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ISSUE BRIEF

ENVIRONMENTAL LEADERSHIP CAN SHAPE THE FUTURE OF CARBON REMOVAL

Authors: Sam F. Savitz, Jennifer DiStefano, Alex Hillbrand, Carrie Schoeneberger

The world will almost certainly overshoot the 1.5 °C global warming limit set by the Paris Climate Agreement, potentially by a considerable margin. According to scientific experts, reducing greenhouse gas (GHG) emissions will no longer be enough. In addition to the GHGs already in the atmosphere, global systems like agriculture and heavy industry continue to produce billions of tons of emissions each year that may be impossible to fully eliminate. To address climate change, we must now accelerate carbon dioxide removal (CDR) solutions that can absorb carbon dioxide (CO_2) directly from the atmosphere, alongside emissions reduction and adaptation.

As CDR scales from small projects to a meaningful climate tool, the environmental community—including both advocates and policymakers—has a critical window to shape how CDR pathways and policies develop. Environmentalists bring essential assets to these efforts: experience navigating complex environmental trade-offs, technical and policy expertise, knowledge of health and community concerns, trusted relationships with frontline communities, and a proven ability to build coalitions.[1] Our engagement can involve more than harm reduction alone. **We, the environmental community, can actively guide CDR toward responsible development while maintaining ambition on emissions reduction.**

Fans pulling in large volumes of ambient air at Climeworks' Orca direct air capture plant (a form of CDR) in Iceland.

For more information, please contact:
Emily Deanne
edeanne@nrdc.org

CARBON DIOXIDE REMOVAL IS NO LONGER OPTIONAL

There is no longer a plausible route to climate stability[a] without large-scale CDR.[2] In the past, it might have been possible to stay within 1.5 °C of warming above preindustrial levels by reducing GHG emissions alone. As recently as 2014, some scenarios showed that such an outcome was still on the table—but only with swift decarbonization.[3] However, the continued growth of global emissions has unfortunately foreclosed that path; leading scientific authorities now agree that we are on track to overshoot that level, with irreversible consequences for both humans and nature.[4] Reducing GHG emissions is essential but no longer sufficient; we now must also remove CO_2 already in the atmosphere.[5]

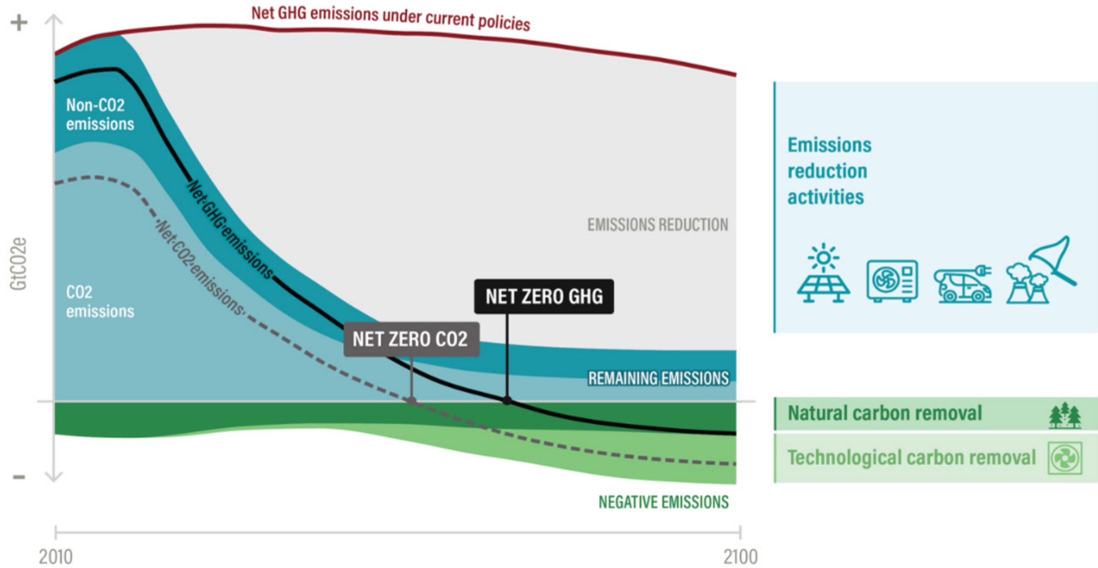
The scientific consensus on this point is clear: CDR is necessary to reach the goal of net zero by mid century (figure 1) and to eventually bring temperatures back down below the 1.5 °C threshold.[6] Even if all of humanity's CO_2 emissions stopped overnight, the planet's average temperature would remain near current levels, and the climate change–fueled harms we are already experiencing would continue for decades.[7] Billions of tons of CO_2 will likely need to be removed globally each year by 2050, according to estimates from the U.N. Intergovernmental Panel on Climate Change (IPCC).[8] The U.N. Environmental Programme (UNEP) said in a recent report on limiting overshoot that this will require global policy action on both scaling and governance within the next decade for CDR to reach sufficient scale.[9]

Our task now is undoubtably complex: We must redouble our efforts to reduce GHG emissions, invest in resilience and adaptation, and *also* lay the groundwork for responsible CDR deployment.[b] There are legitimate concerns about CDR, but with the right policies in place, we can reduce costs and address the social, environmental, and economic questions CDR poses.

A flooded neighborhood in Waialua on the north shore of Oahu, Hawai'i, on March 20, 2026. As global temperatures climb above the 1.5 °C threshold, climate change-fueled disasters will become more frequent and severe.

Figure 1: The role of carbon dioxide removal in reaching net zero

Carbon removal, combined with emissions mitigation, is necessary for minimizing overshoot of the 1.5 °C warming limit. The red and black lines represent the trajectory of net global emissions (i.e., emissions minus removals) under "business as usual" and in a representative "1.5 °C–aligned scenario," respectively. The dashed line is similar but excludes non-CO_2 GHGs. "Technological carbon removal" includes the methods categorized in this brief as technological, geochemical, and biomass-based.



