U.S. DEPARTMENT OF ENERGY

Fossil Energy and Carbon Management

Carbon Dioxide Removal

Frequently Asked Questions

U.S. Department of Energy

1000 Independence Avenue SW, Washington, D.C. 20585

Table of Contents

Defining Carbon Dioxide Removal

What is carbon dioxide removal?

Carbon dioxide removal (CDR) is a term used to encompass a wide array of approaches that remove carbon dioxide (CO_2) directly from the atmosphere and durably store it to create negative emissions. Storage can occur in geological, biobased or ocean reservoirs or in value-added products, like low-carbon concrete. CDR technologies and approaches include but are not limited to:

- Direct Air Capture with Durable Storage (DACS)
- Soil Carbon Sequestration
- Biomass Carbon Removal and Storage
- Enhanced Mineralization
- Ocean-Based CDR
- Afforestation/Reforestation

Note that CDR does not refer to existing systems that remove CO_2 from the atmosphere; for example, CDR does not include CO_2 removal through existing trees or by planting new trees to offset wildfire losses. CDR refers to intentional interventions that introduce new processes or bolster existing processes for the purpose of creating negative emissions.

CDR is distinct from point-source carbon capture from the fossil power sector and heavy industry. CDR approaches can address emissions from the hardest to decarbonize sectors (e.g., agriculture, aviation and shipping) and remove legacy CO_2 emissions from the atmosphere. CDR has a critical role in helping the U.S. Government reach its goal of net-zero emissions by 2050 and also in enabling climate justice through the removal of legacy carbon pollution

Why is CDR defined to include both technological and biological approaches?

CDR includes both technological approaches (e.g., DACS) as well as biological approaches (e.g., afforestation/reforestation)—often referred to as nature-based approaches —because all of these methods remove CO_2 directly from the atmosphere and have the potential to create negative emissions through durable storage.

The massive scale of negative emissions needed requires a suite of diverse CDR approaches. Carbon Negative Shot—the U.S. Government's first major effort in CDR—intentionally includes many CDR approaches so that the U.S. Department of Energy (DOE) can rigorously and consistently evaluate the potential for proposed pathways to meet stringent justice, sustainability and cost targets. Diverse approaches are also needed to ensure that CDR is sufficiently well understood to promote appropriate deployment, matched to specific place-based and community needs.

While these approaches differ significantly in their energy use, land use and social implications, they will all require substantial efforts in research, development, demonstration and deployment (RDD&D) to enable a responsible CDR industry that is responsive to the climate crisis. For example, the development of robust lifecycle analysis and monitoring, reporting and verification (MRV) methods are critical to ensuring effective and permanent CO_2 removal for all CDR approaches.

Why does CDR focus on removing atmospheric CO_2 only and not other greenhouse gases like methane?

CO_2 is the most abundant anthropogenic greenhouse gas in the atmosphere and is significantly higher in concentration than methane, the next-most-abundant anthropogenic greenhouse gas. It is important to address this primary greenhouse gas and remove CO_2 directly from the atmosphere because even if we stopped emitting CO_2 today, a substantial portion of previously emitted CO_2 will persist in the atmosphere and oceans and continue to contribute to climate change. CDR provides an opportunity to remove legacy CO_2 emissions and limit harm from climate change. Even though CO_2 is the most abundant anthropogenic greenhouse gas, capturing CO_2 directly from the atmosphere cost effectively and sustainably is a technical challenge that requires further RDD&D.

DOE is also focused on methane mitigation as a separate effort and important part of "The Long-Term Strategy of the United States, Pathways to Net-Zero Greenhouse Gas Emissions by 2050 (whitehouse.gov)."

What is the difference between CDR and point-source carbon capture and storage?

CDR is distinct from point-source carbon capture and storage (CCS) for fossil fuel power plants and heavy industry. CDR encompasses a wide array of approaches that *remove CO_2 directly from the atmosphere* and then durably store it, resulting in negative emissions. CDR can address emissions from the hardest to decarbonize sectors (e.g., agriculture, aviation and shipping) and eventually remove legacy CO_2 emissions from the atmosphere.

