ENERGY FUTURES INITIATIVE

Statement for the Record

The Honorable Ernest J. Moniz
13th Secretary of Energy

Before the
Senate Energy and Natural Resources Committee
July 28, 2020

Madam Chairman, Ranking Member Manchin and Members of the Committee:

I am pleased to have the opportunity to discuss with you today the issue of carbon dioxide removal (CDR), its role needed in addressing climate change, and the federal investment in Research, Development and Demonstration (RD&D) needed to enable deployment of CDR on a material scale.

My statement today will focus on three major areas, and in summary, makes the following points:

1. As noted in the recent report of the House Select Committee on the Climate Crisis, the world needs to move to a goal of net zero Greenhouse gas (GHG) emissions no later than mid-century and net-negative thereafter. The word "net" is critical. Significant contributions from CDR will be necessary to complement, and not replace, reductions in greenhouse gas emissions needed to meet science-based climate goals;
2. The U.S. will require large scale carbon management solutions -- reaching gigaton scale – involving both carbon capture utilization and storage (CCUS) to mitigate current carbon emissions, and CDR to remove carbon previously emitted into the environment; and
3. Further innovation is required to advance all pathways for CDR. This will require a major, multi-year, multi-agency federal RD&D initiative to deliver the portfolio of CDR technological solutions that will be needed. The initiative needs to be goal-oriented, all-of-government, and efficiently and effectively implemented.

Much of this statement draws from the 2019 CDR study and report by the Energy Futures Initiative (EFI). That report, *Clearing the Air*, provided recommendations and detailed implementation plans for a comprehensive, 10-year, $10.7 billion RD&D initiative to bring new pathways for technological CDR to commercial readiness. I am pleased to see that the report contributed to increasing Congressional awareness and action on this issue, beginning with dedicated RD&D funding for CDR in the FY 2020 (and hopefully FY 2021) DOE appropriations, recognition of the importance of CDR in the recent report of the

House Select Committee on the Climate Crisis and various legislative proposals in process in both Houses of Congress.

The EFI Report presented a CDR RD&D initiative encompassing a broad range of technological pathways and technologically-enhanced natural processes that can remove CO_2 from the environment including direct air capture (DAC); technologically-enhanced carbon uptake in trees, plants, and soils; capture and isolation of CO_2 in coastal and deep ocean waters; and carbon mineralization in surface and subsurface rock formations. Geologic sequestration and CO_2 utilization are essential elements of the CDR RD&D initiative, providing CO_2 disposition options for DAC and bioenergy with carbon capture and sequestration (BECCS) pathways.

The Report found that the wide range of scientific challenges required a whole-of-government approach that reaches the mission responsibilities and research expertise of 12 federal departments and agencies, with the Department of Energy (DOE), Department of Agriculture (USDA), and the National Oceanic and Atmospheric Administration (NOAA) playing key roles. The planning, budgeting, execution, and performance aspects of the CDR RD&D initiative will require effective coordination led by the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB). At an international level, there are opportunities to collaborate with similar efforts in other countries under an expanded Mission Innovation (MI) initiative, which was launched at the 21st Conference of the Parties (COP21) in 2015.

To provide context for a more detailed discussion of the findings and recommendations in the report, I would first like to frame the discussion of why CDR is essential.

I. The Imperative for Carbon Dioxide Removal

Carbon is the fourth most abundant element on earth, and the natural carbon cycle is well known. Carbon dioxide emissions from the burning of fossil fuels, as well as anthropogenic emissions of other GHGs, has adversely altered the natural carbon cycle. The absorption of anthropogenic CO_2 in the oceans to date has led to ocean acidification with attendant adverse impacts on marine resources. The absorption of anthropogenic CO_2 in terrestrial—or land-based—systems has been relatively more benign and there have been efforts to expand terrestrial absorption by expanded tree planting for example.

A. The Adverse Climate Impacts from Anthropogenic GHG Emissions Are Increasingly Clear

Atmospheric CO_2 concentrations have been increasing at a rate of 2-3 parts per million (ppm) per year,[1] with a commensurate rate of warming of 0.2°C per decade. Consequently, the planet is currently on course to an average temperature increase of 1.5°C by as early as 2030, a level determined by the

Intergovernmental Panel on Climate Change (IPCC) to be a threshold for a range of risks to natural and human systems.[2]

The adverse climate impacts resulting from elevated atmospheric CO_2 concentrations and associated temperature increases, as well as elevated dissolved CO_2 in oceans, have already been observed and are increasingly clear. Over the past several years, the impact of extreme weather across the world, such as floods, hurricanes, and droughts of significant intensity and/or frequency, have underscored both the ferocity and costs of a changing climate and it is therefore un-surprising that support for action on climate change is growing with an increasing sense of urgency.

In 2019 record temperatures were seen in Paris (108.7°F), London (101°F), and Anchorage (90°F). In June 2020 Eastern Siberia registered its highest daytime temperature of 38°C (100.4°F) which, if verified, will be the highest temperature on record in the Arctic.[3] The recent wildfires in California offer another case in point: 12 of the state's 15 largest wildfires have occurred since 2000 and estimated costs of a single fire—the 2018 Camp Fire—are as high as $16.5 billion.[4] A major utility providing electricity and natural gas services, PG&E, was driven to bankruptcy. Climate change is increasingly recognized as a factor in the dislocation of significant populations in the developing world, especially in areas of strife, contributing to major geopolitical and humanitarian challenges. While Earth has seen major climate variation over its history, the pace of change today is well beyond that attributable to natural phenomena and is driven by human activity, especially from energy. These trends are consistent with decades of forecasts and predictions.

B. Efforts to Reduce Anthropogenic GHG Emissions Increasingly Focused on an Endpoint of Net Zero Emissions

In 2015, the U.N. Conference of the Parties (COP21) crafted the Paris Agreement, where some 195 countries agreed to take action to limit the rise in global average surface temperature to no more than 2°C above pre-industrial levels, with further ambition to limit warming to no more than 1.5°C.[5]

At the heart of the Paris Agreement are the Nationally Determined Contributions (NDCs), commitments by all Parties to "strive to formulate and communicate long-term low greenhouse gas emission development strategies". Unfortunately, the 186 countries that have registered NDC's are estimated to address only one-third of the needed emissions reductions for a least-cost pathway to stay below 2°C.[6]

In the U.S., CO_2 emissions from fossil fuel combustion in 2018 rose by 2.7 percent while economywide emissions likely increased by 1.5 to 2.5 percent. The next year, 2019, did see a return to decreased emissions from the 2018 level, but CO_2

emitted to the atmosphere has a cumulative effect, so atmospheric concentrations continued to increase. The COVID-19 induced economic downturn has led to a significant emissions reduction thus far in 2020, but the concern is that emissions will snap back dramatically once economic activity recovers, as was the case after the 2008-2009 Great Recession.