Source: WRI.

a NRDC's working definition of "climate stability" involves minimizing the extent and the duration of overshooting 1.5 °C warming above preindustrial global mean temperature (the goal set in the Paris Agreement) and striving to bring global temperatures back down below this limit through concerted and sustained action.

b There is growing discussion of other potential strategies to cope with climate overshoot, such as accelerated mitigation approaches to climate "superpollutants" and even solar radiation management research. NRDC has efforts underway to evaluate these other strategies, though they are not discussed in this document.

WHAT IS CDR AND WHY IS IT NEEDED?

CDR is not a single technology but rather a family of pathways (figure 2) with a shared goal: to capture CO_2 from the atmosphere and lock it away. CDR consists of activities that expand the earth's natural carbon sinks (such as forests and soils),[c] accelerate those natural carbon storage processes, or technologically extract CO_2 from air and water.

These pathways collectively have two core roles in the global climate strategy:[10]

- Counterbalancing ongoing emissions from harder-to-abate sectors where full decarbonization proves to be technologically, socially, or economically infeasible.
- Removing legacy emissions already present in the atmosphere at unsafe levels.

Addressing climate change will require reducing emissions as much as possible, as fast as possible, across the entire economy. However, there are some sources of GHG pollution for which full decarbonization is still decades away at best. These harder-to-abate sectors include things like agriculture, aviation, shipping, and heavy industry.[11] While many options exist to lower these emissions, we do not yet have technologies that can fully eliminate them. CDR can compensate for the remaining emissions from these harder-to-abate sectors.

CDR is also our only tool to remove legacy emissions already present in the atmosphere. The longer we delay serious climate action—and the more we overshoot 1.5 °C—the more CDR will be required to combat past pollution.[12]

In both roles, CDR is an essential complement to—not a substitute for—deep emissions reductions.[13] For most sources of emissions, replacing them with a cleaner alternative remains cheaper and more effective than CDR. In *all* IPCC modeling scenarios, emissions reductions are the primary means of achieving net zero.[14] Neither CDR nor clean energy can solve the climate crisis on its own.

Figure 2: Overview of prominent CDR pathways

Any method of removing carbon from the atmosphere (or oceans) can be considered CDR. Each pathway consists of a method of removal (or capture) that separates CO_2 from the air or water and a method of storage that keeps the carbon from returning to the atmosphere. Some methods rely on transporting carbon from one location to another, such as biomass collection or CO_2 pipelines. This report classifies CDR methods into four categories. Ecosystem-based CDR (also known as natural or nature-based) is by far the most widespread; other varieties are at earlier stages of development.

CDR PATHWAY	DESCRIPTION	CO_2 CAPTURE METHOD	STORAGE MEDIA
Reforestation and improved forest management	Restoring and better managing forests for increased carbon uptake	Photosynthesis and decomposition in soils	Living biomass and soils
Soil carbon sequestration	Agricultural techniques that store more carbon in soil (e.g., cover cropping)		
Coastal ecosystem and wetland restoration	Restoring carbon-rich, anoxic eco-systems (e.g., mangrove, peatland)		
Long-lived wood products	Harvesting and converting trees or other biomass into long-lived products	Photosynthesis by trees or crops	Structural timber and other products
Biomass carbon removal and storage (BiCRS)	Converting harvested plants into durable biomass that resists decomposing via burial, pyrolysis, anaerobic digestion, etc.		Various: buried biomass, biochar in soils, bio-liquids injected underground, geologic CO_2 storage
Marine biomass sinking	Cultivation and sinking of photo-synthetic organisms in the ocean	Photosynthesis (e.g., by phytoplankton, kelp)	Biomass sunk into the deep ocean
Enhanced rock weathering	Crushing up reactive rocks to increase surface area, spreading them in soils	Chemical reaction between water and CO_2 breaks down rocks	Bicarbonate ions that eventually reach the ocean
Ocean and riverine alkalinity enhancement	Introducing natural or artificial sources of alkalinity to rivers and oceans	Alkaline materials dissolved in water induce CO_2 absorption	
Direct air capture (DAC)	Using technology to pull CO_2 out of the air via chemical filters	Capture from ambient air through solvents or sorbents	Geologic storage of CO_2 (e.g., in deep saline formations)
Direct ocean capture	Separating CO_2 from seawater electrochemically	Capture from ocean water, which induces more CO_2 absorption from air	

Ecosystem Biomass Geochemical Technological

Source: Adapted from Carbon Gap.

c As explained below, while expanding the earth's natural carbon sinks via CDR is vital, our most important existing sinks must also be protected.

CDR IS NOT THE SAME AS CARBON CAPTURE

Both CDR and carbon capture and storage (CCS) fall under the umbrella of "carbon management." CDR removes CO_2 already in the atmosphere, while CCS reduces the amount of CO_2 emitted from existing sources, namely industrial facilities and power plants. CCS can be most useful in industrial applications, such as cement-making, that cannot be fully decarbonized with electrification and clean energy. CCS relies largely on engineered systems that capture CO_2 directly from a facility's waste (or "flue") gases using chemicals or other separation methods.

