Innovation Gap: Carbon Dioxide Removal

BY COLIN CUNLIFF | NOVEMBER 2018

This briefing is an excerpt from "An Innovation Agenda for Deep Decarbonization." See itif.org/issues/energy-climate.

Despite our best efforts, the world may not be able to reduce carbon pollution fast enough or at sufficient scale to avoid dangerous levels of warming—prompting the need for technologies that can remove carbon from the atmosphere.[1] However, no carbon dioxide removal (CDR) technologies—also referred to as negative emissions technologies (NET)—have been deployed at a scale that can meaningfully address the magnitude of global climate pollution. And little is known about the viability and scalability of rapid deployment. Federal investment in research, development, demonstration, and commercialization of CDR technologies is urgently needed to create new options for reducing carbon pollution.

Scientists and climate advocates are increasingly coming to view carbon removal as an essential but overlooked element of a deep decarbonize-tion strategy, and many energy-climate models find it impossible to achieve a 2°C (3.6°F) target without relying on CDR technologies.

Removing Carbon from the Air to Restore the Natural Balance of Carbon Levels

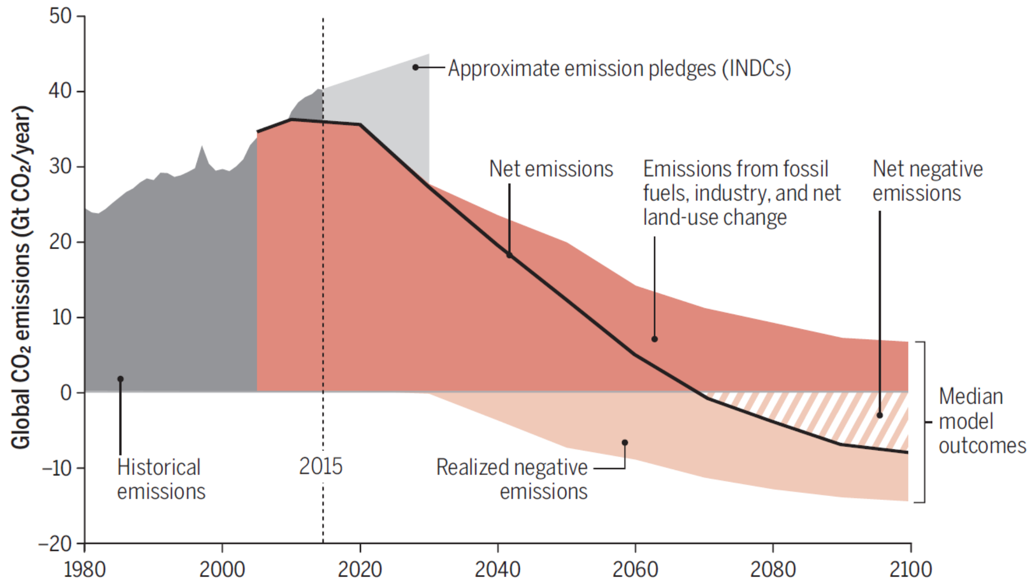
CDR includes a suite of technologies and approaches that remove carbon dioxide from the ambient atmosphere for subsequent storage or use. Many land-use approaches such as reforestation and afforestation have long been included in traditional mitigation efforts; however, these approaches run into competition for land use (e.g., for agriculture) and face barriers to deployment at the needed scales. Technological approaches are relatively immature but have the potential to permanently sequester atmospheric CO_2, on the order of billions of metric tons annually.[2]

Scientists and climate advocates are increasingly coming to view carbon removal as an essential but overlooked element of a deep decarbonization strategy, and many energy-climate models find it impossible to achieve a 2°C (3.6°F) target without relying on CDR technologies.[3] Carbon removal hedges against two key risks that are common to all deep decarbonization pathways: the risk of a carbon budget overshoot, and the need to counter emissions from "difficult-to-decarbonize" sectors.

First, a carbon budget overshoot would occur if emissions do not decline quickly enough to avoid unacceptable and severe climate impacts. Several factors could contribute to a carbon budget overshoot: Clean energy technologies may not advance as quickly as needed. Countries may not set sufficiently aggressive mitigation targets. Failure to reduce emissions rapidly enough would require net emissions to become negative before the end of the century (black line in figure 1).

Second, even the most optimistic technology scenarios still include emissions from "difficult-to-decarbonize" sectors—such as aviation, long-haul shipping, cement, and steel—for which there are few carbon-neutral options on the horizon (dark-pink-shaded area in figure 1). Mitigating emissions from these sectors will either require significant technological breakthroughs or some way of offsetting emissions from these sectors. Additionally, many incumbent technologies and infrastructures have long life spans—a new home built today will still exist in 2050.[4] CDR technologies help smooth the transition to a low-carbon economy by averting the need for accelerated stock turnover in sectors where such turnover would be prohibitively expensive.

Figure 1. Carbon dioxide removal (CDR) technologies are likely essential to achieving deep decarbonized systems.[5]



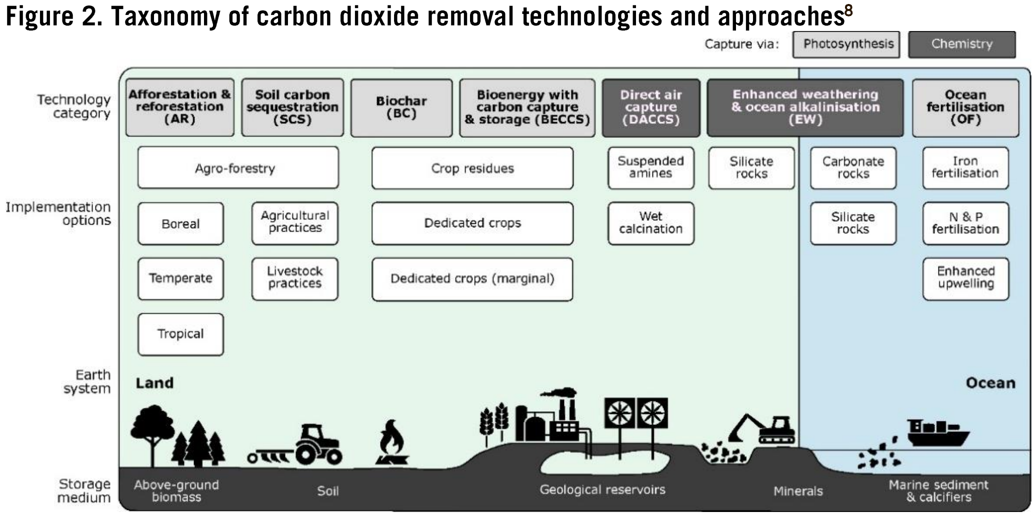
Additionally, CDR technologies help manage risks in our understanding of the climate system and our ability to manage and adapt to the impacts of climate change. Although the notion of a carbon budget provides a simple way to track mitigation efforts, the complexity of energy-climate systems makes it impossible to assign a specific budget to a given temperature increase. The current carbon budget may lead to unacceptably high damages, including greater-than-anticipated sea-level rise or more frequent extreme weather. Carbon removal hedges against the risk of climate impacts being greater than anticipated.

More Innovation Is Needed to Bring CDR to Maturity

Technological approaches to carbon removal have only recently emerged as the subject of climate mitigation research, with the number of publications and technologies regarding carbon removal growing rapidly since the early 2000s.[6] The increased attention to CDR technologies parallels the growing recognition that the world may only be a few decades away from blowing past the carbon budget consistent with a 2°C target. However, research to date has been confined mostly to academic studies and modeling, with limited public support—either domestically or internationally—to develop the technologies that climate models say are needed to achieve deep decarbonization.