CCS on fossil power plants or heavy industry captures CO_2 *before* it enters the atmosphere; CCS is a method to *reduce CO_2* emissions and can help achieve deep decarbonization in existing power and industrial sectors.

What is the difference between CO_2 conversion and CDR?

CO_2 conversion (sometimes referred to as carbon utilization) involves the conversion of CO_2 into products. The process is called CO_2 conversion regardless of whether the CO_2 is captured from a point source via carbon capture (e.g., industrial plant with CCS) or from the atmosphere (i.e., CDR). The term "CO_2 conversion" is used to refer to products that store carbon for both short periods of time (e.g., fuels) and long periods of time (e.g., building materials and plastics), which means CO_2 conversion can be part of emissions reduction strategies (short-term storage) or CDR approaches (long-term storage).

For CO_2 conversion to be a part of a CDR approach, the CO_2 must be directly removed from the atmosphere, converted into long-duration storage products *and* result in negative emissions for the overall process. Atmospheric CO_2 conversion for short-term duration storage products (e.g., fuels which are combusted) is not considered CDR because it does not result in long-term storage of CO_2.

While CO_2 conversion is an important part of potential CDR approaches, it is only relevant for certain approaches and by itself will be insufficient to store the quantity of CO_2 required to reach net-zero greenhouse gas emissions by 2050.

What more needs to be done before CDR can be deployed at scale?

CDR approaches are currently cost prohibitive or lack the means to monitor and verify removal. Different approaches under the CDR umbrella have different challenges and levels of readiness, and they all require additional research, development and demonstration (RD&D) to ensure responsible, permanent carbon removal that can be deployed at scale.

For example, low-cost durable storage will be challenging for pathways like soil carbon sequestration and improved forest management, for which hazards like wildfires and social and economic pressures that drive changes in land management practices can release removed CO_2. For other approaches like DACS, a significant challenge will be reducing the cost of capture directly from the atmosphere.

For all CDR approaches, it is necessary to develop methods to support and verify that pathways store CO_2 sustainably to ensure the nascent CDR industry is a responsible and responsive tool for global deployment.

CDR's Role in Addressing the Climate Crisis

Is CDR necessary to achieve net-zero by 2050?

Yes. Nearly all climate models showing pathways to meet net-zero greenhouse gas emissions by 2050 indicate the need for a near-term focus on CDR deployment *in addition to* deep decarbonization.

We are already experiencing the adverse impacts of climate change, and vulnerable, underserved communities are experiencing these impacts first and worst. These negative impacts will continue even under aggressive, deep decarbonization. CDR provides an opportunity to remove legacy CO_2 emissions and limit harm to climate vulnerable communities and nations.

How does CDR interact with other strategies to tackle the climate crisis?

Achieving net-zero emissions and minimizing the harm of the climate crisis requires:

- *CO_2-avoidance* technologies and practices, such as renewable energy, energy efficiency and land use conservation.

- *CO_2-reduction* technologies and practices in the industries that are hardest to decarbonize, such as point-source CCS for industry and switching to low-carbon fuels in shipping and aviation.
- *CO_2-removal* from ambient air and seawater through CDR approaches.

Avoidance and reduction of greenhouse gas emissions remains the U.S. Government's priority, and CDR must be pursued alongside aggressive decarbonization.

Why is DOE prioritizing investments in CDR?

CDR is one of the toughest remaining barriers to achieving net-zero: CDR approaches have not yet been demonstrated and deployed at scale and are currently cost prohibitive or lack technologies to assure removal. DOE launched Carbon Negative Shot to expand CDR RD&D in the near term to ensure that these approaches are available to be deployed in a just and sustainable way as we strive to meet our climate goals over the coming decades, recognizing that scaling can itself take decades.

