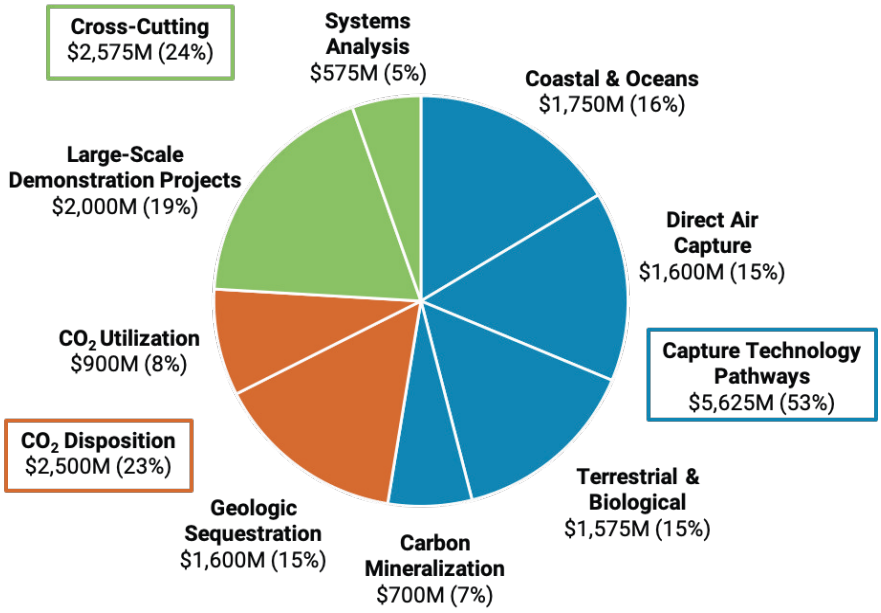
Technological CDR RD&D Budget Planning Estimates

The proposed budget planning estimate is $10.7 billion over 10 years, including the establishment of a single, technology-neutral demonstration fund of $2 billion. The budget supports a robust and balanced portfolio across all CDR and CO_2 disposition pathways plus cross-cutting program elements. At roughly $1B per year, this represents about 15% of the federal energy innovation budget, which in turn has recently been on a trajectory to double over the next decade with bipartisan support. The proposed CDR funding level for the first full year is $325 million.

Technological CDR RD&D Initiative Funding by Year



Technological CDR RD&D Budget Portfolio Totals



Technological CDR RD&D Portfolio Summary

Direct Air Capture (DAC)

Pathway Description: Atmospheric CO_2 can be captured by contacting air with chemical filters that selectively bind the CO_2. The process can then be reversed, releasing CO_2 in concentrated form for ultimate disposition.

RD&D Objective: Reduce the cost and energy use and improve the performance and durability of DAC technologies.

RD&D Portfolio Components: RD&D efforts such as improved sorbent and solvent materials, reduced overall system costs, integrated system development and demonstration, and cost, lifecycle, and environmental analysis.

Proposed Funding: $1,600 million over 10 years

Federal Agencies Involved: DOE, EPA, DOD, NSF, NIST

Terrestrial and Biological

Pathway Description: The natural process of CO_2 absorption in plants and soils can be technologically enhanced through modification of plant genomics, and use of biomass for power generation and fuels conversion with carbon capture and sequestration.

RD&D Objective: Develop new approaches for enhanced carbon uptake in trees, plants, and soils in a manner consistent with advancing traditional food and fiber mission objectives.

RD&D Portfolio Components: RD&D efforts such as the development of cultivars of common crops that store more carbon in the soil, enhanced monitoring for forests and soil carbon measurements, improved bioenergy with carbon capture and sequestration (BECCS) for the production of biofuels and biopower, and implementation of the USDA Agriculture Advanced Research and Development Authority (AGARDA) with a focus on CDR.

Proposed Funding: $1,575 million over 10 years

Federal Agencies Involved: USDA, DOE, NSF, NASA, EPA

Carbon Mineralization

Pathway Description: Natural alkaline rocks and manmade alkaline waste materials absorb CO_2 and convert it to a solid carbonate mineral.

RD&D Objective: Enhance the understanding of the technical feasibility, economics, and scale potential for carbon mineralization as a CDR technology pathway.

RD&D Portfolio Components: RD&D efforts such as expanding support for fundamental research on mineral dissolution and precipitation kinetics, assessing the feasibility of alternative sources of alkaline materials (natural and anthropogenic), implementing in situ and ex situ experiments with various locations and materials, and conducting in-depth assessments of environmental impacts, costs, and scalability.

Proposed Funding: $700 million over 10 years

Federal Agencies Involved: DOE, NSF, DOI, EPA

Coastal and Oceans

Pathway Description: Oceans can absorb more CO_2 and convert it to a stable form through enhancements to costal ecosystems and increased phytoplankton growth from artificial fertilization. Dissolved CO_2 can be directly captured or neutralized.

RD&D Objective: Develop a better understanding of the effectiveness and ecosystem impacts of carbon removal processes in coastal areas and deep ocean waters to provide the basis for determining feasibility of future CDR implementation measures.

RD&D Portfolio Components: RD&D efforts such as incorporating CDR measures into existing coastal restoration programs, performing fundamental research on ocean alkalinity enhancement, electrochemical carbon capture, aquatic BECCS, and creating improved models of ocean-atmosphere greenhouse gas (GHG) coupling.

Proposed Funding: $1,750 million over 10 years

Federal Agencies Involved: NOAA, NSF, DOD, DOE, NASA

Geologic Sequestration

Pathway Description: Captured CO_2 can be liquified and injected deep into subsurface geologic formations such as non-potable saline aquifers.

RD&D Objective: Determine the potential for large-scale (at or near gigaton-scale) geologic sequestration as a permanent storage option for captured carbon.