CDR encompasses a wider range of capture and storage methods, including biological processes; different approaches are required because CO_2 in flue gases is much more concentrated (3–99 percent, depending on the facility type) than CO_2 in the atmosphere (0.04 percent).[15]

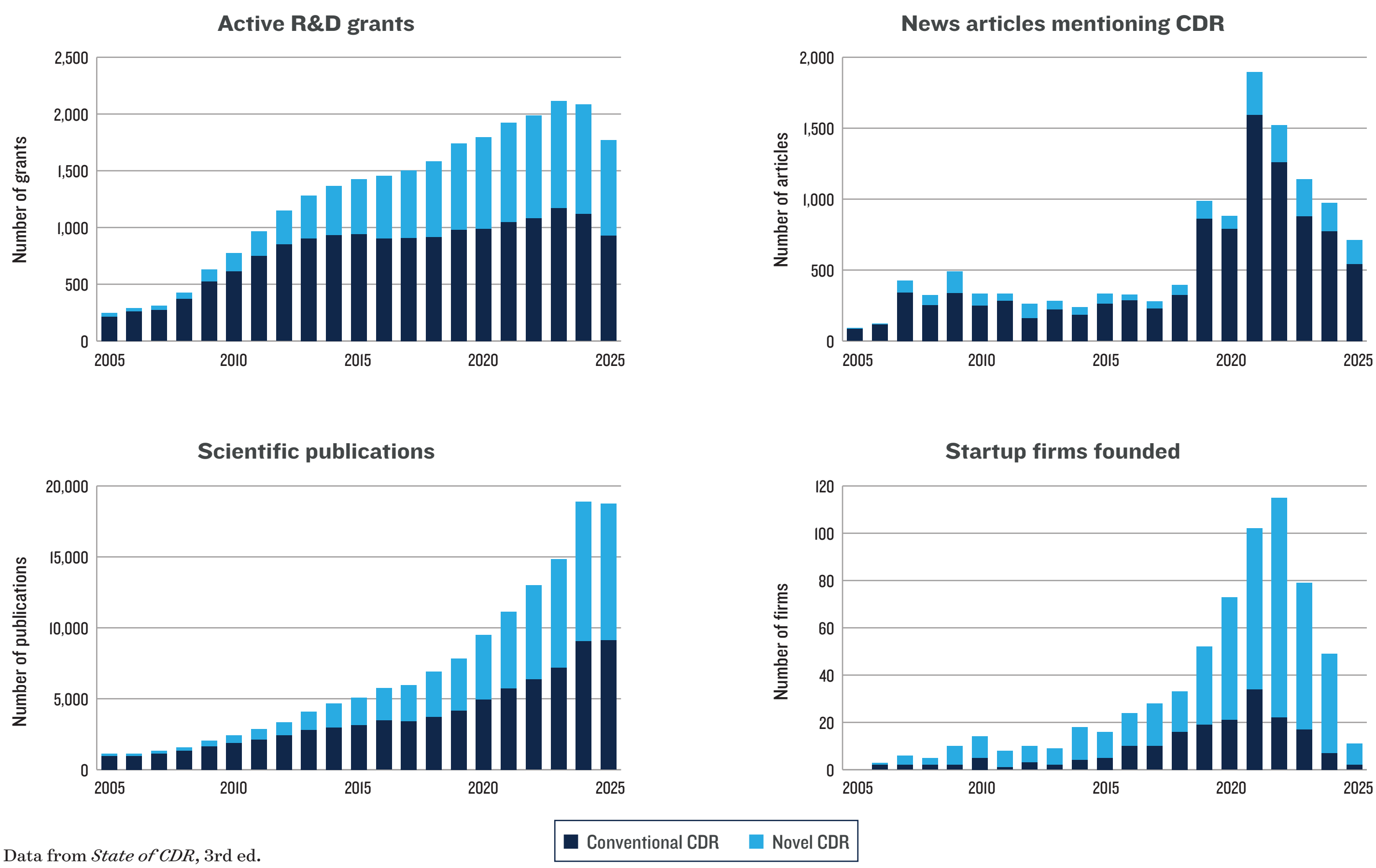
CDR and CCS share some technological similarities and use some of the same methods to capture, transport, and store CO_2, including pipelines and geologic storage wells. They will be deployed in different places and circumstances, however, and raise different considerations for the protection of equity, human health, and nature. They will therefore require divergent approaches for policy and responsible implementation.

MOMENTUM IS BUILDING, BUT CDR STILL NEEDS TO GROW DRAMATICALLY

For decades, discussion of CDR was confined largely to academic literature, speculative fiction, and rhetoric from the fossil fuel industry. But more recently, the field has seen a surge in activity. Calls to action from scientific authorities, such as the IPCC and the National Academies, have driven billions of dollars of government funding (both in the United States and globally) and private investment into CDR (figure 3).[16] This investment reflects the high up-front cost of moving a technology from lab to market, a process that is still ongoing for many CDR pathways.

Figure 3: CDR interest, investment, and innovation have been growing

CDR has seen increased global momentum over the past several years, reflected in government grants, academic publications, technology start-ups, and news coverage. Both "conventional" (in dark blue) and "novel" pathways (in light blue) have seen growth in these metrics. Conventional CDR includes afforestation, reforestation, and forest management; coastal and peatland wetland restoration; durable wood products; and soil carbon sequestration. Novel CDR includes BiCRS, DAC, direct ocean capture, enhanced weathering, ocean alkalinity enhancement, and ocean fertilization.



Data from *State of CDR*, 3rd ed.

Despite this momentum, CDR is still a long way from reaching the levels that the IPCC and other experts say are necessary. Even with aggressive emissions cuts, 7 to 11 billion metric tons per year of CDR will be necessary by 2050 to constrain long-term warming to 1.5 °C with limited overshoot in the interim,[d] according to an analysis of more than 400 climate models.[17] The median scenario requires 4.5 billion tons of "novel" CDR per year,[e] a tremendous undertaking roughly equivalent to capturing and storing the current annual GHG emissions of India.[18] Currently, these novel pathways remove only about 2 million (0.002 billion) tons[f] of CO_2 each year.[19] That is roughly equivalent to the amount of CO_2 emitted globally every 27 minutes.[20] Only about half of that amount is CDR[g] with durable geologic storage.

Notably, we will need to remove billions of tons of CO_2 annually *in addition to* preserving the world's existing natural carbon sinks (e.g., oceans, forests, soils), which store the equivalent of roughly 22 billion tons of CO_2 each year.[21] Over time, the capacity of these natural sinks may decline as climate change worsens.[22] Reaching our climate targets will require preserving and enhancing those natural carbon sinks by building on the decades of work that have gone into protecting the world's forests, oceans, and other natural ecosystems.[23]

Ideally, the lower end of CDR estimates will prove sufficient. The best-case scenario is to limit temperature overshoot beyond 1.5 °C as much as possible; faster emissions reductions would mean less CDR is needed.[24] Yet we are dangerously far from that trajectory; we need to be prepared for a world in which more CDR will be necessary. Every fractional degree of warming will matter tremendously in terms of its human and environmental costs; every incremental amount of CDR we can deploy may prevent some of that warming. There may end up being practical limits to the amount of CDR that can be deployed responsibly and with the resources available. But we are much closer to a world in which we will not have the CDR capacity we need than we are to one in which we have deployed too much CDR.

Regardless of the ultimate target, CDR deployment at scale will require vast mobilization of public and private resources. While daunting, billion-ton-scale CDR is not out of reach. The growing interest and investment in CDR provides a window of opportunity for environmental advocates and policymakers to spark and steer responsible scale-up.

CONCERNS ABOUT CDR SHOULD INFORM, NOT PREVENT, ACTION

There has been reasonable skepticism about CDR, including within the environmental community. The concerns generally fall into four categories:

- **Delayed action:** CDR will enable GHG polluters to continue emitting.
- **Technical and cost feasibility:** CDR is too expensive to ever be a workable climate solution.
- **Infrastructure safety:** CO_2 infrastructure should not be deployed because it is inherently unsafe.
- **Misaligned incentives:** CDR investment will be a windfall to fossil fuel interests or will support projects that do more harm than good.

These are legitimate concerns that require careful consideration, but they are not insurmountable. In the face of temperature overshoot and continually delayed climate action, the need for CDR has become even more acute. We can no longer take a wait-and-see approach. If CDR cannot be deployed economically and responsibly when we need it, we may be unable to rein in overshoot and blunt the most extreme impacts of climate change, wreaking havoc on people and nature. UNEP's recent report emphasizes that "the next decade is crucial for effective and just CDR," including development of both incentives and governance frameworks.[25]

Environmental advocacy and policy should focus on addressing concerns about CDR, mitigating risk as much as possible, and creating the conditions under which CDR can still scale as needed.

Delayed Action

CDR has faced headwinds because of the reasonable concern that it could give fossil fuel companies a free pass to continue emitting, which would delay decarbonization efforts, expose frontline communities to ongoing air and water pollution, and prolong our reliance on fossil fuels. Climate adaptation conversations in the mid to late 2000s saw similar debates about the "moral hazard" of deviating from an exclusive focus on emissions reduction. At the time, many in the environmental movement worried that preparing for climate impacts would reduce the urgency to cut emissions; adaptation became, for a time, viewed as a distraction from emissions reduction, including at NRDC.

d "Limited overshoot refers to exceeding 1.5 °C global warming by up to about 0.1 °C and for up to several decades," according to the Summary for Policymakers for IPCC's *Climate Change 2022: Mitigation of Climate Change*, by Shukla et al.

e Afforestation, reforestation, and other land use changes resulting from human intervention remove about 2 billion tons of CO_2 each year, according to the 2024 *State of Carbon Dioxide Removal* report by Geden et al. Despite this, due to deforestation and other exploitation, land use remains a major net source of emissions.

f This figure comprises 72 percent biomass CDR with biochar storage (solid carbon produced via pyrolysis), 25 percent biomass CDR with gaseous CO_2 storage, and 4 percent all other methods combined (totals do not sum to 100 percent due to independent rounding).

g No method of carbon storage is totally immune to "reversal," or release back to the atmosphere, but some pathways can reliably store carbon on scales more relevant to climate change. European Union regulations, for instance, define "permanent" CDR as pathways that "under normal circumstances" store carbon "for several centuries." Most, but not all, of these permanent pathways rely on some form of underground geologic carbon storage.

With the benefit of hindsight, we now see this caution as ultimately counterproductive: Emissions kept rising, and communities remained unprepared. **Today, we realize mitigation and adaptation work hand-in-hand.**[26] **We must reject a similar false binary when it comes to CDR.** Labeling CDR in its entirety as a false solution risks luring us into a similar trap, ignoring and underinvesting in a critical climate tool until it is too late.

Technical and Cost Feasibility

Nor is the cost of CDR a reason not to pursue it. CDR is always going to be more expensive than first-line climate solutions like renewable energy; it is difficult to put a billion tons of toothpaste back in the proverbial tube. In recent data, average prices for different permanent CDR pathways range from $100 to $1,300 per ton of CO_2 removed.[27] But the alternative—missing our climate targets entirely and experiencing the ensuing societal, ecological, and economic devastation—would be even more costly.

And these high costs will go down. Current prices reflect the early stage of development of many CDR pathways and the expected costs of first-of-a-kind projects. As CDR continues to mature and more projects are built, developers will learn from real-world experience and achieve economies of scale, leading to lower costs. Sustained policy support will be critical to achieving this, just as government-backed innovation has lowered the costs of many other climate technologies.

Finally, regardless of cost, CDR will always face the economic hurdle that it provides a collective environmental good with limited inherent market value. CDR is essentially waste management—except that the unmanaged waste piles up quietly in the atmosphere, rather than in backyards and rivers. Managing that waste will require sustained efforts, including government investment and establishing polluter responsibility. The environmental community has successfully advocated in the past for reparative action to address pollution. Climate change is a problem of staggering scale, but the same moral and legal principles that govern other types of pollution still hold sway. Threats to society and nature demand decisive action; environmental advocates have historically been at the forefront of galvanizing that action.