Even with the challenges of meeting the Paris Agreement 2°C target, a number of countries are urging commitment to the more stringent target of 1.5°C. The reasons for the revised target are compelling. According to the special report by the Intergovernmental Panel on Climate Change (IPCC) published only three years after COP21, "limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans" while a 2°C rise would bring with it greater increases in frequency and intensity of heavy precipitation in several regions along with an increase in intensity or frequency of droughts in others. [7]

Equally concerning, the U.S. Fourth National Climate Assessment released in 2019 noted that, "Without significant reductions, annual average global temperatures could increase by 5°C or more by the end of this century compared to preindustrial temperatures."[8] The report found that "Climate change creates new risks and exacerbates existing vulnerabilities in communities across the United States, presenting growing challenges to human health and safety, quality of life, and the rate of economic growth" and that "Without substantial and sustained global mitigation and regional adaptation efforts, climate change is expected to cause growing losses to American infrastructure and property and impede the rate of economic growth over this century."

Momentum has increased toward strengthening and accelerating the global emissions reduction target. Many economies have now shifted their focus toward the establishment of net-zero emissions targets by mid-century.[9] As of June 2020, 20 countries and regions have committed to net-zero emissions economywide or in their power sectors by the middle or end of the century. Of these 20 countries and regions, 12 have committed to net-zero for all GHGs by mid-century. In the U.S., 10 states and 25 cities—representing about 35 percent of the U.S. population—have adopted net-zero emissions targets (either economywide or electricity sector specific) by mid-century.

In 2020, there is growing consensus among scientists, policy makers and citizens that addressing climate change is now an urgent issue, and the reasons are clear. However, failure to take into account the practical aspects of economic and social need will produce political head winds for tackling the climate challenge. Former President Obama made this point in October 2016 during a White House South Lawn Panel Discussion on Climate Change moderated by Leonardo Di Caprio:

"…we're going to have to straddle between the world as it is and the world as we want it to be, and build that bridge…because we're actually recognizing that some people have some real concerns about what this transition is going to do to them…"

C. Carbon Dioxide Removal is Necessary to Meet Net-Zero and Net-Negative Emissions Targets

The IPCC has reported that the ability to stay below 2°C would require a 25 percent decrease in CO_2 emissions by 2030 and achievement of net-zero emissions by 2070. Staying below 1.5°C requires significantly more ambition: 45 percent decrease in CO_2 emissions by 2030 and net-zero by 2050. The report also noted that, in addition to mitigation efforts, carbon dioxide removal (CDR) on the scale of 100 to 1,000 gigatons (Gt) of CO_2 (cumulative) by 2100 would be needed to limit any potential temperature overshoot above 1.5°C and also help compensate for residual emissions that may be too difficult or expensive to eliminate from the economy within the necessary timeframe.[10]

Meeting the target of net-zero emissions by mid-century, and net negative emissions thereafter, will require pragmatism. We face complex multi-dimensional social, technical, and economic challenges along the way and there are no silver bullet solutions. We cannot effect accelerated sustainable change of our massive energy systems without doing the hard work of building broad coalitions. Labor and business; NGOs and financial institutions; religious and military leaders; public and private sectors; and political leaders of all persuasions will need to work together towards a common end. Sustainable major societal changes in democratic countries have always required such broad coalitions. There are no short cuts.

We also need to recognize that the energy needs and challenges vary considerably by region, and clean energy solutions will need to take account of those regional differences, with social justice a key consideration. Insistence on "one-size-fits-all" solutions for all regions are a detriment to practical coalition building.

In the transition to net-zero we need a wide range of measures that will include energy efficiency across all economic sectors. Advanced renewables, such as offshore wind and advanced biofuels, will be essential. Electricity storage will help balance the system but cannot yet complete it; we need practical affordable storage not just for minutes and hours, but also for weeks, months and seasons. Energy security at the national and regional level will necessitate the development of secure supply chains, including for critical minerals and metals needed at much greater scale for expanded deployment of clean energy technologies.

Achieving net zero emissions by solely relying upon complete elimination of carbon from our energy systems likely will not be viable in the timeframes needed to address climate change. We also must develop the tools for large scale carbon management – CCUS and CDR. Negative-carbon technologies will also make possible, in the long term, a reversal of ever-increasing GHG concentrations in the atmosphere, thereby reducing the impact of past actions. CDR can thus compensate for residual emissions in difficult-to-decarbonize sectors like aviation that may be too difficult or expensive to eliminate from the economy, as well as address the problem of historical emissions created by the lack of past action on climate change. Removing CO_2 that previously was emitted to the atmosphere could assist in lowering CO_2 concentrations and help stabilize the climate at safer levels.

II. Large Scale Carbon Management—at Gigaton Scale—with CCUS and CDR

Large scale carbon management encompasses both the capture of carbon emissions from fossil fuel combustion as well as the direct removal of carbon already in the environment as a result of historical emissions. Carbon capture, utilization, and sequestration (CCUS) for both electricity and industrial facilities can be a major enabler of deep decarbonization; it also can foster large scale conversion of methane to hydrogen for cross-sectoral market applications. CDR from the atmosphere and upper ocean, employing a range of natural, technological and hybrid solutions, will enable net-zero and eventually net-negative emissions.

A. Scaling of CCUS Is Underway

Regarding CCUS, the International Energy Agency (IEA) reports that "substantial progress has been made in advancing carbon capture, utilization and storage (CCUS) around the world, but current trends still fall well short of what would be needed to meet global sustainable energy goals."[11] The IEA notes that, as of December 2019, CCUS facilities around the world are capturing more than 35 million tonnes of CO2 per year, equivalent to the annual CO2 emissions of Ireland and that recently announced commitments "have the potential to more than double current global CO2 capture capacity." But the IEA's report also calls for a 20-fold increase in annual CO2 capture rates from power and industrial facilities in the next decade in support of climate goals. The IEA analysis underscores the view that international and sector partnerships and coalitions will be critical to achieving these goals.

B. CDR at Scale Also is Essential

CDR approaches also require significant scaling in order to have a material contribution to a goal of net zero emissions. The 2018 National Academies of

Sciences, Engineering, and Medicine (NASEM) report, *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda,* estimated the need for CDR at a scale of approximately 10 $GtCO_2$ per year globally by mid-century and 20 $GtCO_2$ per year globally by 2100 to achieve climate goals while accounting for economic growth.

C. Establishing New Large-Scale Carbon Management Industries

Scaling of both CCUS and CDR to the levels needed to achieve net zero emissions will ultimately require the creation of large new carbon management industries as well as the development of substantial geologic storage capacity. The challenges are not insignificant, but the rewards will be substantial in terms of savings to the economy and creation of new jobs.

Capturing carbon from the environment at gigatonne scale, through CCUS and CDR, would require the creation of new industries comparable in size to the steel, concrete, and petroleum industries of today.[12] For example, 1 $GtCO_2$, when liquefied during subsurface sequestration, is nearly 9 billion barrels of supercritical CO_2, equivalent to twice the current annual U.S. domestic oil production. It is worth noting in the context of material scale that three of the major economic sectors in the United States emitted CO_2 at or near the gigaton scale through fossil fuel combustion in 2017: transportation (1.8 $GtCO_2$); electricity (1.7 $GtCO_2$); and industry (0.8 $GtCO_2$).[13] Therefore, an important feature of any comprehensive effort to develop and deploy CCUS and CDR pathways at material scale will be a strategic view of how to incentivize industries to actively support and adopt CDR into their business practices.