Carbon Negative Shot's inclusive approach mobilizes the entire DOE RD&D enterprise—engineering, chemistry, geology and biology—to achieve the major innovation breakthroughs needed to achieve negative emissions at the scale required, while operating in a justice-based framework to ensure an equitable industry and advancements that benefit vulnerable climate populations.

What scale of CDR does the United States need to deploy by 2050?

The scale of necessary CDR in the United States will depend significantly on the country's ability to avoid emissions through CO_2-avoidance and CO_2-reduction activities. Reaching net-zero emissions requires a combination of avoidance, reduction and removal activities.

Even in scenarios with aggressive decarbonization, current estimates based on modeled pathways to net-zero suggest deployment of CDR on the gigaton-scale per year in the United States by 2050. To put this into perspective, one gigaton of CO_2 is equivalent to the annual emissions from the U.S. light-duty vehicle fleet, or emissions from approximately 250 million vehicles driven in one year.

Currently, CDR approaches remove a negligible amount of CO_2 (functionally 0 gigatons CO_2) via a limited set of pilot projects. To achieve climate goals, the nascent CDR industry must reach a scale similar in size to the global steel industry in terms of tons of material handled.

Note that CDR does not refer to existing systems that remove CO_2 from the atmosphere; for example, CDR does not include CO_2 removal through existing trees or by planting new trees to offset wildfire losses. CDR refers to intentional interventions that introduce new processes or bolster existing processes for the purpose of creating negative emissions.

Will RDD&D of CDR disincentivize critical decarbonization activities like renewable energy deployment?

Avoidance and reduction of greenhouse gas emissions (e.g., through the deployment of renewable energy or CCS for heavy industry) is the U.S. Government's priority. CDR is an additional, critical tool DOE supports to reach net-zero emissions by 2050 and is *not* a replacement for deep decarbonization. CDR must be pursued *alongside aggressive decarbonization*. Efforts around CDR will not replace or take away from ongoing work on avoidance and reduction of emissions at DOE.

Unfortunately, historic and ongoing greenhouse gas emissions are already sufficient to cause climate harm, especially to vulnerable communities. CDR provides an opportunity to limit harm to these communities by removing CO_2 that has already accumulated in the atmosphere. As an agency primarily focused on research and development, DOE will work in partnership with a variety of stakeholders to enable a suite of CO_2 avoidance, reduction and removal strategies.

Justice and Labor Considerations and Implications of CDR

What implications does CDR have for climate justice?

We are already experiencing the adverse impacts of climate change, and structurally marginalized, climate vulnerable communities and nations are experiencing these impacts first and worst. By removing CO_2 directly from the atmosphere and durably storing it to create negative emissions, CDR can reduce the amount of time we spend above global warming of 1.5 °C and limit the resulting climate harm to vulnerable communities. To achieve just approaches and outcomes of CDR, it is crucial that we work with local and global partners, especially in the global South, to ensure responsible RD&D of CDR approaches.

What stakeholders will be impacted by CDR?

Because CDR spans a wide array of technological, commodity, biological, land-based and ocean-based sectors and has significant implications for local economies and climate justice, CDR has a wide range of stakeholders. These stakeholders include but are not limited to:

- Communities most vulnerable to climate change
- Labor unions and communities with relevant skills and geographical locations (miners, agriculture, forestry, fossil fuels, power sector, etc.)
- Communities that implement CDR approaches
- Industry (new and existing)
- Academia
- Local, state and federal government
- Indigenous nations and communities
- Civil society organizations (environmental NGOs, environmental justice organizations, etc.)
- Global partners

Early and meaningful engagement across this range of stakeholders is critical to the success of CDR as the nascent CDR industry grows.

How is DOE incorporating justice considerations into CDR efforts?