Infrastructure Safety

There are very real reasons for caution when designing and deploying CDR projects; one source of inherent risk for many permanent CDR pathways is the need for CO_2 pipelines and storage. Concerns about safety, as well as environmental damage during construction, have fed opposition to CDR. While CO_2 infrastructure has a fairly good safety record,[h] accidents have happened.[28] These accidents highlight the need for guardrails such as robust safety and construction regulations, public participation, safety and emergency response protocols, monitoring requirements, and incentives to encourage co-location of removal and storage facilities.[29]

Nonetheless, even with a perfect regulatory framework, moving CO_2 around will never be completely risk free; any type of pipeline, even water or sewage, involves risk.[30] Deploying CDR at a meaningful scale will require determining the acceptable level of risk, much as we must for other critical infrastructure like power lines, roads, and dams. Environmental advocates and policymakers should have a hand in shaping these decisions and ensure that equity, health, and nature are all included in the calculus.

Misaligned Incentives

Right now, the loudest voices in the pro-CDR conversation come from industry, including fossil fuel companies, agribusiness, and corporate CDR buyers (especially Big Tech). This industry dominance, along with the insufficiency of the current regulatory environment, has enabled investment in some projects where harm outweighs any climate benefit. There have been projects, nominally intended to remove CO_2, that have failed to deliver and/or come at an unacceptable cost to communities, health, or nature (see "Cautionary Tales" text box).

CAUTIONARY TALES FROM PRIOR CARBON MANAGEMENT EFFORTS

Industry dominance, along with an incomplete policy and regulatory framework, has enabled investment in projects antithetical to climate or environmental goals, such as:

- biomass-based projects that have harmed old-growth forests and local air quality while failing to deliver promised carbon benefits;[31]
- open-ocean iron fertilization experiments—a proposed pathway for marine CDR—without proper oversight and notification, prompting condemnation from the International Maritime Organization and marine pollution treaty signatories;[32]
- voluntary forest carbon offsets[i] that have been plagued with integrity issues, including systematic over-crediting, leakage, outright fraud, and harm to Indigenous peoples and vulnerable populations;[33]
- carbon management projects that use CO_2 for "enhanced oil recovery," which can wipe away the climate benefits of CDR and greenwash fossil fuel production.

h Since CO_2 pipelines were first regulated in the United States, in 1988, they have caused no reported fatalities, and serious injuries have been rare. CO_2 accidents have been less costly on average than other pipeline failures, with fewer remediation costs. In 30 years of data on dedicated geologic storage, there have been no reported major leaks from storage sites around the world. See citations in endnote 28.

i Carbon offsets are financial tools used to encourage decarbonization. CDR is often conflated with carbon offsets, but many (if not most) offsets are *not* CDR. CDR projects must prove that they have measurably lowered the existing amount of CO_2 in the atmosphere. Offsets, on the other hand, merely must show that emissions that might have happened were prevented.

In the absence of an existing framework for responsible CDR, the nascent CDR industry and buyers have taken tentative steps toward establishing best practices. But existing frameworks have not prevented the kind of projects that cause harm, waste precious resources, and undermine trust in CDR. Communities, especially overburdened and frontline communities, fear becoming a testing ground for another emerging technology without the environmental health implications and potential hazards being fully understood. The only way to mitigate these risks is for advocates and, eventually, governments to advance a vision for responsible CDR. Staying on the sidelines only perpetuates the current dynamic.

We must make it abundantly clear, repeatedly and publicly, that CDR is needed to address emissions from harder-to-abate sources and legacy emissions; it is *not* a free pass for the fossil fuel industry.

THE ROLE OF ADVOCACY IN ADVANCING RESPONSIBLE CDR

The concerns and challenges discussed above do not justify inaction—instead, they make it imperative that the environmental community advocate for and implement CDR policies with the right safeguards in place. Large-scale CDR deployment is not without risk, but this risk can be managed. The current moment—with CDR gaining momentum but far from reaching the necessary scale—presents a critical opportunity for environmental advocates and policymakers to shape the role that CDR will play in helping the world reach its climate goals.

We must make it abundantly clear, repeatedly and publicly, that CDR is needed to address emissions from harder-to-abate sources and legacy emissions; it is *not* a free pass for the fossil fuel industry and others with clear emissions reduction options. CDR does not diminish the urgency of addressing non-GHG pollutants, nor should it change the advocacy and regulations that hold polluters to account. Our role is to maintain these distinctions through dedicated policy and prevent CDR from becoming an excuse for delayed action.

At the same time, GHG emissions are typically not the only pollutant coming from fossil fuel plants. Frontline communities are rightfully concerned that diverting focus from emissions reductions will allow harmful air and water pollutants into their neighborhoods. These communities will require technical resources, informed advocacy, and support in order to accept CDR infrastructure on the ground.

The environmental community and its partners—by virtue of our resources, credibility, experience, and technical knowledge—are uniquely positioned to advance a vision for responsible CDR. This vision will have to balance two separate goals: protecting communities, human health, and nature while scaling CDR to the levels necessary to achieve net zero. If we are to reach billion-ton CDR within a few decades, it will require appropriately managing risks and trade-offs.

OUR VISION FOR RESPONSIBLE CDR

A vision for responsible CDR must do more than divide projects into "good" and "bad." It requires navigating some short-term costs for the sake of long-term benefits. It requires consideration of options that may have previously been ruled out as too impractical or risky. It requires investing in efforts that might not pan out. And it requires, at times, allying ourselves with political and economic forces with whom we might otherwise disagree.

This pragmatic approach also means keeping multiple options for CDR on the table. We must be clear-eyed that there is no silver bullet for CDR. Pathways vary in terms of technological readiness; cost; measurability; storage permanence; and potential health, social, and environmental impacts. No single pathway outperforms all others in all dimensions, and no pathway can provide sufficient scale on its own to meet the global need.

Different types of CDR will inevitably have physical and practical limitations, whether from geophysical interactions or from resource availability. For instance, there is only so much land that can be reforested without ecological disruption or impingement on food crops and other essential land uses; DAC may be limited by the availability of clean energy.

Moreover, the optimal CDR end state will most likely be one with a diversity of pathways that can contribute in different ways to achieving our climate goals. Ecosystem-based pathways may be the cheapest option and allow near-term deployment. But they can reliably store carbon only on the scale of decades and are more vulnerable to reversal than other alternatives. They should be part of the solution but will not be sufficient on their own.[34] Novel technologies that can store carbon for centuries to millennia will have to play a large role by mid century, even if they come with a higher price tag, greater infrastructure needs, and other uncertainties.

But CDR does not always have to be treated as a bitter pill to swallow. Some CDR projects can bring additional benefits beyond their CO_2 impact, such as creating jobs and economic activity, protecting natural landscapes, adapting to climate

Natural basalt formations at Stuðlagil Canyon in Iceland. Basalt and other magnesium-rich minerals can be used for geochemical CDR.

effects, and supplying low-emissions products that durably store carbon. These benefits can be scientifically validated and integrated into project planning.[35]

The nascent CDR industry also offers a relatively blank canvas and possibilities for transformative change. For many types of infrastructure—including other climate and clean energy solutions—community input and consent have been treated as an afterthought.[36] Communities—especially historically disadvantaged ones—face structural barriers to effective engagement; they often have less time, money, information, and political power than project developers or government agencies.[37] CDR projects can follow a different paradigm, one that that centers community consent, accountability, and good governance.

CDR also offers an opportunity to take a more just approach to global climate accountability. Though wealthy countries have contributed disproportionately to GHG pollution, the worst impacts of climate change will fall hardest on the planet's vulnerable populations. CDR—one of the few ways to directly remediate existing damage to the climate—offers an opportunity for wealthy countries, including the United States, to take responsibility for their past pollution. The United States also has the technological and financial resources to get CDR off the ground. As part of a comprehensive path to limiting temperature rise, CDR can also aid vulnerable populations by averting worse climate outcomes.

KEY PRINCIPLES OF RESPONSIBLE CDR

It is essential to steer CDR development toward responsible, beneficial projects and policies. NRDC has developed a set of principles (figure 4) that represent our vision and guiding priorities for responsible CDR. These principles define the outcomes NRDC hopes to see and are meant to provide direction as we advocate for policies to grow global CDR capacity. The following nine principles apply to all carbon removal pathways and all parts of the CDR value chain (removal, transport, and storage).

Climate Principles

- **GHG Emissions Reductions as the Primary Climate Protection Tool:** Rapid, deep reductions in GHG emissions remain the most important aspect of climate protection. CDR should supplement, not replace, activities that reduce existing emissions, and emission reductions should be the dominant component of a comprehensive climate portfolio. CDR policies, projects, and investments should minimize diversion of investments from critical emissions abatement and/or adaptation programs.
- **Unambiguously Net-Negative Carbon Removals:** Carbon removal projects must have net-negative emissions across their entire life cycles, especially when used to generate credits or meet regulatory requirements. The amount of carbon removed and sequestered should be accurately, transparently, and verifiably quantified using credible scientific methodologies and cradle-to-grave emissions accounting. CDR projects should be able to demonstrate additionality relative to a credible baseline. Policies should account for the time value of carbon—i.e., the fact that removing a ton of CO_2 today is more valuable than removing a ton in the future.
- **Durable Carbon Storage with Credible MMRV:** All CDR projects or claims should be supported by robust and enforceable measurement, monitoring, reporting, and verification (MMRV) protocols to substantiate net-negativity and carbon storage permanence. Organizations and companies involved in CDR should be obligated to share methodologies and data with regulators to prevent misleading claims, and publicly funded projects should have requirements for transparency and public data-sharing. The durability of carbon storage methods should be well characterized and accounted for appropriately. CDR that stores carbon for at least hundreds of years is essential for meeting our long-term climate goals.

Environment and Health Principles

- **Protect Existing Carbon Sinks and High-Value Ecological Areas:** CDR policy should avoid degradation and other harm to carbon-rich ecosystems and avoid activities that release stored carbon or degrade the integrity of these systems. CDR projects should not imperil the ecological integrity and biodiversity of aquatic and terrestrial ecosystems, especially highly sensitive areas (e.g., old-growth forests, at-risk wetlands, and marine protected areas). CDR projects should avoid impacts on wildlife whenever possible, especially threatened, endangered, and sensitive organisms and native species and their habitats.
- **Ensure Public Health and Safety:** The public should be protected from negative impacts to health, air quality, and water quality and activities that would otherwise endanger worker or community safety. Potential hazards, pollutant emissions, and hazardous chemicals used should be avoided where possible and otherwise minimized and

disclosed to the public. Projects should conduct community health assessments to understand and prevent local health impacts.

- **Implement Environmental Impact Accountability and Monitoring:** In implementing environmentally responsible CDR, project developers should address potential negative environmental impacts, from siting and design through operation. Addressing these impacts should include long-term monitoring, clear mitigation strategies, enforceable agreements, and dedicated funding for implementation of these accountability mechanisms where applicable. Projects should implement science-based best practices and employ best available control technologies to address potential negative environmental impacts.