D. Scaling Geologic Sequestration Capacity to Support Large Scale Carbon Management

Sequestering CO_2 at the gigatonne scale also will require rapid development of geologic sequestration capacity. Fortunately, the U.S. has extensive geologic sequestration resource capacity and the technology for sequestration can be readily adapted from the experience of oil and gas production. Estimates of U.S. carbon storage potential range from 2,000 to 15,000 $GtCO_2$, with the vast majority in saline aquifers.[14] Other countries do not appear to have as abundant storage capacity: China, for instance, is estimated to only have storage space for roughly 140 $GtCO_2$ in its saline aquifers.[15] Several areas of the U.S. contain suitable geological formations, with ideal locations located on both sides of the Rocky Mountains, the Midwest, the Gulf Coast, and offshore of both the East and West Coasts. Development of an extensive CO_2 pipeline system would be necessary to connect other areas of the country to geologic storage operations.

The pathway identified by the IPCC to limit temperature changes under 1.5°C by the end of the century foresees a gradual shift in emissions from 40 $GtCO_2$–equivalent per year today to *negative* 20 $GtCO_2$ per year by the end of the century.[16] To put that in perspective, ***if the U.S. deployed 20 $GtCO_2$ CDR today, it*** *could meet the entire planet's end-of-century sequestration needs every year for the next century, with room to spare.*

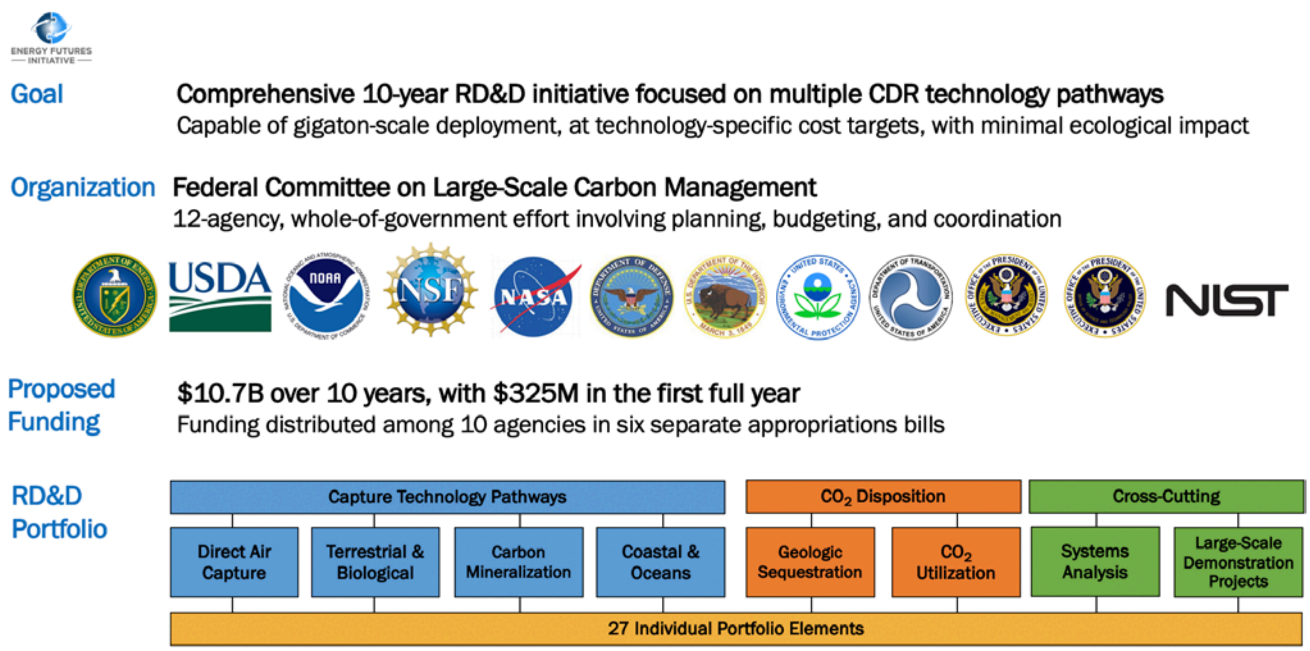
While the geologic capacity is available and the technology is known, there are economic and social challenges. The costs of drilling, compressing, injecting, and monitoring are estimated to be in the range of $20-25 per ton of CO_2.[17] When adding the cost of carbon capture, the total cost makes it difficult to break even with the current $50/ton 45Q tax credit for geologic sequestration, which itself is further complicated by time limitations on the credit. There could also be non-technical societal issues that would need to be resolved for Gigatonne scale U.S. sequestration. Consequently, many of the initial CCUS projects have focused on utilization of CO_2 for enhanced oil recovery, where the utilization sites were well established and the cost was offset from the value added from incremental crude oil production

III. The Proposed CDR RD&D Initiative

In 2019, the Energy Futures Initiative (EFI) published a major assessment of the need for, and design of a government-wide CDR RD&D initiative. The assessment drew heavily from a series of emerging reports on CDR, beginning with a 2016 Report by the Secretary of Energy Advisory Board and a 2018 Report by the National Academies of Science, Engineering and Medicine (NASEM). The EFI Report, *Clearing the Air*, led by EFI principal Joseph Hezir, provided recommendations and detailed implementation plans for a comprehensive, 10-year, $10.7 billion RD&D initiative to bring new pathways for technological CDR to commercial readiness (Figure 1).

Figure 1

Overview of CDR RD&D Initiative



The CDR RD&D initiative is proposed to span 10 years and involve multi-agency collaboration and coordination.
Source: EFI, 2019.

A. Strategic Framework for the Technological CDR RD&D Initiative

The proposed technological CDR RD&D initiative is both goal-focused and time-focused.

The ***overarching goal*** of the CDR RD&D initiative is to provide policymakers a suite of technological CDR approaches that can safely augment the natural carbon cycle to complement mitigation efforts and reduce atmospheric CO_2 concentrations.

The ***strategy*** to achieve this overarching goal is to implement a comprehensive 10-year CDR RD&D initiative that will demonstrate the commercial readiness of multiple technological and technologically enhanced CDR pathways that can be deployed at or near gigaton scale.

The ***strategic elements*** necessary to enable successful achievement of the goal are summarized in Box 1. Several of these elements—the scope of technology options, the span of innovation support, cost targets, and deployment scale—merit further elaboration.