CDR is a new, nascent industry, and as such there is an opportunity to build this industry so it is rooted in community needs. DOE is committed to pursuing CDR within an energy, environmental and climate-justice framework such that CDR maximizes benefits and minimizes harms for the most vulnerable communities. The nascent nature of CDR provides an opportunity to integrate equity and justice considerations throughout the development of this new industry. As the United States pursues RDD&D of CDR, we must operate in a justice-based framework to ensure an equitable industry and advancements that benefit vulnerable climate populations. This framework will include a focus on the following areas:

- Measurement of CDR investments against robust environmental justice criteria to avoid harm and provide equitably distributed benefits.
- Early, frequent and meaningful engagement with communities that could participate in or be affected by CDR, such as environmental and climate justice organizations, tribal nations, labor groups, industry and academia.
- Support of CDR methods that are diverse, have wide applicability across regions and allow for place-based approaches.
- Engagement with global partners to facilitate the use of CDR as a tool to address global climate justice.

How will DOE engage with labor and structurally marginalized communities that could participate in or be affected by CDR?

Ensuring the fair and just deployment of CDR means that there must be early, frequent and meaningful engagement with environmental justice communities, indigenous communities and tribal nations, labor groups and frontline communities.

Aligned with the U.S. Government, DOE is committed to operating in a justice-based framework throughout its CDR activities. Through the Carbon Negative Shot framework, DOE will hold a variety of engagement opportunities to inform our RDD&D activities. These conversations are particularly important to ensure the responsible development of the nascent CDR industry.

DOE's Office of Fossil Energy and Carbon Management (FECM), which leads DOE's CDR efforts, is working in close partnership with other offices in DOE, including the Office of Economic Impact and Diversity, the Office of Indian Energy and the Office of Energy Jobs to establish robust communication and engagement practices regarding the development of CDR.

What are the potential co-benefits of CDR approaches?

In addition to removing CO_2 from the atmosphere to limit harm to climate-vulnerable communities, many CDR approaches could have additional co-benefits (e.g., potential reduction of criteria air pollutants and job creation). The extent to which co-benefits are realized will depend on how CDR pathways are developed and deployed. Robust MRV mechanisms, safeguards and community consultation are required to maximize co-benefits.

What are the potential negative impacts CDR technologies could cause for communities?

Deployment of CDR on the gigaton-scale raises important concerns around land-use, energy-use and implications for local communities. It is critical to consider potential harms throughout the RDD&D phases to ensure that each pathway minimizes these potential harms while maximizing benefits for local communities. DOE is working to study these impacts and develop safeguards to minimize them across CDR approaches.

What does CDR mean for tribes and indigenous communities?

DOE is committed to tribal sovereignty and is prioritizing tribal consultation in its CDR work. Because the diverse set of CDR approaches allows for place-based solutions tuned to specific community needs, engagement with tribes and indigenous communities across the United States is essential.

FECM is working in partnership with the Office of Indian Energy to establish robust communication and engagement practices across its programs, including the development of CDR.

What does CDR mean for labor groups?

Deployment of CDR at the gigaton scale calls for advancing technologies so that the workforces of industries like agriculture, forestry, mining and manufacturing can participate in addressing the climate crisis by building CDR at scale.

For example, farmers, ranchers and foresters will be able to use CDR approaches like those supported by Carbon Negative Shot to attest they have removed carbon via soils, trees and products. Mining skillsets are potentially applicable to the enhanced mineralization pathway for CDR, which removes CO_2 through reactions with alkaline-rich materials.

Deployment of CDR on a gigaton-scale has the potential to create a significant number of jobs. For example, analysis has estimated that a hypothetical 1 megaton capacity DACS plant could generate roughly 3,500 jobs—both short- and long-term—across the sectors in the DACS supply chain.

DOE is committed to engaging with labor groups and communities to discuss job training opportunities and to ensure place-based considerations are integrally woven into CDR development and deployment.

CDR Costs and Markets

What markets exist for CDR?

CO_2 removal is currently driven by a small voluntary market.

45Q is a federal tax credit that incentivizes CO_2 utilization, sequestration and removal. Currently, 45Q provides:

- $35/ton for CO_2 stored geologically through enhanced oil recovery;
- $35/ton for other beneficial uses of CO_2 such as converting carbon emissions into fuels, chemicals or useful products like concrete; or
- $50/ton for CO_2 stored in geological formations and not used in enhanced oil recovery.
-

How is CDR distinct from existing carbon offsets?