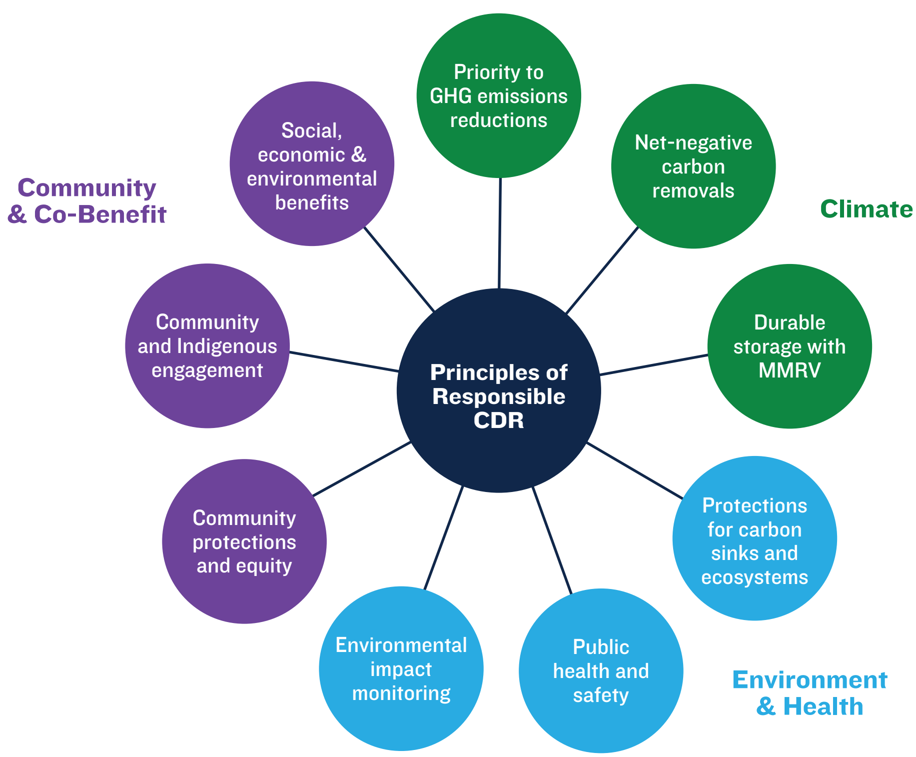
Community and Co-benefit Principles

- **Ensure Community Protections and Equity:** All communities should be protected from displacement and reduced access to housing due to CDR facilities and infrastructure. CDR should avoid contributing to the destruction of cultural and historic resources and further burdening of disproportionately impacted communities, including their health, land use, and access to resources. CDR policies should establish clear mechanisms of accountability for negative impacts to communities. CDR projects should support the self-determination of these disadvantaged communities and where feasible, bring increased investment and other direct benefits to them.

- **Implement Early, Meaningful, and Accessible Community and Indigenous Engagement and Tribal Consultation:** CDR projects should conduct early and ongoing engagement with impacted communities, Indigenous Peoples, and other stakeholders. Projects in the United States with a federal nexus require a government-to-government consultation between impacted Tribal Nations and relevant federal agencies. CDR projects and policies should respect Indigenous rights and self-determination. Decision-making processes should be open, inclusive, transparent, representative, accessible, and respectful of both community and Indigenous leadership and the rights and sovereignty of U.S. Tribes. Public engagement should include clearly defined periods for community input, meaningful opportunities for communities to shape project outcomes, and built-in protections for community priorities and benefits. Projects should remove barriers to stakeholder participation in these engagement efforts.

Figure 4: NRDC's principles for responsible CDR

These principles collectively represent NRDC's vision for responsible CDR. The three themes depicted in the figure are not mutually exclusive. For instance, community protections could include maintaining access to nature in addition to economic and health guarantees.



- **Emphasize Direct Non-CO_2 Benefits:** When evaluating CDR projects, pathways, and programs, policymakers and other CDR stakeholders should consider the value of benefits provided by CDR pathways beyond drawdown of atmospheric GHGs. CDR policies should incorporate valuation of benefits such as reduction of environmental hazards, ecological restoration, adaptation against climate impacts, and production of clean energy and products. CDR projects should incorporate strategies for maximizing their direct social, economic, and environmental benefits. As the CDR market develops and more pathways become available, policies will be able to increasingly prioritize projects that have the broadest benefits.

This set of principles is meant to serve as our North Star for responsible CDR development; they are not an end in themselves. The next step will be to develop policies in line with these principles that can shape the CDR landscape as pathways transition from early-stage to on-the-ground deployment.

No individual CDR policy or project will be able to address every element of these principles as they inevitably encounter the exigencies of climate change, political realities, and even each other. It is in those situations that the environmental community's leadership will be critical in weighing trade-offs.

NEXT STEPS FOR POLICY ADVOCACY

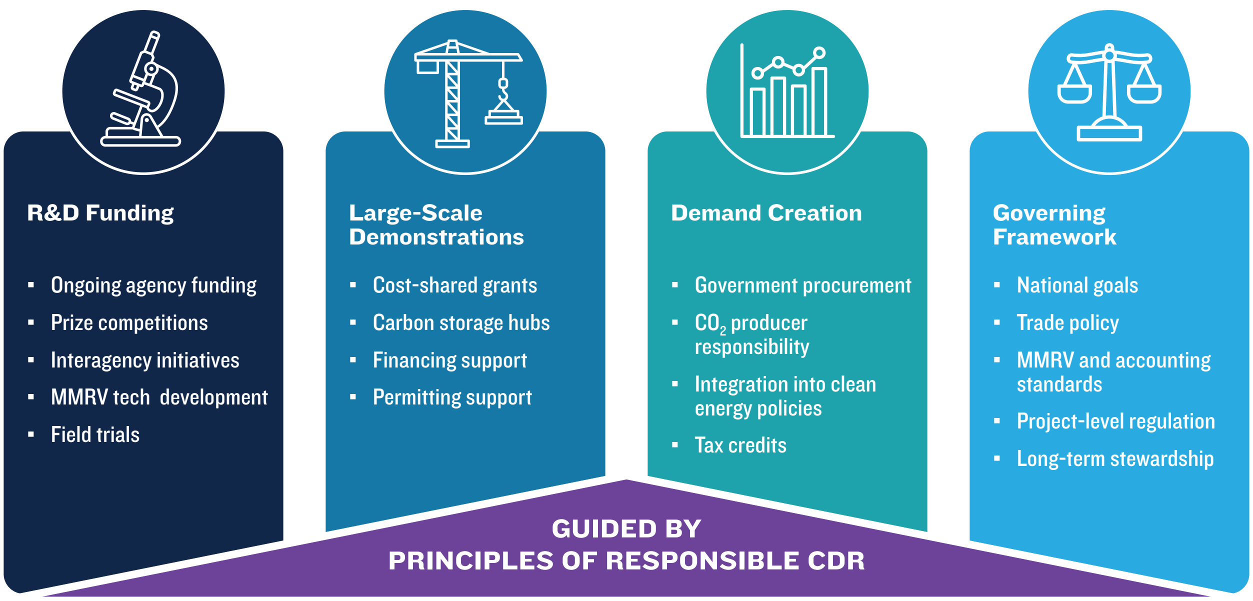
Looking forward, we can build upon the vision set forth by these principles and use them as a springboard for responsible CDR advocacy. In the United States specifically, there is a real opportunity for the environmental community to shape the fledgling CDR landscape and for environmental policymakers to advance responsible CDR. Although CO_2 accumulation is a global problem requiring global solutions, the United States has the technical, financial, and natural resources—not to mention the moral responsibility due to its historic emissions—to become a leader in CDR development.

Because CDR pathways span a range of technological and commercial readiness, multiple complementary policies are needed to achieve deployment at scale. There are four main policy levers (figure 5) that, in combination, can advance CDR to the point where it can be deployed broadly and responsibly.

- **Research and development funding** can introduce new pathways, improve measurement and monitoring techniques, and increase our understanding of how the global carbon cycle will respond to CDR.

Figure 5: Four policy levers for advancing CDR

The diversity of CDR approaches requires an interwoven set of policies to support scale-up. The example policies in this figure's bulleted lists represent just some of the options available within each pillar and may not apply equally across CDR types.



- Many CDR pathways need **large-scale demonstrations** to help cross the "valley of death" between the laboratory and commercial deployment. Lacking an established track record, first-of-a-kind technologies often struggle to secure enough investment without government support.
- Unlike most climate solutions, which replace existing energy and products with clean alternatives, CDR's primary purpose is environmental remediation. It faces a classic economics problem: Markets do a poor job of providing public goods.[38] In the long-term, **policies to create demand** for CDR will be necessary to support deployment. The limited voluntary market that exists for CDR will not be sufficient.
- Public and private actors should work together to establish a **foundational governing framework** for responsible CDR deployment. These "rules of the road" must include MMRV and carbon accounting regulations; separate goal-setting for CDR and emissions reduction; research codes of conduct; health, community, and environmental protections; and community benefit requirements.

There are multiple specific policy designs that could advance each of these goals. The work ahead will involve determining how, when, and where these tools can be utilized while establishing environmental and social responsibility frameworks from the start.

CONCLUSION

Environmentalists have cheered on several critical climate industries over the past decades: photovoltaic power, wind power, electric vehicles, batteries, and more. It is now time to set the stage for another—an industry that removes carbon dioxide from the atmosphere—to contribute to the fight for climate stability.

It will not be easy; the economics of creating brand-new infrastructure and systems are more challenging than replacing polluting incumbents with clean alternatives. There will be real consequences for our communities and the environment if this scale-up is not done responsibly. But responsible and sustainable CDR can be a real asset in reaching our climate goals.

Together, we, the environmental movement, with advocates and policymakers working hand-in-hand, must find a way to make responsible, effective CDR a reality.

Glossary of CDR Terms

Additionality: A CDR project or activity can be considered additional if it removes more carbon than would otherwise have been removed if the project did not exist or if the policies and financing intended to incentivize the project did not exist. Additionality is a key requirement for CDR.

Co-benefits: Co-benefits are positive impact attributes of a CDR project that extend beyond the climate benefit of CO_2 removal alone. This could include other climate benefits, such as low-carbon energy production, emissions mitigation, and climate adaptation. It also encompasses potential environmental, ecological, health, social, and economic benefits.

Durability/permanence: Durability and permanence are often used interchangeably to refer to how long carbon can be expected to stay stored away from the atmosphere.

Leakage: Leakage generally does not refer to physical CO_2 leaks, but rather to circumstances in which a CDR project increases GHG emissions outside the project boundary, canceling out some or all of the project's climate benefit.

Life-cycle analysis/assessment: A life-cycle assessment for a project or activity is used to evaluate the environmental impacts of a product's value chain. In the case of CDR, this means measuring the aggregate climate impacts of a ton of stored carbon throughout CO_2 capture, conversion, transport, and storage (i.e., "from cradle to grave").

MMRV: Measurement, monitoring, reporting, and verification can help quantify the efficacy, storage permanence, and non-climate impacts of CDR projects. MMRV involves measuring all emissions and removals related to a CDR project; monitoring carbon storage, reversals, and non-climate impacts; reporting data to relevant parties (such as regulators and buyers); and independent third-party verification to improve data reliability.

Net-negativity: A net-negative CDR project results in a net reduction in the concentration of CO_2 in the atmosphere. In other words, more carbon is removed than emitted over the project lifetime.

Overshoot: Overshoot refers to a period in which global warming temporarily exceeds a temperature target before later being brought back below that level. The larger and longer the overshoot, the more CDR will likely be needed to return to the target temperature.

Reversal: A reversal occurs when carbon that was removed and stored by a CDR project is released back into the atmosphere. Reversals can be caused by disturbances such as wildfire, disease, or land-use change or by structural and mechanical failures of storage.

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