Box 1

Strategic Elements of the Carbon Dioxide Removal RD&D Initiative

- An effectively coordinated "whole-of-government" approach in addressing and coordinating CDR research needs;
- Incorporation of CDR into the strategic research mission objectives of the participating federal departments and agencies in a manner that creates synergy and complementarity with other national goals that can garner broad acceptance and be readily translated into specific projects with measurable progress and outcomes;
- A comprehensive and robust portfolio that:
  1.) Reflects the full range of potential CDR pathways;
  2.) Spans the full innovation spectrum from fundamental research to demonstration at scale;
  3.) Addresses near-, mid-, and longer-term research opportunities; and
  4.) Incorporates regional variation among technological CDR approaches.
- Clearly defined technology-specific cost objectives and commercial application potential;
- Carefully defined research protocols to fully address and promote collateral environmental and resource benefits and minimize any adverse environmental impacts;
- A logical and transparent initiative structure, with clearly defined management roles and responsibilities, and supporting budget plans, that can garner broad-based acceptance and be readily translated into specific projects with measurable progress and outcomes;
- Engagement with the international scientific community to accelerate the pace of RD&D progress and promote the application of CDR technologies on a global scale;
- A budget planning process reflecting the long-term nature of research projects, interagency coordination needs, and specific budget line item allocations;
- Effective and efficient utilization of the nation's technology innovation infrastructure; and
- Disciplined program management and accountability, including stage-gated processes and independent evaluations of program performance, with sufficient flexibility to change course when informed by research outcomes.

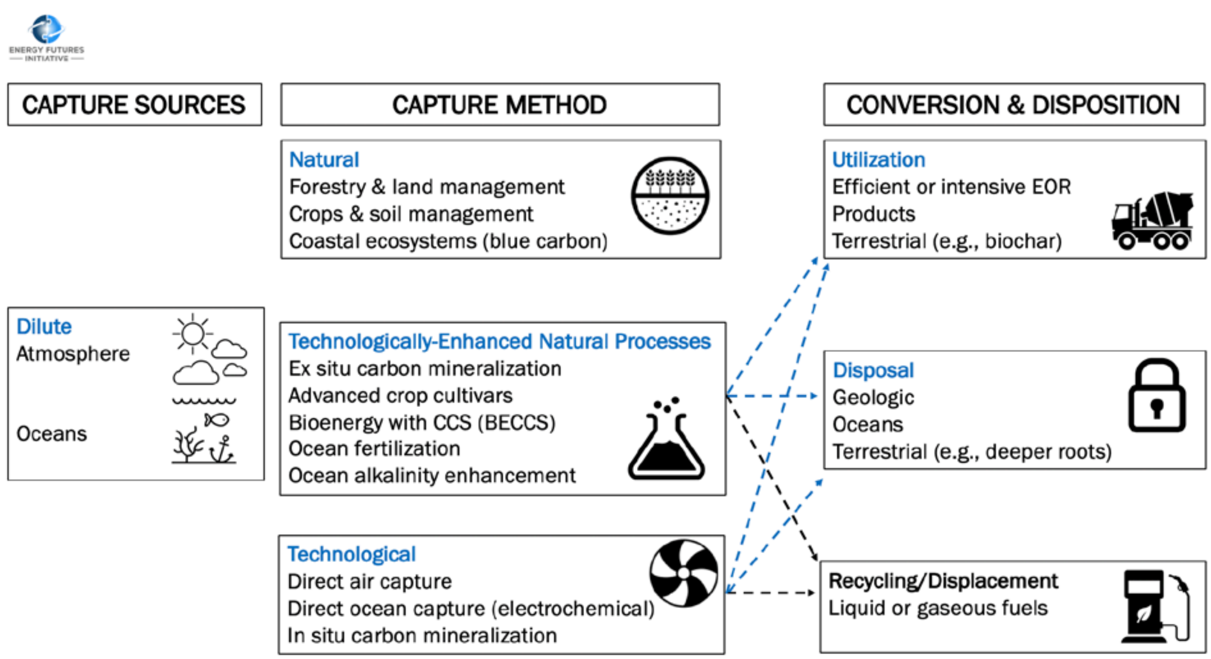
B. CDR Involves Multiple Technological Pathways

The three broad approaches to CDR, illustrated in Figure 2, are **natural, technologically enhanced natural processes** (or hybrid), and **technological** CDR from the atmosphere and oceans.

Natural CDR includes pathways such as afforestation, reforestation, soil carbon sequestration, and coastal ecosystem carbon uptake ("blue carbon"). Natural CDR pathways remove carbon from the atmosphere at gigaton (Gt) scale but are currently insufficient to offset anthropogenic emissions and thus cannot keep the carbon cycle in a net-neutral balance. The natural carbon cycle can be enhanced for example by expanding forested areas, avoiding deforestation, and preserving and expanding wetlands. These pathways already are the subject of considerable research studies and policy discussion. The potential scale of expansion ultimately is limited by competing uses of land for food and fiber production and human habitat.

Figure 2

Selection of Pathways for CDR from Dilute CO_2 Sources



There are a variety of natural, technologically-enhanced natural processes, and technological pathways that can facilitate CDR through the capture of CO_2 from dilute sources. Source: EFI, 2019.

The functioning of natural systems, however, can be ***technologically enhanced*** in various ways. Technologically enhanced natural processes include elements of both natural and technological CDR and include pathways such as ex situ carbon mineralization, advanced crop cultivars, ocean alkalinity enhancement, and BECCS. The technologically enhanced CDR options (other than BECCS) also have the advantage or providing both capture and sequestration in the same process.

The third pathway is ***direct technological capture***, including DAC and electrochemical separation of CO_2 from seawater. These pathways do require some form of sequestration or utilization in order to achieve permanent disposition of the captured CO_2. Since some of these technological CDR pathways can capture CO_2 in a relatively pure form, there are a range of CO_2 utilization options that might be available.

It is extremely important to note that the scope of various pathways for CDR is distinct from geoengineering. Consistent with the IPCC methodology, CDR pathways discussed in the EFI Report focus on managing carbon as the means to address climate change, while geoengineering involves techniques that modify climate through other means, such as the management of solar radiation, but do not affect CO_2 fluxes or CO_2 atmospheric concentrations.