A carbon offset is CO_2 emissions that are avoided, reduced or removed in order to compensate for emissions made elsewhere. Carbon offset markets allow for the purchase of carbon offset credits from a project designed to avoid, reduce, or remove greenhouse gas emissions. Because CDR approaches remove CO_2 directly from the atmosphere, they could be used to offset emissions from other hard-to-decarbonize sectors like aviation.

However, due to the lack of regulations and standards in carbon offset markets, ensuring offsets actually reduce emissions for the long-term is challenging. Permanently storing CO_2 that has been removed directly from the atmosphere has the potential to be more verifiable and robust than some current offset approaches based on promises of avoided emissions. Through Carbon Negative Shot, DOE is prioritizing the development of robust lifecycle analysis and MRV methods. These tools are essential to ensure CDR results in effective and permanent CO_2 removal.

Specific CDR Approaches

CDR refers to approaches that capture CO_2 directly from the atmosphere and durably store it in geological, biobased and ocean reservoirs or in value-added products to create negative emissions. The below is a non-exhaustive list with additional information on individual CDR technologies and approaches.

- **DACS** refers to technologies that use a chemical approach to capture CO_2 from ambient air and then durably store it. Today's leading approaches capture CO_2 by passing air over either solid sorbent materials or liquid solvents, which react selectively with the CO_2. After the CO_2 is captured from the atmosphere it is removed from the solvent or sorbent, typically by heating, enabling the solvent or sorbent to be re-used. To be a CDR approach, a direct air capture facility must be paired with durable storage, such as geologic sequestration or products with durable storage opportunities and result in negative emissions.

  In addition to removing CO_2, models have shown that DACS may be able to remove some quantity of other air pollutants like particulate matter (PM), nitrogen oxides (NO_x) and sulphur oxides (SO_x). However, these predictions have not been verified experimentally and more research is needed to determine the significance of this potential.

- **Biomass Carbon Removal and Storage (BiCRS)** describes a range of processes that use plants or algae to remove CO_2 from the atmosphere and store it underground or in long-lived products. CO_2 is produced from the combustion, gasification, or other conversion of low- or zero-carbon biomass, for example to generate electricity or produce hydrogen, and the resulting CO_2 emissions are captured and then stored in a manner that prevents it from reentering the atmosphere. Like DACS, infrastructure for geological sequestration or products with durable storage is required.

  One common type of BiCRS is bioenergy with carbon capture and storage (BECCS), which pairs plants' ability to capture CO_2 from the atmosphere with energy-producing technologies like power generation. BECCS works by generating electricity via burning biomass, which creates a high concentration CO_2 stream. That CO_2 can be captured and stored underground or in products. BECCS is distinct from to CCS because the original source of CO_2 is the atmosphere (through biomass) as opposed to fossil fuels. BECCS pathways do *not* include CO_2 captured and stored from the combustion of human-made waste, such as plastics commonly found in municipal solid waste streams, as those waste streams do not result in removal of carbon from the atmosphere.

- **Soil Carbon Sequestration** increases the carbon content of soil, resulting in a net removal of CO_2 from the atmosphere through changes in land management practices such as no-till agriculture, planting cover crops and compost application. These approaches rely on plants to remove CO_2 from the atmosphere via photosynthesis, which is then transferred into carbon stocks in the soil in the form of soil organic matter. Key challenges in soil carbon sequestration include ensuring durable, measurable and verifiable storage, as well as the large land requirements for deployment at scale.

- **Afforestation/Reforestation** uses forests to remove CO_2 from the atmosphere by growing forests on land where there was never a forest (afforestation) or where there was once a forest (reforestation). Trees remove CO_2 from the atmosphere as they grow and can potentially store that carbon for long periods of time. Similar to soil carbon sequestration, challenges in forest management CDR approaches include ensuring durable, measurable and verifiable storage and the large land requirements for deployment at scale.