RD&D Portfolio Components: RD&D efforts such as enhancing and accelerating current DOE Carbon Storage Assurance Facility Enterprise (CarbonSAFE) site characterizations, initiating six to eight regional geologic sequestration demonstrations, conducting one or more experiments at CO_2 enhanced oil recovery sites to co-optimize CO_2 sequestration with oil recovery, and supporting research on advanced sub-surface monitoring technologies.

Proposed Funding: $1,600 million over 10 years

Federal Agencies Involved: DOE

CO_2 Utilization

Pathway Description: Captured CO_2 can be converted into chemicals, fuels, or other carbon-based products through a chemical, biological, or mineralization conversion process.

RD&D Objective: Accelerate development of innovative carbon conversion processes and new carbon-based materials through carbon mineralization and chemical and biological conversion.

RD&D Portfolio Components: RD&D efforts such as fundamental research on carbon mineralization, materials and processes, catalyst and new materials development for chemical conversion, and bioprospecting.

Proposed Funding: $900 million over 10 years

Federal Agencies Involved: DOE, NSF, USDA, DOT, DOI, NIST

Technological CDR RD&D Program Organization and Management

Interagency Coordination: The proposed initiative would be governed by a new entity, the Committee on Large-Scale Carbon Management, to be established within the National Science and Technology Council (NSTC). Co-chaired by OSTP, DOE, USDA, and NOAA, the Committee would be responsible for:

- Developing the CDR RD&D strategic plans and detailed roadmaps;
- Identifying promising CDR technologies for large-scale demonstration;
- Coordinating budget planning with the agencies and budget review with OMB;
- Overseeing independent evaluations of program performance; and
- Providing an annual report to Congress and the public.

Agency Actions: DOE, USDA, and NOAA are proposed as the leading federal agencies in this initiative.

- DOE should establish an interim organization for Large-Scale Carbon Management within the Office of Fossil Energy, headed by a new Deputy Assistant Secretary selected on the basis of scientific qualifications appointed for a term basis. Longer term, Congress should re-establish the Office of Under Secretary for Science and Energy, which would provide a more appropriate longer-term organizational home for the CDR initiative.

- NOAA should incorporate CDR within the NOAA Research and Development Plan and establish a new Office of Ocean Technologies within the Office of Oceanic and Atmospheric Research, headed by the Chief Scientist.

- USDA should incorporate CDR as a new strategic element within the Department's research focus, incorporate CDR in appropriate existing research programs across the Department, and designate the Under Secretary for Research, Education, and Economics as the lead coordinator for all CDR-related research activities. USDA also should stand up the newly authorized AGARDA with CDR as a high priority.

International Collaboration: Climate change is a global challenge, and the scale of CDR needed to meet that challenge is more than one country can feasibly address within its own borders.

- The U.S. should organize an international dialogue on technological CDR RD&D under the auspices of the InterAcademy Partnership (IAP).
- The U.S. should also seek to include CDR as the ninth Innovation Challenge area within the Mission Innovation (MI) framework.

About the Energy Futures Initiative

The Energy Futures Initiative (EFI) was established by Ernest J. Moniz, the 13th U.S. Energy Secretary, to provide policymakers, industry executives, NGOs, and other leaders options on how to advance a cleaner, safer, more affordable, and secure energy future. EFI is committed to objective analysis-based reports on important energy issues to inform policymakers, regulators, and others engaged in debates on public policy. Consistent with the prior practice of the principals, EFI seeks multi-source funding, including from relevant industries, for its analytical products. Once a study is initiated, the work and results are EFI's; they are in no way vetted or approved by any sponsor, public or private. All EFI analysis is published and publicly available on our website at: www.energyfuturesinitiative.org.

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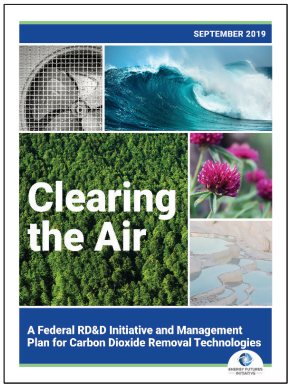
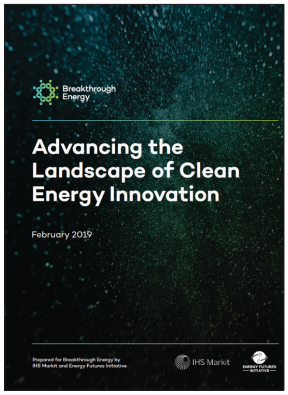
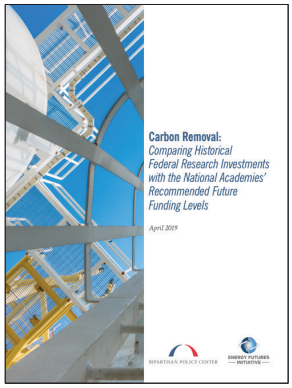
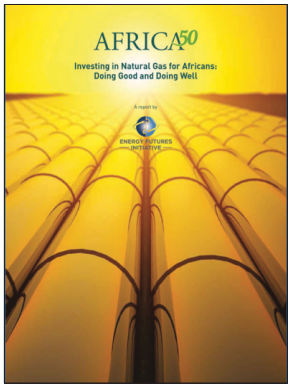
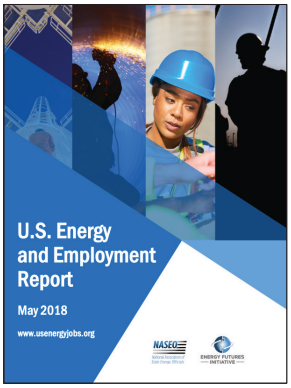
Leading the way to a low-carbon future











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