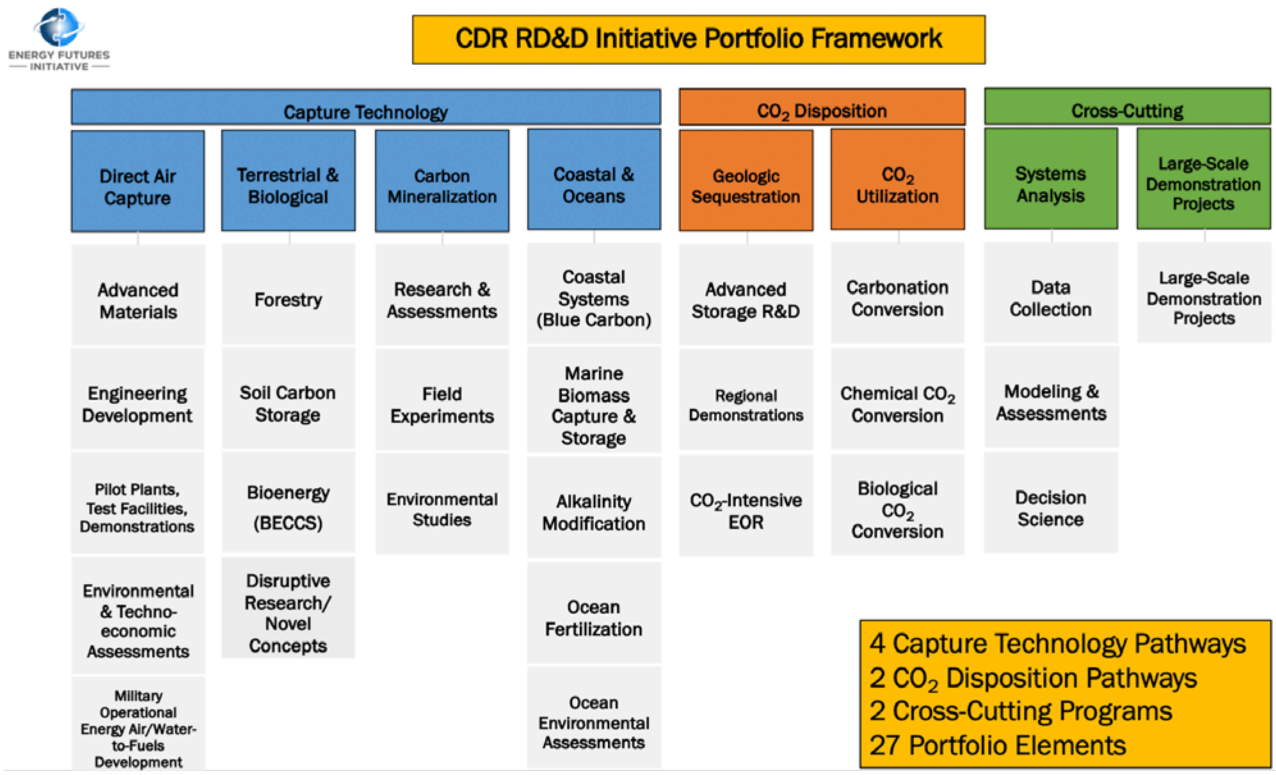
C. The Program Portfolio Structure for the CDR RD&D Initiative

The proposed technological CDR RD&D portfolio framework consists of:

- *Four capture technology pathways* (DAC, terrestrial and biological, carbon mineralization, coastal and oceans). For the terrestrial and biological, carbon mineralization, and many coastal and oceans CDR pathways, sequestration is an integral part of the capture mechanism;
- *Two CO_2 disposition pathways* (geologic sequestration, CO_2 utilization). The two CO_2 disposition pathways are needed primarily to support DAC, BECCS, and oceans direct capture options; and
- *Two cross-cutting programs* (systems analysis, large-scale demonstration projects) that provide holistic or common support to all of the CDR pathways.

Figure 3 illustrates the portfolio design. The organization of the four capture technology pathways largely stems from those discussed in the NASEM report but were expanded to include CDR in the deep oceans. In total, the RD&D portfolio comprises 27 separate elements.

Figure 3
CDR RD&D Initiative Portfolio Framework



The CDR RD&D portfolio consists of four capture technology pathways, two CO_2 disposition pathways, and two cross-cutting programs. Source: EFI, 2019.

D. Direct Air Capture (DAC)

DAC uses heat and electricity to separate CO_2 from ambient air with various sorbent or solvent materials. DAC processes are energy intensive; low-cost, carbon-free process heat is a key requirement. Current cost estimates for DAC vary widely and are subject to considerable uncertainty. Little is known about its longevity under real-world conditions. However, DAC has a very large potential scale for CDR. The overarching RD&D objective for DAC is to reduce the cost and energy use and improve the performance and durability of DAC technologies to be a viable option for CDR. The components of the RD&D portfolio include: (1) fundamental research on the development of new sorbent and solvent materials; (2) applied research and development on components and system-level integration; (3) full-system scale up and manufacturing research; (4) research on cost, lifecycle emissions, and environmental impacts; and (5) applied technology development of air-to-fuels and seawater-to-fuels systems for military use at forward operating bases and at sea.

E. Terrestrial and Biological CDR

Terrestrial and biological pathways include increased growth of trees to store carbon as living or dead woody biomass (afforestation and reforestation), increased storage of carbon in the soil by crops and other herbaceous plants (soil carbon), and BECCS. Forest-related techniques require improved monitoring systems and expanded utilization and disposal options for woody biomass; soil carbon techniques require improved monitoring systems, the development of high-carbon-input crop cultivars, and better understanding of soil treatments; BECCS requires advances in biomass supply (including algae), as well as conversion to liquid fuels and electricity with carbon capture. Terrestrial and biological techniques are relatively mature, but their potential scale for CDR is limited by land availability and long-term permanence. The overarching RD&D objective for terrestrial and biological CDR is to develop new approaches for enhanced carbon uptake in trees, plants, and soils, in a manner consistent with advancing traditional food and fiber mission objectives. The components of the RD&D portfolio include: (1) enhanced monitoring systems, integrating modeling, and frontier techniques for forest carbon storage; (2) fundamental and applied research on carbon-relevant soil properties, soil carbon monitoring, advanced cultivars, biochar and reactive mineral impacts in agricultural soils, optimizing cultivation systems for carbon, and predictive modeling tool development; and (3) enhanced methods for biomass supply and pre-treatment (including algal biomass), and advanced technologies for biomass conversion to fuel, biochar, and biopower. High-risk, high-reward research on advanced CDR technologies relevant to agriculture are proposed for support through the Agriculture Advanced Research and Development Authority (AGARDA).

F. Carbon Mineralization

CO_2 naturally reacts with a variety of minerals to form carbonates, a process that leads to long-term solid storage of carbon. These reactions cause natural weathering of rock formations over thousands of years; carbon mineralization CDR techniques seek to accelerate this process, by using various sources of minerals and exposing them to CO_2 in a variety of ways. Challenges for these techniques include identifying sufficient supplies of reactive minerals, minimizing energy and transport costs for CO_2 exposure and carbonate disposal, and understanding environmental impacts from the process. The overarching RD&D objective for carbon mineralization is to enhance the understanding of the feasibility and potential for carbon mineralization as a CDR technology pathway. The components of the RD&D portfolio include: (1) fundamental research on geochemistry and rock physics to improve understanding of reaction rates and potential scale of CDR; (2) resource assessments to identify sustainable sources of reactive minerals; (3) applied research and field tests of surface and subsurface carbon mineralization methods (including mine tailings and industrial waste); and (4) research on environmental impacts.

G. Coastal and Oceans CDR

The oceans interact extensively with the atmosphere, and currently absorb a quarter of anthropogenic CO_2 emissions directly from air.[18] Coastal CDR techniques (also referred to as "blue carbon") include the growth of plants in coastal environments such as salt marshes, mangroves, and seagrass meadows, and subsequent natural burial of their biomass in coastal soil. Ocean CDR techniques aim to accelerate the absorption of atmospheric CO_2 by the oceans, storing it as dissolved bicarbonate and/or carbon exported to the deep ocean; other techniques focus on cultivating macroalgae at sea and using the resulting biomass for a variety of purposes, accompanied by CO_2 capture and storage. These techniques are all relatively immature, with some being almost entirely untested. There is little information about the potential costs, but the theoretical scale is extremely large, reflecting the fact that the oceans naturally regulate planetary atmospheric CO_2 levels over millennia. The overarching RD&D objective for coastal and oceans techniques is to develop a better understanding of carbon removal processes in coastal areas and deep ocean waters to provide the basis for determining feasibility of future CDR implementation measures. The components of the RD&D portfolio include: (1) fundamental research and resource assessment for blue carbon coastal techniques; (2) regional field trials and database development for coastal CDR; (3) applied research on aquatic biomass cultivation, harvesting, and conversion; (4) fundamental research and small-scale applied field trials of ocean alkalinity modification; (5) fundamental research and preparation for small-scale applied field trials of ocean iron and macronutrient fertilization; and (6) fundamental research and modeling on environmental impacts from ocean and coastal CDR techniques.

H. Geologic Sequestration

Sequestration of CO_2 in geologic formations is a critical enabling technology for CDR; without validated, at-scale sequestration capability, removed CO_2 cannot be permanently kept out of the atmosphere. Techniques for geological sequestration are relatively well understood, although new approaches beyond saline aquifer storage are in development. Key issues include accurate and low-cost resource characterization, monitoring, and at-scale demonstration. The overarching RD&D objective for geologic sequestration is to determine the potential for large-scale (at or near Gt scale) geologic sequestration as a permanent storage option for captured carbon. The components of the RD&D portfolio include: (1) applied research on a range of advanced storage topics including reduction of seismic risk, improved site monitoring, secondary trapping, and CO_2 fate and transport simulation; (2) augmenting the existing DOE CarbonSAFE program by adding additional sites and accelerating the timetable for full site characterization; (3) regional large-scale CO_2 injection demonstrations at multiple sites characterized under CarbonSAFE; and (4) applied research and demonstration of techniques to co-optimize CO_2 injection and oil production in enhanced oil recovery (CO_2-EOR).

I. CO_2 Utilization

There are multiple technology pathways currently under development to utilize CO_2 for economically beneficial purposes. The largest of these by current volume is CO_2-EOR, but others include the production of liquid fuels, building materials, plastics, commodity chemicals, and advanced materials; accelerating plant and algal growth; and food & beverage production. Many of these techniques remain energy intensive or cost prohibitive. While the feasible potential scale of CO_2 utilization will not reach the total required for CDR as discussed above, utilization can provide revenues to compensate for the costs of early CDR deployment and help with technology development. The overarching RD&D objective for CO_2 utilization is to accelerate development of innovative carbon conversion processes and new carbon-based materials through carbon mineralization, chemical, and biological conversion. The components of the RD&D portfolio include: (1) fundamental and applied research on carbonation reactions and process integration with CO_2 capture; (2) resource assessment on alkalinity sources for carbonation; (3) applied research and demonstration of CO_2-based construction materials for buildings and roads; (4) fundamental research and systems integration for chemical conversion of CO_2 including catalyst development and reactor design; (5) fundamental research on engineered organisms for biological CO_2 conversion and bioprospecting; and (6) applied research on co-products from biological CO_2 conversion.

J. Cross-Cutting Programs

The portfolio design highlights activities that span all CDR pathways and disposition options. An expanded carbon data collection effort is proposed to develop comprehensive lifecycle data on carbon flows in the economy. Independent techno-economic assessments will provide the capability to periodically assess technological CDR alternatives on a common basis with the credibility of a third-party perspective. The integrated carbon systems modeling program will assess systems-level impacts of large-scale CDR deployment, reflecting environmental, social, and economic issues. The decision science program will assess socio-economic issues, such as risk analysis and societal acceptance, associated with large-scale deployment of CDR approaches such as geological sequestration.

The proposed CDR RD&D portfolio includes a major cross-cutting element for large-scale demonstration projects. The CDR technology demonstration program is proposed as a cross-cutting initiative because it incorporates an innovative program design. Specifically, the CDR technology demonstration program:

- Will be a technology-neutral program, supported by a separate fund; major technology demonstration programs are not budgeted separately within each CDR pathway portfolio;

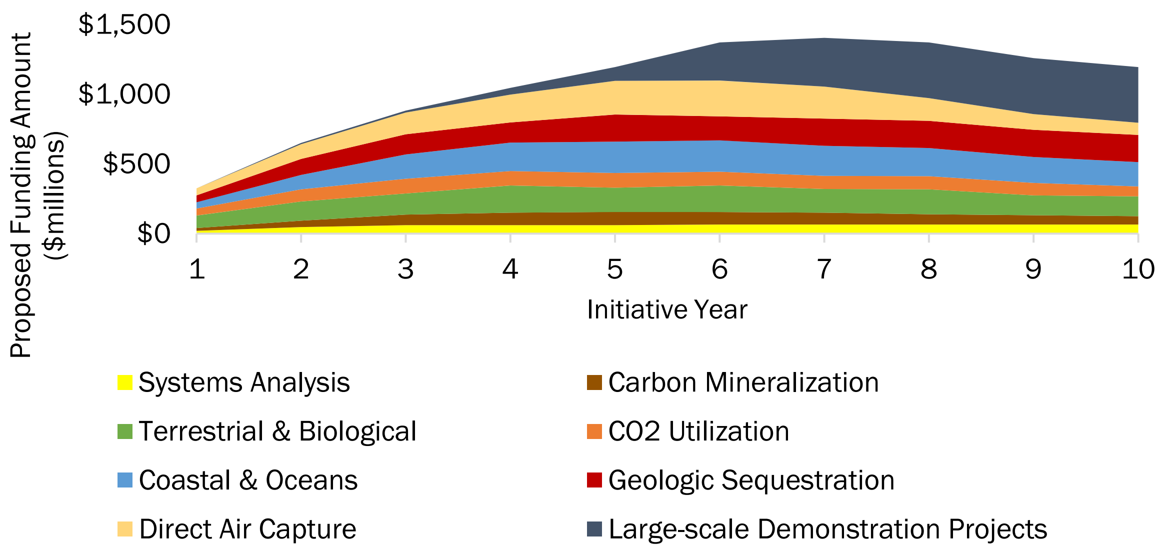
- Will support demonstration projects competitively, based on threshold qualification criteria; not all CDR technologies will qualify for large-scale demonstration;
- Will be initiated several years after the start of the CDR research programs, to take advantage of early research results and not commit prematurely to technology concepts that may need further maturation;
- Will be operated with flexible and innovative cost-sharing arrangements to take maximum advantage of the Section 45Q tax credits and emphasize incentives for demonstration project performance; and
- Will be managed centrally by a new demonstration program office with robust project management expertise.

K. Estimated Budget Planning Targets

Budget planning estimates were developed for each of the 27 portfolio elements. One or more agencies were identified to lead the RD&D work within each element, and the budget planning estimates reflect the proposed scope of work for that element.

The total RD&D initiative budget is estimated at $10.7 billion over the proposed 10-year span of the program (Figure 4). The proposed funding level for the first full year of the initiative is $325 million, with total initiative funding allocated among 10 federal departments and agencies.

Figure 4
CDR RD&D Initiative Proposed Total Funding by Year

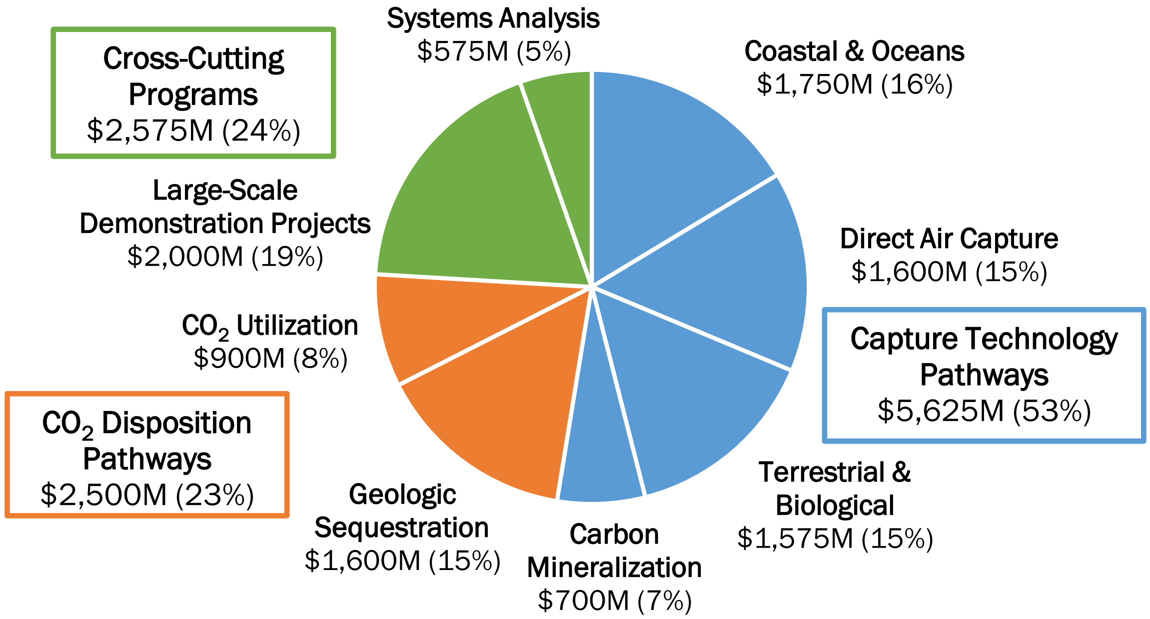


Proposed funding ramps to $325 million in Year 1 and peaks at $1,404 million in Year 7. Source: EFI, 2019.

The distribution of funding by portfolio component is illustrated in Figure 5. Funding for the four capture technology pathways totals $5,625 million over 10 years (53 percent), while funding for the two CO_2 disposition pathways and two cross-cutting programs totals $2,500 million (23 percent) and $2,575 (24

Figure 5

CDR RD&D Initiative Proposed Total Funding by Portfolio Categories



Proposed funding is divided between four capture technology pathways, two CO_2 disposition pathways, and two cross-cutting programs. Source: EFI, 2019

percent), respectively.

Achieving a diversified RD&D portfolio is essential, for several reasons.

- First, the alternative CDR pathways have widely varying degrees of technological maturity; the differences were clearly highlighted in the NASEM report. In short, it is too soon to declare a "winner."
- Second, because of the complexity of the carbon cycle, it is critical to understand the movement and interactions of carbon among the atmosphere, terrestrial biosphere, and oceans in response to removal of carbon in any one ecosystem.
- Third, while the various elements in the technological CDR portfolio may have Gt-scale deployment potential, there will be technology-specific limitations on deployment due to many factors. The NASEM report articulated the major factors, including land use and other environmental

constraints, energy requirements, and public support and institutional issues.[19]

- Finally, CDR pathways have strong regional characteristics that need to be reflected in the CDR RD&D initiative.

The CDR RD&D initiative will involve proposed funding for 27 offices or organizations across 10 federal agencies, with a prominent role for DOE, USDA, and NOAA. DOE is proposed to receive more than $4.8 billion in funding (45 percent of the total), while USDA, NOAA, and the National Science Foundation (NSF) are each proposed to receive over $900 million. Funding would be enacted through six appropriations bills: Agriculture; Commerce, Justice, Science; Defense; Energy and Water; Interior and Environment; Transportation, Housing and Urban Development (HUD).

I am pleased to see that Congress has made substantial down payments on the budget for the CDR RD&D initiative in the case of DOE. The FY 2020 Energy and Water Development Appropriations Act provided a total of $60 million to DOE across three appropriations accounts: $20 million in Fossil Energy (FE), $20 million in Energy Efficiency and Renewable Energy (EERE) and $20 million in Science. The pending FY 2021 Energy and Water Appropriations bill in the House would provide a further substantial increase to DOE, with $50 million to FE, $20 million in EERE and $25 million in Science. Hopefully the Senate will follow suit when it takes up FY 2021 appropriations. It is important that Congress consider the funding estimates for the other federal agencies as well.

L. Effective Federal Agency Organization and Management Structure and Processes

The proposed RD&D portfolio identifies research responsibilities for 10 federal departments and agencies, along with the participation of OSTP and OMB for the purposes of planning, budgeting, execution, and performance-tracking for the CDR RD&D initiative (Figure 6).[a]

Achieving effective coordination in portfolio planning, budgeting, performance management and evaluation, and reporting to Congress, the scientific community, and the public will be challenging. This challenge is not unique; the federal government has successfully implemented other interagency science and technology initiatives in the past, and the lessons learned can serve to guide the technological CDR RD&D initiative.

[a] A previous analysis identified a baseline of nine federal agencies that historically supported RD&D activities related to CDR, which could help provide a framework for a federal CDR RD&D initiative. Individual RD&D projects related to CDR were funded in 23 separate appropriations accounts contained in five different appropriations bills.