- **Enhanced Mineralization** (also known as enhanced weathering or accelerated weathering) refers to processes that accelerate the natural mechanisms whereby CO_2 from the atmosphere reacts with certain minerals or rocks and is permanently stored. Specifically, CO_2 reacts with alkaline materials (such as magnesium and calcium) to form solid carbonate minerals. Sources of alkalinity can be naturally occurring rocks like basalt or waste material from industrial or mining operations.

There are several types of mineralization processes: in situ (e.g., CO_2 reactions in geologic formations underground), ex situ (e.g., CO_2 reactions that involve extraction, transport, and grinding of minerals) and surficial (e.g., CO_2 reactions with minerals distributed across land or coastal areas). Enhanced mineralization can help stabilize and permanently store waste from certain industries like mine tailings. Additional research is needed to assess this potential across different waste streams and ensure real benefits in environmental remediation are seen by local communities.

- **Ocean-based CDR** refers to processes that amplify of the ocean's biological and abiotic carbon pumps, which pull CO_2 from the atmosphere and transport the carbon into the deep ocean and marine sediments. These approaches can be biological, chemical/physical or hybrid. Examples of ocean-based approaches include **s**eaweed cultivation for carbon sequestration, ocean alkalinity enhancement, direct ocean capture or coastal blue carbon.

Specific CO_2 Storage Approaches: What Must Happen to CO_2 to Be Considered Removal?

For some CDR approaches CO_2 is removed from the atmosphere and durably stored in a single step (e.g., afforestation/reforestation, where trees absorb and store CO_2 at the same time). Other CDR approaches have separate removal and storage processes (e.g., DACS and BECCS). Below are two examples of methods that can be used to durably store CO_2.

- **CO_2 Conversion** involves the conversion of CO_2 into products. CO_2 can be converted through carbon mineralization, chemical or biological means. The process is called CO_2 conversion regardless of whether the CO_2 is captured from a point source via carbon capture (e.g., industrial plant with CCS) or from the atmosphere (i.e., CDR). The term "CO_2 conversion" is used to refer to products that store carbon for both short periods of time (e.g., fuels) and long periods of time (e.g., building materials and plastics). Some—but not all—types of carbon utilization could be part of a negative emissions CDR approach.

  For CO_2 conversion to be a part of a CDR approach, the CO_2 must be directly removed from the atmosphere, converted into long-duration storage products *and* result in negative emissions for the overall process. An example of carbon utilization that is part of a CDR pathway is atmospheric carbon removal (e.g., through DACS) and utilization in aggregates for concrete that result in negative emissions.

- **Geologic Storage** involves injecting CO_2 into rock formations deep underground, where it remains stored for thousands of years or more. Geologic sequestration (also referred to as geologic storage) can be paired with a variety of removal pathways as part of CDR, including DACS and BECCS to permanently store CO_2. It is also relevant for emission reduction technologies like CCS. Estimates indicate that the United States has billions of tons of capacity for geologic storage, or more than 5,000x its 2018 CO_2 emissions.

Learn More About CDR: What Resources are Available?

As CDR is a nascent field, the terminology and understanding of these technologies is evolving. These referenced organizations and reports do not represent the views of the U.S. Department of Energy, and providing this information is not an endorsement of these reports or organizations. This list is provided to support education and awareness, and readers are encouraged to seek additional information and resources outside of the short list identified.