Figure 2 provides a taxonomy of biological and technological carbon removal approaches, distinguished by their carbon capture method (photosynthetic or chemical) and carbon storage medium. Bioenergy with carbon capture and storage (BECCS) is one promising approach to achieving negative emissions because of its ability both to produce energy and sequester carbon. BECCS is the process by which biomass such as wood or switchgrass is converted to heat, electricity, or liquid or gas fuel, followed by carbon capture and storage (CCS). The carbon capture process is similar to the capture process from coal- and natural gas-fired power plants (see the section on CCUS). Deployment on a large scale runs into land-use and other resource constraints, e.g., competition with agriculture for land, water, and fertilizer. Additional research is needed to address sustainability concerns and to identify energy crops with lower resource requirements.[7]

Figure 2. Taxonomy of carbon dioxide removal technologies and approaches[8]



Direct air capture (DAC) of carbon dioxide is another nascent CDR technology with a large potential for carbon removal. DAC is not a new technology, as small systems have been installed in submarines, space applications, and other closed environments to prevent CO_2 buildup from exhalation. Although not traditionally a factor for these small, niche applications, cost is the key hurdle in scaling up DAC systems to climate-relevant scales—with current cost estimates ranging from $100 to $600 per metric ton of CO_2 captured.[9]

Other innovative carbon removal approaches include carbon mineralization—trapping carbon dioxide in solid mineral carbonates, which can be used in building materials—as well as biotechnology approaches to enhance soil carbon, which can improve soil quality and boost crop yields. Most proposed CDR approaches have the potential for widespread deployment on a scale relevant for climate mitigation, but many face significant knowledge and technical gaps that will require substantial investment in R&D.

A Carbon Dioxide Removal Technology Mission

A carbon removal technology mission would harness U.S. strengths in science and engineering, and provide an opportunity for the United States to lead the world in the emerging carbon removal sector. In October 2018, the National Academy of Sciences (NAS) released a detailed roadmap supporting innovation in carbon removal technologies and identifying R&D needs. Many other scientific and advisory bodies have also recommended greater investment in carbon removal research, reflecting a growing

BOX 1: CARBON REMOVAL IN ENERGY-CLIMATE MODELS

CDR technologies are increasingly relied on in integrated energy-climate assessment models to achieve deep decarbonization—and this reliance is robust across different energy-climate models, as well as assumptions about population growth, economic growth, technology availability, and other inputs. In the Fifth Assessment Report on climate change, IPCC assessed 900 mitigation scenarios across 30 energy-climate models. Out of the 116 scenarios consistent with warming below 2°C, 101 (87 percent) use carbon removal approaches in the second half of the century, with average net carbon removal exceeding 12 billion metric tons annually by 2100.[10]

consensus that carbon removal technologies are important for national goals in economic growth and environmental stewardship.[11]

Bipartisan Congressional support for carbon removal is growing. In the February 2018 budget agreement, Congress extended and expanded the 45Q tax credits for carbon storage to include direct air capture. Both the USE IT Act in the Senate and the Fossil Energy R&D Act introduced in the House would establish R&D programs for carbon removal, though neither legislation would fund R&D at the level proposed by the NAS report—or fund the full suite of carbon removal technologies.[12]

The National Academies report found that direct air capture and carbon mineralization have nearly unlimited carbon removal potential and fewer potential negative environmental impacts than other approaches, but are limited by high costs and technical feasibility. Investment in carbon removal technologies should span the entire innovation spectrum, from fundamental research to commercialization.

- **DOE's Office of Science (SC) should establish a new energy innovation hub that addresses the basic science needs for carbon removal pathways, including direct air capture and carbon mineralization.**

- **DOE should establish an applied RD&D program that implements the recommendations of the National Academies report and prioritizes pilot-scale demonstrations of direct air capture.**

Land-based approaches to carbon removal—including BECCS, afforestation and reforestation, biochar and soil carbon sequestration, and changes in forest management and agricultural practices—are viable today at relatively low costs, but have limited scalability due to competition for land and concerns about environmental impacts. **Federal agencies should research ways to increase the carbon removal capacity and mitigate environmental impacts of land-based approaches.**

The full set of R&D needs spans basic energy science to applied research to technology commercialization and deployment—and the technical capabilities to address carbon removal research needs are distributed across multiple agencies, especially DOE, EPA, DOI, USGS, and NSF. **Federal policymakers should establish an interagency working**

group with the National Science and Technology Council (NSTC) to coordinate federal research and facilitate information exchange.

ENDNOTES

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