Figure 6

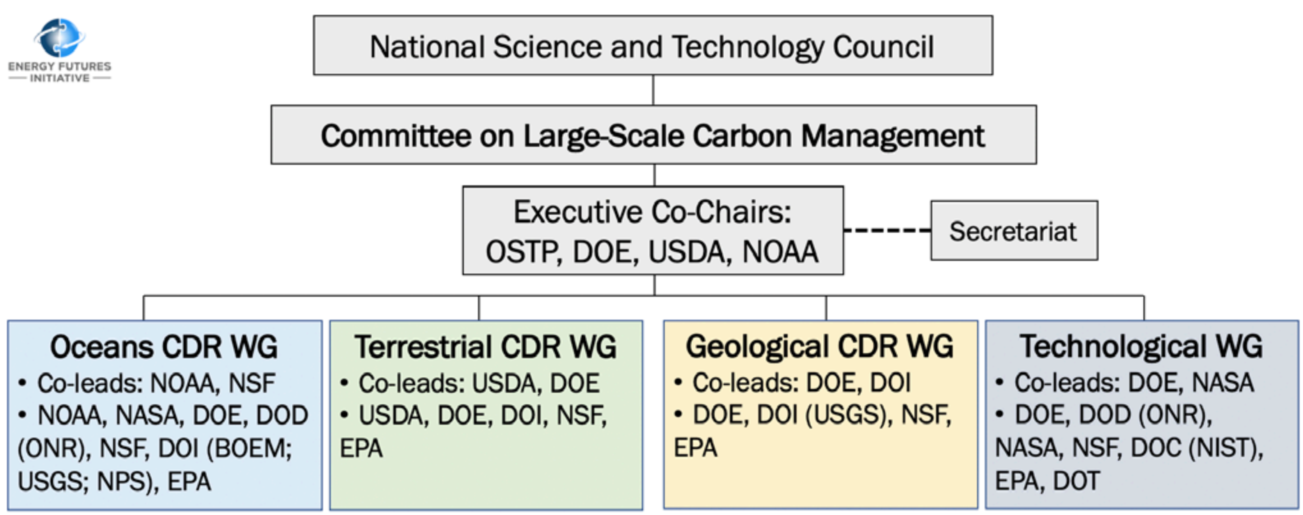
Federal Participation in CDR RD&D Initiative

Federal participation in the CDR RD&D initiative includes 10 agencies and EOP. Source: EFI, 2019.

Best practices were identified through a survey of lessons learned by experts involved in the implementation of prior federal interagency RD&D initiatives. Drawing from this assessment, the recommended organizational framework for the technological CDR RD&D initiative is outlined in Figure 7.

Figure 7

Interagency Integration and Coordination



The CDR RD&D initiative would be governed by a new entity within the National Science and Technology Council. Source: EFI, 2019.

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). The new committee would be co-chaired by an Executive Committee comprised of the OSTP Associate Director for Science, and senior officials from DOE, USDA, and NOAA. Co-leadership is essential to reflect the key roles and responsibilities of these organizations in the overall planning of the initiative.

The Committee would have a broad set of responsibilities including:

- Developing a technological CDR RD&D strategic plan;
- Overseeing task forces responsible for more detailed RD&D road-mapping;
- Coordinating budget planning with the agencies and budget review with OMB;
- Identifying candidate CDR technologies for large-scale demonstration;
- Overseeing independent evaluations of program performance; and
- Providing an annual report to Congress and the public.

It is recommended that OMB assist in the coordination of the technological CDR RD&D initiative by conducting an annual budget crosscut review. The budget crosscut would have two principal objectives: ensure that budget proposals from the program offices with technological CDR RD&D responsibilities are integrated with the overall budget for each participating department and agency, and ensure that the various OMB staff review and act on agency budget proposals for technological CDR RD&D elements in a holistic fashion. The OMB budget crosscut process can thus act as the “glue” to ensure that the CDR RD&D initiative is implemented in a fully integrated manner.

Implementation of these recommendations could be initiated by Presidential Executive Order. Congressional authorizing legislation would ultimately be desirable.

Three federal agencies in particular—DOE, USDA, and NOAA within the Department of Commerce (DOC), are proposed to be responsible to lead major elements of the CDR RD&D initiative. These three agencies have extensive existing research infrastructure and relatively large research and development (R&D) budgets that will require some realignment in order to effectively incorporate CDR RD&D into their mission objectives.

The recommended organizational structural and process changes for DOE, USDA, and NOAA include:

- ***DOE***: 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 consider re-establishing the Office of Under Secretary for Science and Energy, which, among other benefits for Departmental management, would provide a more appropriate longer-term organizational home for the CDR program.

- *NOAA*: Incorporate CDR as a new strategic objective within its Oceans Research Plan and establish a new Office of Ocean Technologies within the Office of Oceanic and Atmospheric Research, headed by the Chief Scientist.
- *USDA*: 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 and assign CDR a high priority for this organization.

M. International Collaboration on Technological CDR RD&D

Other countries are currently moving forward with research initiatives on technological CDR approaches. Innovation in CDR technologies and approaches could be accomplished more effectively and rapidly if countries create durable RD&D collaborative frameworks that facilitate pooling of both intellectual and monetary resources. The implementation process emerging from the 2015 Mission Innovation initiative appears to have the characteristics needed to foster an effective and efficient international collaboration in technological CDR RD&D.

There are also facets of CDR that will specifically require international collaboration because they could have legal and regulatory impacts that cross borders. Several CDR pathways involve practices that are already governed by international law, such as ocean fertilization[b] or biological sequestration with genetically modified organisms.[c] Other pathways pose issues that are common to any country contemplating deployment of geologic sequestration. These include technical issues, such as induced seismicity, as well as legal and regulatory issues, such as monitoring, reporting, and verification (MRV) for sequestered carbon. Common legal and regulatory frameworks around these issues, built upon a shared understanding of the science and technology base, will be essential to ensure effective deployment of CDR on a gigaton scale globally.

Another important component of building durable international collaboration efforts is establishing ground rules for the management and sharing of intellectual property (IP). Safeguarding U.S. IP is crucial to stimulating innovation around CDR; without those protections, the economic motivation for innovation could be diminished. At the same time, knowledge-sharing across international borders is important to global deployment of CDR methods. The federal government will need to work closely with international partners to find the appropriate balance

[b] The London Convention/Protocol applies to this topic. The U.S. is a signatory to both agreements.
[c] The Cartagena Protocol applies to this topic, although the U.S. is not a party to this agreement.

between protecting the IP of CDR innovators while ensuring that all countries have the opportunity and incentives to deploy CDR at the needed Gt-scale.

Conclusion: Value Proposition from the Proposed CDR RD&D Initiative

The proposed CDR RD&D initiative is designed to offer significant value in several ways:

- The proposed initiative is highly focused to deliver commercial-ready CDR innovations within a decade to address the climate crisis. A $10.7 billion investment is small compared to the potential range of economic damage resulting from unchecked climate change.
- The CDR technological pathways provide additional optionality and flexibility to achieve net zero GHG emissions in order to limit temperature increases to a target of 1.5 degrees Celsius in the most cost-effective manner possible, as well as reverse atmospheric CO_2 concentrations resulting from past emissions.
- CDR RD&D innovations can also benefit other national research objectives in ocean ecosystems and fisheries restoration and management, forest and agriculture productivity, and resource conservation; and national security.
- The large-scale deployment potential for CDR innovation offers significant economic benefits in terms of new industries and new jobs on a global scale.

All of these factors shape the value proposition for a new federal CDR RD&D initiative.

I want to thank the Committee for its leadership in holding this hearing, and appreciate the opportunity to discuss this important issue with you today.

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Figure 2.5

[17] Redacted

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