Reference List

- American University. 2020. "Fact Sheet: Enhanced Mineralization." Accessed on November 2, 2021. https://www.american.edu/sis/centers/carbon-removal/fact-sheet-enhanced-mineralization.cfm
- American University. 2020. "Fact Sheet: Forestation and Carbon Removal." Accessed on November 2, 2021. https://www.american.edu/sis/centers/carbon-removal/fact-sheet-forestation.cfm
- American University. 2020. "Fact Sheet: Soil Carbon Sequestration." Accessed on November 2, 2021. https://www.american.edu/sis/centers/carbon-removal/fact-sheet-soil-carbon-sequestration.cfm
- Carbon180. "Agricultural Soil Carbon" Fact Sheet. Accessed on November 2, 2021. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/602b5c52f4275a2cb115f164/1613454423228/Carbon180+Ed+Packet+Agriculture.pdf
- Carbon180. "Bioenergy with Carbon Capture and Storage (BECCS)" Fact Sheet. Accessed on November 2, 2021. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/602b5c259cb534098dccc0a7/1613454463819/Carbon180+Ed+Packet+BECCS.pdf
- Carbon180. "Carbon Use" Fact Sheet. Accessed on November 2, 2021. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/602b5c3e64681006f654b313/1613454404910/Carbon180+Ed+Carbon+Use.pdf
- Carbon180. "Direct Air Capture" Fact Sheet. Accessed on November 2, 2021. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/602b5c61fcd7254f1bd13f9f/1613454437930/Carbon180+Ed+Packet+DAC.pdf
- Carbon180. "Forest Carbon Removal" Fact Sheet. Accessed on November 2, 2021. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/602b5c7110a23e723d4e06db/1613454456899/Carbon180+Ed+Packet+Forestry.pdf
- Carbon180. "Geologic Carbon Storage" Fact Sheet. Accessed on November 2, 2021. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/608202c0e117a10a93849313/1619189650359/Carbon180+ENG+FactSheet+GeologicStorage.pdf

- climateworks Foundation. "Ocean Carbon Dioxide Removal (CDR)." Accessed on November 2, 2021. https://www.climateworks.org/programs/carbon-dioxide-removal/oceans/
- D. Sandalow, R. Aines, J. Friedmann, C. McCormick, D. Sanchez. 2021. B*iomass Carbon Removal and Storage (BiCRS) Roadmap.* ICEF. https://www.icef.go.jp/pdf/2020/roadmap/roadmap.pdf
- Energy Futures Initiative. 2019. *Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies.* https://energyfuturesinitiative.org/efi-reports
- IPCC. 2018. *Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* World Meteorological Organization: Geneva, Switzerland. https://www.ipcc.ch/sr15/chapter/spm/
- J. Goodward and A. Kelly. 2010. *Bottom Line on Offsets.* Washington, DC: World Resources Institute. https://www.wri.org/research/bottom-line-offsets
- J. Wilcox, B. Kolosz and J. Freeman. 2021. *CDR Primer. Available at* https://cdrprimer.org/
- K. Lebling, N. McQueen, M. Pisciotta and J. Wilcox. 2021. *Direct Air Capture: Resource Considerations and Costs for Carbon Removal*. Washington, DC: World Resources Institute. https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal
- K. Paustian, E. Larson, J. Kent, E. Marx and A. Swan. 2019. *Soil C Sequestration as a Biological Negative Emission Strategy.* Frontiers in Climate. https://www.frontiersin.org/article/10.3389/fclim.2019.00008
- National Academies of Sciences, Engineering, and Medicine. 2019. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25259
- Ocean Visions. "Harnessing the Power of the Ocean to Restore the Climate and the Ocean" Fact Sheet. Accessed on November 2, 2021. https://oceanvisions.org/wp-content/uploads/2021/10/Ocean-Based-CDR-factsheet_FINAL.pdf
- Rhg.com. 2021. *Capturing New Jobs: The employment opportunities associated with scale-up of Direct Air Capture (DAC) technology in the U*.S. Accessed on November 3, 2021. https://rhg.com/wp-content/uploads/2020/06/Capturing-New-Jobs-Employment-Opportunities-from-DAC-Scale-Up.pdf> [Accessed 3 November 2021
- U. Kosar and V. Suarez. 2021. *Removing Forward: Centering Equity and Justice in a Carbon-Removing Future.* Washington, DC: Carbon180. https://static1.squarespace.com/static/5b9362d89d5abb8c51d474f8/t/6115485ae47e7f00829083e1/1628784739915/Carbon180+RemovingForward.pdf
- U.S. Department of State and U.S. Executive Office of the President. 2021. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050.* https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf