DEEP DIVE

Carbon Dioxide Removal

2024 | OCT

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Executive summary

- **What is carbon dioxide removal**? Carbon dioxide removal (CDR) is an umbrella term used to describe a suite of interventions that have the potential to pull carbon dioxide (CO_2) directly from the atmosphere and store it for varying lengths of time within other carbon pools, such as rocks, soils, trees, oceans, and manmade materials.
- **How is CDR contextualized within climate strategies?** CDR targets CO_2 already in the atmosphere without addressing the sources of emissions. While it is not a substitute for emissions reductions, it is widely viewed as a critical part of the larger carbon management portfolio needed to reach midcentury net-zero targets, potentially address temperature overshoot, and rebalance atmospheric concentrations of CO_2.
- **What are the potential co-benefits and risks of scaling CDR?** CDR deployment could potentially have ecological, social, and economic co-benefits. Associated risks include moral hazard; co-option by extractive industries; fraud and failure; energy, land, and resource demands; and negative ecological impacts.
- **What are the major challenges to scaling CDR?** Major challenges to scaling CDR include knowledge and technology gaps; land, energy, and resource constraints; lack of a social license to operate; high cost; and limited demand.
- **What strategies are nonprofits developing to address these challenges?** Nonprofits are employing a broad range of strategies to address the challenges facing scaling CDR. We think that strategies to increase demand through innovative policies could be effective: It may be highly feasible to scale CDR demand through a broad portfolio of different policy vehicles, globally and at every level of government, into which CDR demand can be embedded. A portfolio approach may also unlock contexts in which economic and ecological co-benefits are more directly valued.
- **Is there room for more philanthropic funding?** Given the broad consensus that policy will generate longer-term demand for CDR, the nascency of policy efforts critical to achieving the requisite scale to meet climate goals, and the important role that nonprofits play in influencing these policies, we think it is important to grow philanthropic support for CDR.
- **Key uncertainties:** Key uncertainties include the size of CDR demand from companies choosing to purchase CDR, the feasibility of large-scale government procurement, and the magnitude of potential CDR demand creation from innovative policy approaches.
- **Bottom line / next steps**: In 2024, the Giving Green Fund is planning to award a series of ecosystem grants aligned with a strategy of supporting foundational work to unlock innovative policy for CDR demand. Sub-strategies of focus include (i) supporting policy innovation to embed CDR into alternative policy frameworks across sectors; (ii) developing standards to match the needs and opportunities of a broad and diverse array of policy vehicles; and (iii) enabling community-driven projects and subnational policies as testbeds for novel contexts, applications, policies, and markets.

Overview

Carbon dioxide removal (CDR) is an umbrella term used to describe a suite of interventions that have the potential to pull CO_2 directly from the atmosphere and store it, for varying lengths of time, within other carbon pools, e.g., rocks, soils, trees, oceans, manmade materials.

CDR targets CO_2 already in the atmosphere without addressing the sources of emissions. While it is not a substitute for emissions reductions, it is widely viewed as a critical part of the larger carbon management portfolio needed to reach midcentury net-zero targets, potentially address temperature overshoot, and rebalance atmospheric concentrations of CO_2.

We think it is important to highlight that CDR is distinct from carbon capture, utilization, and storage (CCUS). CCUS refers to technologies that capture CO_2 directly from emissions sources, such as industrial processes, before its release into the atmosphere; at best, CCUS can neutralize emissions, while CDR could theoretically achieve negative emissions. CDR and CCUS technologies are inherently different, and so are their applications, strategies, potential co-benefits, risks, and policy and market contexts. This report focuses solely on CDR.

Classification of CDR pathways

CDR interventions encompass many different pathways through carbon cycles, each with its own distinct features, potential, and challenges; this range reflects the complexities, variances, and interdependencies of earth systems. There are various conventions for categorizing intervention types to systematize the CDR space. Example criteria include the perceived level of human intervention (natural vs. engineered), the length of time before the removed carbon returns to the atmosphere (durability), system boundaries (open vs. closed), and technological or market maturity (novel vs. conventional). See **Figure 1** for some examples of CDR interventions.

However, as of yet, there does not exist a widely accepted, standardized categorization, largely because (i) the relevance of certain categories varies by use case and context and (ii) it is often difficult to find clear delineation between categories.[1]

[1] For an overview of the variance of CDR terminology and definitions, see Supplement 1.1 of the CDR Primer.

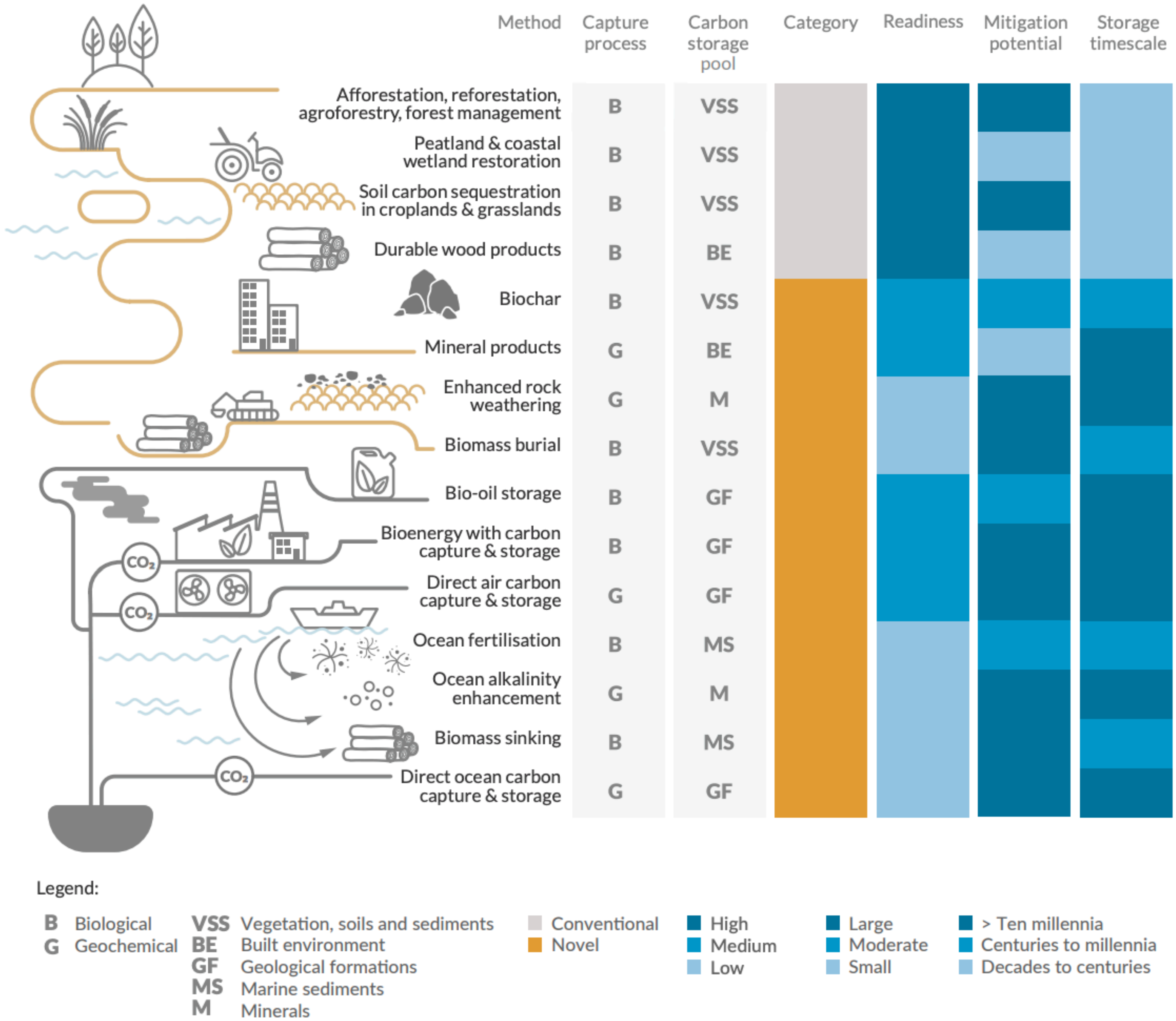

Figure 1. Summary of CDR Methods, from *The State of Carbon Dioxide Removal, 2nd edition (2024)*[2]

Contextualization in climate strategies

CDR is considered a complement to emissions reductions as it removes CO_2 already in the atmosphere rather than targeting emissions sources. Below we describe three different scenarios and framings; it is our impression that the context in which CDR is deployed has profound implications for scale, policy, markets, justice, and social license.[3]

[2] "Summary of Carbon Dioxide Removal methods, noting their respective capture process and carbon storage pool, categorization as 'Conventional' or 'Novel', their current readiness to scale (based on technology readiness levels), their maximum mitigation potential (Large: >9 GtCO2/year; Moderate: 3-9 GtCO2/year; Small: <3 GtCO2/year), and characteristic storage timescale. (Based on Babiker et al., 2022, Bustamante et al., 2023, and Cobo et al., 2023.)" [The State of Carbon Dioxide Removal, 2nd edition (2024)]

[3] "Nearly all CDR applications involve critical social, economic, and political questions that go far beyond the narrow confines of technological feasibility." https://cdrprimer.org/read/chapter-1#sec-1-5

- **Net zero:** All viable pathways to achieving net zero will require some level of CDR deployment to balance residual emissions from hard-to-abate sectors such as aviation.[4] Estimates suggest that the scale of CDR needed to meet midcentury net-zero goals falls in the range of 6-12 gigatons (billions of tons) of CO_2 per year.[5,6] For context, this is about 16-32% of 2023 global emissions.[7]

- **Temperature overshoot:** If we overshoot critical temperature thresholds, CDR could theoretically be deployed to restore atmospheric levels of CO_2 and reduce global temperatures.[8,9] Temperature overshoot is possible even when net zero is reached, given that a substantial amount of emitted CO_2 remains in the atmosphere for hundreds to thousands of years.[10] However, while reducing atmospheric CO_2 may reverse warming, it may not reverse many other impacts of climate change, including changes to regional temperature and precipitation patterns.[11] Other serious, irreversible impacts of climate change include sea level rise, loss of life, and destruction of ecosystems.

- **Legacy emissions:** Humanity has emitted 1.5 trillion tons of CO_2 since the Industrial Revolution, and the US alone has contributed the most at over 400 billion tons.[12] Addressing these legacy emissions can help restore global temperatures and curb future climate damage. Advocacy for net-negative goals is growing within civil society, the private sector, government, and the scientific community.[13,14,15,16]

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[4] "This idea of achieving a 'balance between anthropogenic emissions by sources and removals by sinks' was enshrined in Article 4.1 of the Paris Agreement and has become a prominent feature of recent IPCC assessments as well as country strategies." Buck,et al, 2023

[5] "According to the Intergovernmental Panel on Climate Change (IPCC), the use of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 is to be achieved. Our analysis suggests that between 6 and 10 gigatons per annum (Gtpa) of residual CO_2 emissions are likely to remain unabated globally in 2050...This is an immense scale-up from 125 kt of durable CDR delivered in 2023 to ~6 to 10 Gt of durable CDR needed in a 2050 net zero CO2 world..." BCG, 2024

[6] "Should the rest of the world make similar projections, the resulting residuals would be over 12 Gt yr–1 (if weighted by current emissions). This sets out a need for a substantial carbon-removal effort." Buck,et al, 2023

[7] "Global energy-related CO2 emissions grew by 1.1% in 2023, increasing 410 million tonnes (Mt) to reach a new record high of 37.4 billion tonnes (Gt)." IEA

[8] "If global temperature temporarily overshoots 1.5°C, CDR would be required to reduce the atmospheric concentration of CO2 to bring global temperature back down. " IPCC, 2018

[9] "The need for carbon removal includes past, present and future emissions, not only the "residual emissions" remaining at the year of net zero. Policymakers should begin accounting for this growing carbon debt, ultimately adjusting climate ambition to ensure these excess emissions are addressed in time to avoid unsafe temperature overshoot." Höglund & Mitchell-Larson, 2024

[10] "The models agree that 20–35% of the CO_2 remains in the atmosphere after equilibration with the ocean (2–20 centuries)." Archer, et al, 2009.

[11]" We note that while temperature rise may be reversible, there are many other effects of climate change that are not. For example, see Kim, et al, 2022

[12] NOAA, 2022; Our World in Data, 2019

[13] "Net zero is a pit stop, albeit an important one, on the road to tackling legacy carbon pollution." Carbon180, 2024

[14] "While the world will need to reach net zero, those of us who can afford to move faster and go further should do so." Smith, 2020

[15] "I believe that it's important for all the developed countries to talk about, not net zero, but about removing more carbon from the atmosphere than they are adding — net negative is what they need to talk about." Minister Singh, IEA-COP26 Net Zero Summit, 2021

[16] "The world will be net negative once removal exceeds emissions. If it takes us more than a decade or two to lower the level of CO2, we definitely will have overshot our targets and will need to maintain net negative emissions for decades into the future. Therefore, time is of the essence." Jackson, 2021

Potential co-benefits

CDR has the potential for ecological, social, and economic co-benefits; we describe these categories in more detail below. However, we note that many co-benefits are speculative, vary by CDR pathway and project context, and may depend greatly on *how* CDR projects are conceived, planned, and implemented.

- **Ecological:** Some CDR pathways may improve the health of ecosystems, especially in the context of interventions that seek to enhance natural processes. For example, enhanced rock weathering (ERW), the process of spreading finely ground rocks to accelerate CO_2 uptake, could improve ecosystem health by reducing soil acidity and the need for fertilizer.[17]

- **Social:** Given that CDR is a new industry, there is potential to shape it in a more decentralized way compared to legacy industries and to place greater emphasis on community engagement when designing and implementing projects, for example, through community benefit agreements (CBAs) and public ownership.[18] There are also theories of change that frame CDR in terms of reparative justice, elevating CDR as a public good or service.[19]

- **Economic:** Some CDR pathways have the potential to unlock economic benefits, especially when projects are community-driven and integrate local resources and industries. For example, a study examining the potential for biochar in Central California found the opportunity for "benefit in terms of employment, labor compensation, value addition, and gross output."[20] Our impression is that there is untapped potential for CDR projects that leverage regional resource availability and existing economic activity.

Potential risks

While CDR has many potential benefits, it also has serious associated risks, especially in the context of large-scale deployment. We think that some of these risks could be mitigated through robust governance and regulation. However, our impression is that this will depend greatly on the priorities of policymakers and other decision-makers.

[17] "ERW in soils can improve soil quality by reducing soil acidity, which has been traditionally achieved by the practice of liming while avoiding CO2 emissions associated with lime application. ERW can also release macro and micro nutrients and thereby reduce the need of soil fertilization with fertilizers, thus improving productivity across agroecosystems." Deng et al, 2023.
[18] "Publicly owned systems work for provisioning removal services like solid waste and water treatment because waste management is a pure cost, just something we have to deal with together, as well as a public good. We should extend this logic to carbon removal as well. Climate tech investors and entrepreneurs see carbon removal as a technological innovation problem, and carbon as a commodity. Rather, we need to think about carbon removal as what social scientists call a 'sociotechnical system.'" Bergman et al, 2022
[19] See Táíwò, O. O. Reconsidering Reparations. (Oxford University Press, 2022).
[20] "We find that all regions would benefit in terms of employment, labor compensation, value addition, and gross output though Madera County would have the least economic returns. Meanwhile, Fresno County with the most biomass would have the most economic impacts, suggesting that policy should be directed at encouraging biomass production and marketing in areas with the most biomass." Nematian, Ng'ombe, & Keske, 2023.

- **Moral hazard:** CDR, or even the promise of CDR, could reduce efforts or funding that would otherwise be directed toward emissions reductions—especially if demand is dominated by market-based drivers that favor who can pay over what is most climate-beneficial. Efforts to address this concern include climate frameworks that separate emissions reduction targets from CDR targets and the framing of CDR as a public good.[21] Our impression is that most people working on CDR are very adamant that CDR should not be a substitute for emissions reductions; however, we think outcomes will depend greatly on policy, regulation, and governance structures.

- **Level of extractive industry involvement:** The extent to which extractive industries like oil and gas should play a role in CDR development and deployment remains an open question. This is especially relevant in the context of DAC, where the captured CO_2 can be used for enhanced oil recovery and is even subsidized by certain policy incentives in the US. We think scale-up of CDR across pathways, especially when co-opted by extractive industries, could be detrimental to climate progress and perpetuate existing social and environmental injustices.[22]

- **Fraud:** The complexity of measurement, reporting, and verification (MRV) across CDR pathways, especially those in open systems, makes high-certainty claims about the amount of CO_2 removed difficult.[23,24] Given that the current demand for CDR comes from market-based structures, especially the voluntary carbon market (VCM), we think it is highly likely that there may be the potential for fraudulent claims, as has happened with offsets.[25] While conditions for fraud may always exist, we think risks can be reduced through improved MRV technologies and strengthened governance and regulatory standards.

- **Failure:** We think it is inevitable that some projects or companies will fail and that some CDR pathways cannot scale. How these failures are addressed could have serious implications for the CDR market and sector at large, especially with respect to trust and, consequently, demand.[26]

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[21] "Targets and accounting for negative emissions should be explicitly set and managed separately from existing and future targets for emissions reduction. Failure to make such a separation has already hampered climate policy, exaggerating the expected future contribution of negative emissions in climate models, while also obscuring the extent and pace of the investment needed to deliver negative emissions." McLaren et al, 2019.

[22] "U.S. oil and gas producer Occidental Petroleum on Tuesday agreed to pay $1.1 billion for technology supplier Carbon Engineering Ltd to help it develop a string of carbon-capture sites it hopes will profit from tackling climate change." Reuters, 2023.

[23] Open systems (as opposed to closed systems) refers to CDR implementation contexts without well-defined physical boundaries, or those where the CDR intervention occurs "in the environment" and has biological/ecological/geological impacts. Open systems are thought to have high potential for scale although MRV is generally more challenging than for closed systems. Note that this is not a well-defined binary.

[24] "Open system approaches, such as enhanced rock weathering or ocean-based approaches, have a larger scale potential due to lower energy costs and a reliance on nature to enable the reaction, but are inherently variable and difficult to measure because of dispersion in natural open systems over large timescales." Quadrature Climate Foundation, 2024

[25] "The voluntary carbon market relies on registries — the marketplaces where credits are purchased — to verify that each offering is legitimate and to calculate its carbon emissions reduction. But these mechanisms are loosely regulated and do not follow a uniform verification process. The Post's investigation found that two international verification groups, Verra and Cercarbono, certified at least 29 illegitimate projects in the Amazon." Washington Post Editorial Board, 2024.

[26] "Absent legal regimes to properly regulate the new CDR sector, to incentivise deployment and ensure safe development, both the effectiveness and legitimacy of CDR will be cast into doubt." Ghaleigh & Macinante, 2023.

- **Implications on land, energy, and resource use:** Gigaton-scale CDR will require substantial land, energy, and other resources. Large-scale deployment could take up land needed for agriculture, redirect clean energy away from direct decarbonization efforts, and consume substantial resources for project infrastructure and operations.[27] Efforts to optimize where projects happen and how and which resources should be used may depend on geographic and political context as well as the CDR pathway. For example, in the case of biomass carbon removal and storage (BiCRS), general best practices include using waste biomass over purpose-grown crops.[28]

- **Ecological and public health impacts:** Potential negative ecological impacts vary greatly by CDR pathway. In the context of closed systems, concerns include the ecological footprint of building new infrastructure and pollution from producing and disposing of requisite materials.[29] Concerns for open systems include disruption of ecosystems and impacts on air and water quality.[30]

Challenges to scaling

While certain challenges to scaling are pathway-specific, we think the following list of major barriers is broadly applicable across much of the CDR portfolio.

- **Knowledge and technology gaps:** Much of the CDR sector remains in the research, development, and demonstration (RD&D) phase. In addition, MRV technologies and governance structures are uncoordinated and, in some instances, still in developmental stages; this could greatly impede the trust and clarity needed to scale.[31]

- **Land, resource, and energy constraints:** Demand for resources such as land, water, and clean energy will be shared between CDR and other efforts such as food production, protection of biodiversity, and direct decarbonization interventions. It isn't clear whether CDR will–or should be–considered a priority end-use for these resources.

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[27] "This is because terrestrial carbon removal at the scales indicated in this Article would require vast amounts of land and entail severe risks for food production and/or biosphere functioning as well as the land rights and livelihoods of rural communities and Indigenous peoples. While some industrial carbon-removal techniques such as direct air carbon capture and storage have a much smaller direct land footprint, this approach comes with large energy requirements20, which could divert energy, and critical minerals and the associated land for renewables, from other societal needs." Buck,et al, 2023

[28] "To fully harness the carbon removal potential of BiCRS pathways, policy and market incentives are needed to encourage the use of waste biomass and disincentivize the use of purpose-grown crops that could undermine the natural ability of forests and soils to sequester carbon." Mulligan et al, 2023.

[29] "Ongoing impacts of operating DAC plants will come from energy, land, and water use (for DAC plant and energy source), and chemical use for the sorbents and solvents that capture CO2." WRI, n.d.

[30] "ERW is an agricultural practice that could exert an environmental influence across terrestrial, atmospheric, freshwater, and marine systems, with potential to significantly impact nontarget ecosystem services at scales from local to global." Levy et al, 2024.

[31] "In addition to scientific gaps, there are gaps around MRV governance that merit careful attention in the near term as they will establish precedents for how the CDR sector will develop. " Quadrature Climate Foundation, 2024

- **Lack of a social license to operate:** Public perceptions of CDR can greatly affect whether and how quickly CDR can scale.[32] Public support of CDR could enable and even accelerate progress. In contrast, negative public perceptions could slow or even halt projects or policies, ultimately inhibiting the sector's ability to scale to meet climate goals.

- **High cost:** CDR's cost varies greatly by pathway but is generally too high to spur the scale of voluntary demand and public investment needed.[33] For example, Frontier's offtake portfolio, which only includes highly durable CDR pathways, costs $550 per ton.[34] There is some optimism that even the most expensive pathways, such as DAC, can reach viable price thresholds with sufficient investment, deployment, and learning-by-doing, and there are government efforts to enable substantial cost declines across all CDR pathways.[35] However, even with a significant cost decline, reducing emissions will generally remain more cost-effective than removing CO_2 from the atmosphere.[36]

- **Limited demand:** CDR does not provide a good or service to which the current economic and political system assigns a high value, nor is it directly replacing a good or service that is currently valued by these systems. Because of this, voluntary demand is limited, and the policy and regulatory frameworks in place are not enough to generate the demand necessary to substantially scale the market.

- **Market constraints:** Voluntary financing and market mechanisms have been critical to jumpstarting CDR, especially in the absence of robust demand creation from policy. However, we think these mechanisms have limited scale and can prematurely define and lock in structures, practices, and applications that may not be the most climate-beneficial options.[37,38] As of September 2024, we have only 0.12% of the annual CDR capacity needed by 2050, and only about 3.3% of the carbon removal purchases ever made have been delivered.[39] In a 2024 report, BCG estimates that in the most optimistic scenario, voluntary demand for durable CDR will reach 0.75 gigatons by 2040 and decline by 2050 as demand is usurped by compliance markets. According to the report, "the voluntary market cannot induce enough CDR demand to meet requirements—in

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[32] "Public attitudes towards new technologies can have a crucial influence on their development and deployment." State of CDR, 2024
[33] "It turns out that the cost of CDR varies by a factor of 30,000—from a few cents to a thousand dollars to remove a ton of CO2 from the atmosphere." MAHB, 2024
[34] Per Stripe carbon removal portfolio inventory: Stripe, n.d., accessed 2024
[35]"Applying the conventional rules of learning-by-doing in the mass-manufacturing realm, the cost of DAC should come down rapidly, provided one can tap into niche commercial carbon dioxide markets or assure an artificial demand for CO2 at higher prices." Lackner & Azarabadi, 2021.
[36] "It is scientifically, environmentally and economically more effective to avoid a ton of emissions than it is to remove it from the atmosphere." Quadrature Climate Foundation, 2024
[37] "While CDR is starting to get more attention from policymakers in G20 countries, the voluntary carbon market is playing a key role in scaling up CDR. This is especially true for novel methods, although these still represent only a small fraction of total market-based CDR." State of CDR, 2024.
[38] "We argue that the emerging tendency toward market-based, unconstrained, and for-profit CDR presents fundamental and predictable risks for climate and justice goals." Grubert & Talati, 2023.
[39]As of September 22, 2024; see cdr.fyi for live updates.

part because, unlike other climate technologies such as solar and wind power, CDR produces no product or service that creates its own demand. Instead, CDR could be considered a public good, and it is likely that only changes in government regulation and policy will lift the barriers to scaling the durable CDR demand needed."[40,41]

Philanthropic sub-strategies

Assessment

Based on a literature review, investigation into the work of civil society, and conversations with a variety of stakeholders in the CDR ecosystem, we have curated the following list of the top strategies employed by nonprofits to overcome the challenges of scaling CDR; we refer to these as "sub-strategies" of our philanthropic strategy of supporting the scale-up of CDR. In addition, we have assessed these sub-strategies qualitatively in terms of scale, feasibility, and funding need. We recognize that (i) this list is not exhaustive and (ii) there is inevitable overlap between sub-strategies.

Table 1. Philanthropic sub-strategies to scale CDR

Strategy	Scale	Feasibility	Funding Need	Notes
Scaling demand, especially through tactical policy advocacy	High	High	High	Although a benchmark exists for the CDR capacity needed by 2050 to meet climate goals, there is uncertainty as to how and where this scale of demand will be created. Much of the existing demand is being driven by the private sector through the VCM. These private sector efforts have been critical in catalyzing CDR development, especially in the absence of robust policy. However, we do not think that voluntary efforts can be relied upon to remain consistent and scale to the requisite levels. Policy is widely perceived to be the most effective and feasible way to overcome the challenges of scaling CDR, especially with respect to generating demand.[42] To a large extent, policy has been focused on supply-side contexts, and demand-side efforts have been more neglected.[43] We think nonprofits can be highly influential in supporting CDR demand generation through policy and that more funding is needed to support this work.

[40] BCG, 2024.
[41] We used durable to mean interventions that store carbon for >100 years.
[42] "Unlike other climate technologies, CDR could primarily be considered a public good. As a result, there are barriers to scaling CDR demand that are unlikely to be overcome without governmental policy demand drivers." BCG, 2024.
[43] "However, existing regulations have thus far focused on supporting durable CDR through supply-side policies aimed at lowering costs of investment and production, including research and development subsidies and tax credits. Demand-side policies, such as market-based schemes and direct government procurement, are either in their infancy or at the legislative proposal stage." BCG, 2023.

Strategy	Scale	Feasibility	Funding Need	Notes
Developing MRV technologies and frameworks	High	High	Medium	We think developing MRV technologies and frameworks is critical to scaling CDR as it can help quantify impact and build trust. We also think developing these tools is highly feasible from both a technological and market standpoint. Our impression is that there has been a growing amount of resources devoted to this, predominantly to fit the context of the VCM. There have been fewer efforts to develop standards and frameworks applicable outside of the VCM and other market-based schemes.
Coordinating RD&D efforts, especially in the context of open system pathways	High	High	Medium	Given the many challenges and opportunities of open system CDR pathways, we think coordination of RD&D, especially at early stages, is both critical to scaling and highly feasible. We also believe that there has been a growing amount of philanthropic funding supporting these efforts, especially in the context of ERW and marine CDR.
Capacity and coalition building	Medium	High	Medium	This is a broad category that encompasses a variety of different contexts for building capacity and forming coalitions. Our impression is that there are a number of well-resourced efforts, especially in high-income countries, supported by the private sector. Given that these coalitions have been formed mostly in the context of the VCM, we think it may be limited in scale. However, we think there are more neglected areas of capacity- and coalition-building that are critical to scaling CDR, including bolstering the technical expertise of policymakers, supporting the ecosystem of CDR stakeholders in lower- and middle-income countries, and guiding the emergence and coordination of industry associations across geographies.
Building public support	Medium	High	High	This category includes efforts such as public education, community engagement, environmental justice, and governance. We think building public support could have a significant impact given that it helps generate political will from the bottom up and embeds considerations for equity and justice into the development of the sector. In the absence of broad social acceptance, we think CDR development could be slowed, halted, or further removed from the context of being a public good. At the same time, we do not think building a social license to operate directly drives scaling CDR to the same extent as other strategies.
Supporting companies and startups	Medium	Medium	Medium	Supporting private sector growth is one component of scaling CDR, but we think scale and feasibility are limited in the absence of more robust policy measures. In addition, our impression is that there are a growing number of nonprofit industry associations supporting the CDR private sector.

Based on the assessment criteria, our impression is that efforts to scale demand, especially through policy, could be a philanthropic strategy with exceptionally high impact and intrinsic intersection with other strategies, including developing MRV frameworks and building a social license to operate.

The conclusion that more demand creation efforts are needed is not new and is supported by the private sector, government, and philanthropy. However, our impression is that there is uncertainty with regard to exactly how this demand will be structured and from where it will come, and we think that there may be specific demand-generating contexts that hold great potential but remain relatively underexplored.[44] To assess this, we evaluate the full range of demand drivers with which we are familiar and assess them in terms of scale, feasibility, and funding need for advocacy.

Given that we use BCG's 2024 estimates for scale, we adopt the same categorization where applicable. We also assess demand-generation for durable CDR as we think pathways with longer storage timescales are more optimal for neutralizing residual emissions.[45] Here we use 'durable' to mean pathways that store carbon for 100+ years, such as biochar, enhanced rock weathering, and direct air capture coupled with geologic storage.

[44] "Policymakers and advocates should seek opportunistically and pragmatically to continue to advance the portfolio of demand-support policies for CDR outlined in this Primer, to catalyze public-private partnership, and to innovate on additional novel policy mechanisms not contemplated here." Carbon Business Council (2024)
[45] "This is an immense scale-up from 125 kt of durable CDR delivered in 20239 to ~6 to 10 Gt of durable CDR needed in a 2050 net zero CO2 world—a 50,000 to 80,000 times increase." BCG, 2024

Table 2. Durable CDR demand drivers

<table>
<tr><th colspan="2">Type of demand driver</th><th>Associated scale of demand generation[46]</th><th>Feasibility</th><th>Funding need for advocacy</th><th colspan="2">Notes</th></tr>
<tr><td rowspan="2">Credit-based approaches</td><td>Carbon pricing mechanisms</td><td>Medium</td><td>Medium</td><td>High</td><td>Carbon pricing mechanisms include direct carbon pricing, emissions trading schemes, and carbon border adjustments. These policies are projected to generate about 1.25 gigatons of CDR demand in 2050, according to Exhibit 4. BCG (2024). Given the building momentum for these policies, we think feasibility is medium even though progress has been slow.</td><td rowspan="2">In total, these policy types (p. 13 and 14) are projected to generate, at most, about 2.5 gigatons of durable CDR demand in 2050, or about 30% of estimated residual emissions, from Exhibit 4. BCG (2024). See Appendix for figures.</td></tr>
<tr><td>Standards and regulatory requirements</td><td>Medium</td><td>Medium</td><td>High</td><td>Standards and regulatory requirements include performance and fuel standards. These policies are projected to generate about 0.83 gigatons of CDR demand in 2050, according to Exhibit 4. BCG (2024). We think feasibility is medium given that some implementation has been made, such as California's Low Carbon Fuel Standard.</td></tr>
</table>

[46] Using BCG's 2024 estimates where applicable.

Table 2. Durable CDR demand drivers (cont.)

Type of demand driver		Scale	Feasibility	Funding need	Notes	
Credit-based approaches (cont.)	Subsidies and incentives; Other regulatory devices; Other voluntary demand	Low	High	Medium	Subsidies, incentives, and other regulatory devices that drive voluntary demand include tax credits, contracts for difference, and national climate commitments that require CDR to meet targets. This, along with the other voluntary market demand, is projected to reach about 0.42 gigatons in 2050, as shown in Exhibit 4. BCG (2024). We think feasibility is mixed; tax credits have been successfully implemented in certain contexts, such as the US Inflation Reduction Act, but advocacy for other incentives and regulatory devices has gotten less traction. While we think there is still room for more advocacy efforts in these directions, we think it is less neglected than other pathways. Some nonprofits work to increase voluntary demand through efforts such as advocacy for modifications to corporate accountability frameworks or research and coalition-building for the creation of additional financing mechanisms, such as variants of advance market commitments that are tailored to the needs of specific CDR pathways. While we think market-shaping efforts can be catalytic and relatively feasible, our understanding is that scale is limited by the maximum viable size of the voluntary market, estimated by BCG to be at most 0.75 gigatons in 2040. See Appendix for figures. Also, given the increased involvement of the public and private sectors, we think that the marginal impact of philanthropic resources is lower.	In total, these policy types (p. 13 and 14) are projected to generate, at most, about 2.5 gigatons of durable CDR demand in 2050, or about 30% of estimated residual emissions, from Exhibit 4. BCG (2024). See Appendix for figures.

Table 2. Durable CDR demand drivers (cont.)

<table>
<tr><th colspan="2">Type of demand driver</th><th>Scale</th><th>Feasibility</th><th>Funding need</th><th colspan="2">Notes</th></tr>
<tr><td>Credit-based approaches (cont.)</td><td>Direct public procurement of CDR</td><td>High</td><td>Medium</td><td>High</td><td>We do not have a direct scale estimate for public procurement, although we think it could be very high. The feasibility of some level of procurement is high, and there has already been some momentum. However, we think it is politically less feasible to rely on procurement at the levels required to close the demand gap, considering the large and consistent investment this would entail.[47] We think it is important to push procurement to reach the highest levels possible and further philanthropic engagement is critical in this effort.</td><td rowspan="2">We are unaware of estimates for scale. However, given the above projections, and assuming these categories are the only additional options, they would need to generate the remaining 3.5-7.5 gigatons of CDR demand in 2050 to meet an estimated 6-10 gigatons of residual emissions. For this reason, we optimistically assess these categories as having the combined potential to generate a high scale of demand.</td></tr>
<tr><td colspan="2">Alternative policy approaches for durable CDR demand generation (e.g., pay-for-practice policies)</td><td>High</td><td>High</td><td>High</td><td>We do not have a direct estimate of demand; our belief is that aggregate demand creation could be quite high. We also think that it may be more feasible to scale through a portfolio of different policy vehicles into which CDR demand can be embedded and for which economic and ecological co-benefits may be more directly valued.[48,49] In addition, we think this policy approach may enable more decentralized, application-driven deployment structures, be more suitable for open system pathways, and create opportunities for niche markets—a critical driver in historical innovation successes such as solar photovoltaics.[50] We think this approach has been highly neglected by philanthropy.</td></tr>
</table>

[47] "The investment in CO2-Secure is substantial— the cumulative cost over the initial 10 years is estimated at $33.2 billion, with an estimated cumulative cost of $106 billion through 2050. Annual costs rise to a peak of $87.5 billion in 2060. The cost estimates could prompt discussion of its relative contribution to the benefits and costs of the broader portfolio of federal investments in climate change mitigation and adaptation, as well as how the cost will be accommodated within the federal budget." EFI, 2022

[48] "These regions vary in terms of their geography, climate, biomass, economies, histories, and populations, and each has its unique resources that can contribute to achieving CO2 removal targets." Roads to Removal, 2023

[49] "One key attribute of demand-support policy is the opportunity to consider factors beyond price – including the co-benefits enumerated here, as well as jobs and union jobs creation, and benefits to disadvantaged communities – in order to ensure safe, responsible, and equitable deployment" Carbon Business Council (2024)

[50] "In part because of the massive scale of the decarbonization challenge discussed above, serving small idiosyncratic markets is often dismissed as proof that a technology is not serious. Yet, niche markets are a central feature in the literature on innovation." Nemet, Gregory F. *How solar energy became cheap*. Routledge, 2019.

Discussion

In the leftmost column, we've delineated two broad categories of demand drivers. We note that this terminology is not standard and is an attempt to describe the dichotomy presented by stakeholders when discussing contexts for CDR demand.

The first category, *credit-based approaches*, comprises the most commonly discussed public and private demand contexts for durable CDR. A characteristic shared across this category is a market-based framework requiring the generation of credits and/or ton-for-ton matching. Although most of the mechanisms in this category are forms of policy, to a large extent they replicate the structure of the voluntary carbon market. According to recent projections, the combination of these drivers, without direct public procurement of CDR, would fall far short of 2050 durable CDR demand targets. Theoretically, direct public procurement of tons of CDR has the potential to fill this gap. In practice, however, we think it may be infeasible to rely too heavily on large-scale procurement given the requisite magnitude of investment and sustained buy-in from policymakers globally, especially in the near-to-medium term. While we think that efforts to promote procurement remain important, it may be that there are more feasible and relatively underexplored policy contexts that can build future support for procurement.

The second category, *alternative policy approaches for demand generation*, represents the potential for opportunities beyond the credit-based, ton-matching frameworks described above. Examples that fall into this category are pay-for-practice policies that subsidize implementation rather than tons removed. Our understanding is that this is a prevalent policy framework in the US, especially within the agricultural sector – for example, the Environmental Quality Incentives Program. These types of policy vehicles could be especially relevant for ERW and other open systems, but they may require alternative frameworks for MRV.[51]

While we are uncertain regarding the specific characteristics or potential magnitude of alternative policy contexts, we find it compelling to consider possibilities unconstrained by current credit and market structures. We think it may be feasible to scale through a portfolio of different policy vehicles into which CDR demand can be embedded and for which economic and ecological co-benefits may be more directly valued. Not only do we think these policies could scale CDR in their own right, but we also think they could, over time, increase the feasibility of other efforts, such as procurement. In addition, we think this type of policy approach may enable CDR pathways that favor more decentralized, context-specific deployment structures, be more suitable for open system pathways, and create opportunities for critical niche markets. Because of this, we have decided to prioritize this direction.

[51] "Pay-for-practice is the most prevalent incentive policy adopted in the US (Campbell et al., 2021, da Costa et al., 2012, Evans and Skaggs, 2004, Radcliffe, 2001), where the funding agencies cost share partial or full BMP implementation cost based on ranking formula. The level of support depends on the rank." Lin, Yang, & Chaudhary, 2023.

We highlight three specific approaches that (i) lay the groundwork for unlocking alternative policy contexts for durable CDR demand and (ii) for which we believe there to be highly effective funding opportunities.

1. **Supporting policy innovation to embed CDR into alternative policy frameworks across sectors**: We think that exploring questions and contexts outside of conventional demand typologies, such as the pay-for-practice policies mentioned above, could motivate new and creative research design and applications, expanding our understanding of how, where, and to what extent CDR can be embedded across industries and applications. Nonprofits can support this effort through research, techno-economic analyses, and policy advocacy.

2. **Developing standards to match the needs and opportunities of a broad and diverse array of policy vehicles:** Given that current demand is driven by credit-based markets (especially the voluntary market), the development of requisite standards and quantification frameworks has largely reflected the needs and the structures of this demand context. However, these tools may not be directly transferable or applicable to contexts beyond credits or ton-matching, such as the pay-for-practice example discussed above. Creating fit-for-purpose standards may help to unlock demand outside of existing market regimes.

3. **Enabling community-driven projects and subnational policies as testbeds for novel applications, niche markets, and new policy approaches:** We think community-driven projects and subnational policies can enable economic opportunities and unexplored applications. In addition, local initiatives can build political will and serve as blueprints to be scaled or replicated in amenable contexts; each new application has the potential to unlock new learning, applications, contexts, markets, and even geographies. Historically, national and international policies have often been preceded by and catalyzed through local policy or community-led initiatives.[52]

Theory of change

It would be difficult to provide a meaningful but concise theory of change summarizing the intricate social, technological, and political factors needed to scale CDR. Instead, we focus our theory of change (**Figure 2**) on CDR demand creation. In particular, we highlight the role of the approaches articulated above in driving more CDR demand from alternative policy contexts for demand generation in the context of net-zero goals.

[52] "Aachen served as a model for municipalities across Germany to adopt PV policies that subsidized the cost of installing systems...One consequence of the utility programs is that they stimu- lated firms to enter the PV industry, as module manufacturers and installers. A second consequence is that the diffusion of the Aachen model to other cities, and the PV adoption it stimulated, legitimized PV and made clear that there was substantial public interest in PV." Nemet, Gregory F. *How solar energy became cheap: A model for low-carbon innovation*. Routledge, 2019.

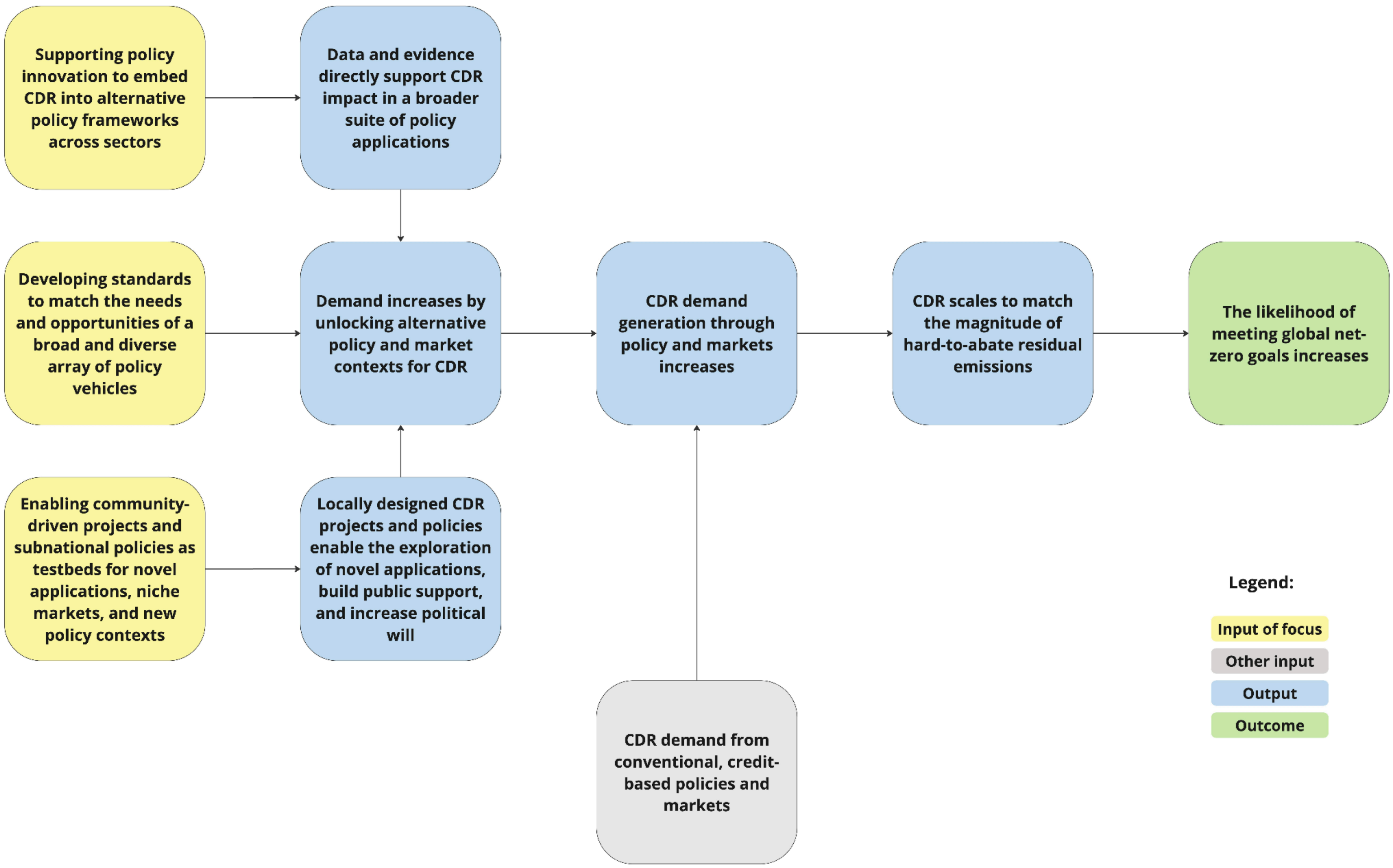

Figure 2. High-level theory of change for CDR demand creation

Key uncertainties

- **Size of the voluntary carbon market:** Our assessments and strategy decisions are based on the projection that the maximum size of the VCM in 2050 has an upper bound and that this bound is quite small relative to the expected magnitude of residual emissions.[53] Our understanding is that estimates for the size of the VCM assume that accountability frameworks remain similar to their current form and rely heavily on ton-for-ton accounting. We think the demand created from the voluntary market could exceed projections if these accountability frameworks are modified. For example, in 2023, we published a white paper exploring climate strategies prioritizing maximizing impact and enabling global net-zero goals rather than satisfying accounting schemes. If accountability frameworks were to change to encourage more catalytic investments and elevate efforts toward global net-zero over direct supply-chain impact, then our impression is that the size of the VCM could exceed the referenced estimates. If this is true, we may have undervalued efforts to grow the voluntary market in our assessment.

[53] See Exhibit 4, BCG, 2024

- **Feasibility of direct government procurement:** Our decision to prioritize advocacy for alternative policy context for CDR demand generation over government procurement was based on our assessment of feasibility. For public procurement to reach a meaningful scale, we think CDR must be broadly accepted as a public good to ensure sustained and substantive public investment. We do not think this is tractable at a high scale, especially in the near-to-medium term, given continued reticence on climate action and investment globally. We think we could be wrong, which would mean we may not be supporting the most effective form of policy advocacy.

- **The magnitude of CDR demand creation from alternative policy approaches:** We have chosen to prioritize support for alternative policies given that more conventional, credit-based policies considered for CDR, in combination with voluntary markets, may have limited scale or feasibility (see Appendix). We have high certainty that untapped demand opportunities exist, especially outside of the context of credit-based structures. For example, our understanding is that there are a growing number of projects to explore certain CDR pathways and their potential co-benefits in the context of integration into local industries and pay-for-practice policies. However, we have low certainty regarding the scale of CDR demand that alternative policy vehicles can generate; substantial demand growth would ultimately depend on the propagation and aggregation of these efforts. If the demand generation potential of these policies is small, then it may have been more impactful for us to focus on ensuring that the more conventional credit-based policies and markets reach the greatest possible scale.

Is there room for more philanthropic funding?

Current philanthropic trends

From 2018-2022, philanthropic foundations gave an annual average of $130 million to CDR.[54] This represents about 5-6% of the total given to climate from philanthropy each year.[55] During this period, ~72% of the funding went to "nature-based" pathways such as reforestation, biochar, peat rewetting, and soil carbon solutions (**Figure 3**).[56] We think this is imbalanced as it does not reflect a diverse portfolio of interventions and underrepresents more novel and durable pathways which are considered to be more cost-effective in the long term.[57]

[54] We use foundation giving as a proxy for philanthropic funding. Given that individual donations are not included here, we think these are likely lower bounds.
[55] Climateworks, 2023
[56] Climateworks, 2023
[57] "Conventional removals on land, on the other hand, are currently deployed at scale and have a higher a near-term cost-effective mitigation potential when compared to novel carbon removal options, with a likely lower potential in the future given land competition and storage permanence risks caused by future climate change. Novel removal options may provide more cost-effective CDR in the longer term with lower permanence concerns compared to conventional removals on land." Ganti et al, 2024.

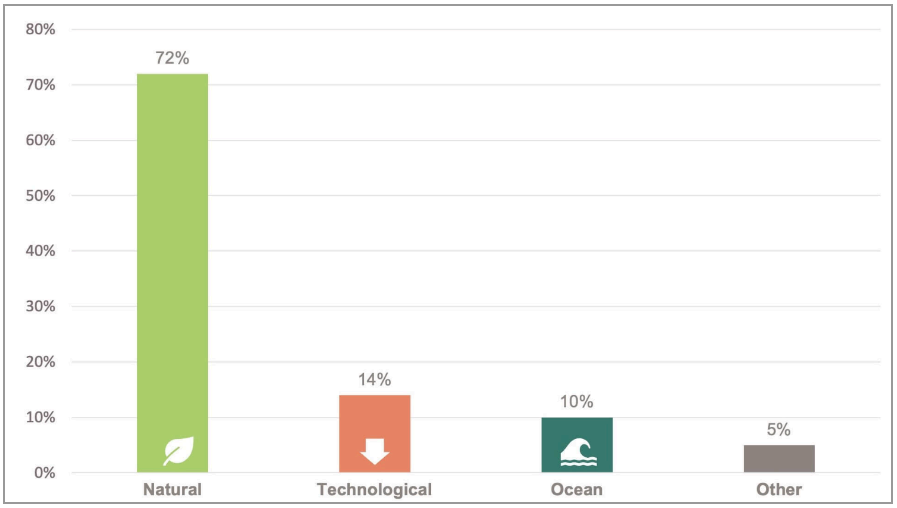

Figure 3: Share of foundation funding for CDR by subtype (2018-2021), *Climateworks (2023)*

The role of philanthropy in CDR

Early-stage private investment in CDR reached $1.2 billion in 2023.[58] As of September 2024, corporate purchases of CDR totaled ~$3 billion.[59] Public spending on carbon removal has also reached the billions as governments around the world increase CDR investments.[60] Although there is more interest in CDR than ever, we think that the role of philanthropy is critical to balance efforts in service of long-term goals. In addition, our impression is that philanthropic funding for CDR has either plateaued or decreased as some funders previously supporting CDR have shifted areas of focus.[61]

Bottom line / next steps

Given the broad consensus that policy will generate the longer-term demand of CDR, the nascency of critical policy efforts to achieve the requisite scale to meet climate goals, and the important role that nonprofits play in influencing these policies, we think it is important to grow philanthropic support for CDR. In 2024, the Giving Green Fund is planning to award a series of ecosystem grants supporting foundational work to unlock alternative policy approaches for durable CDR demand. Strategies of focus include (i) supporting policy innovation to embed CDR into alternative policy frameworks across sectors; (ii) developing standards to match the needs and opportunities of a broad and diverse array of policy vehicles; and (iii) enabling community-driven projects and subnational policies as testbeds for novel contexts, applications, policies, and markets.

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[58] "In 2023, we saw 66 companies receive USD$1.25 billion in earlier-stage capital investment from 211 investors in 68 deals across all forms of carbon removal. Of the $1.2B, $838M went to carbon removal solution developers, and $412M to companies providing supporting services for the ecosystem, such as Management, Reporting and Verification services (MRV), credit certification, credit rating, marketplace, insurance, project development, and carbon management services." 2023 Investment Landscape in Carbon Removal

[59] CDR.fyi, October 2024

[60] "To date, $4 billion has been committed by governments to CDR research and demonstration activities, with the majority ($3.5 billion) of that happening in the USA." Quadrature Climate Foundation, 2024.

[61] This is based on conversations with funders and observations of funding trends.

Acknowledgments

This work has greatly benefited from the feedback provided by various advisors, experts, and reviewers throughout the research process; Giving Green is grateful for those who shared their time, experience, and ideas. All opinions remain those of Giving Green alone, and any remaining errors are our own.

Appendix

Below, we include helpful figures from [BCG (2023)]() and [BCG (2024)]() illustrating the projected magnitude of CDR demand creation from markets and policy:

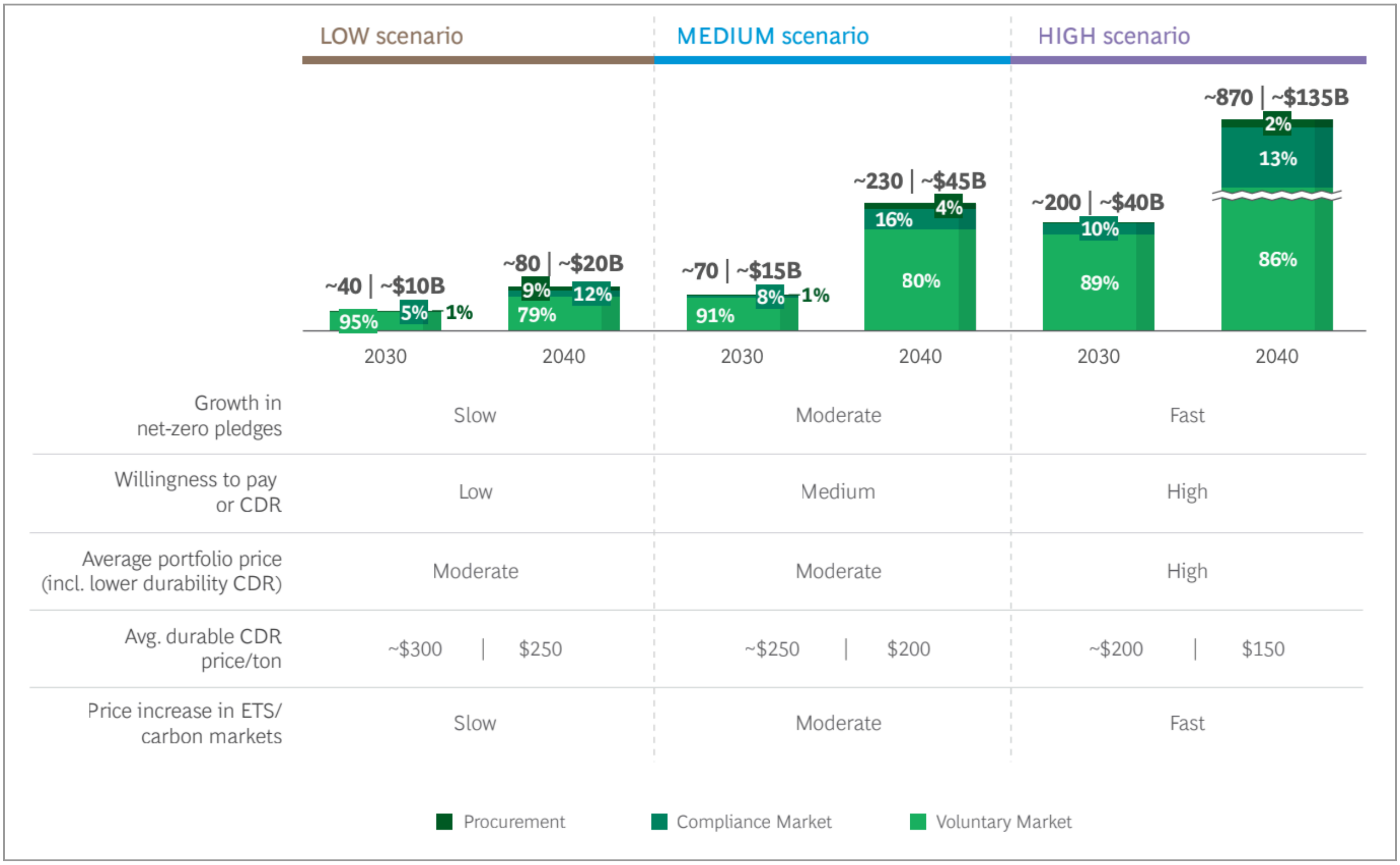
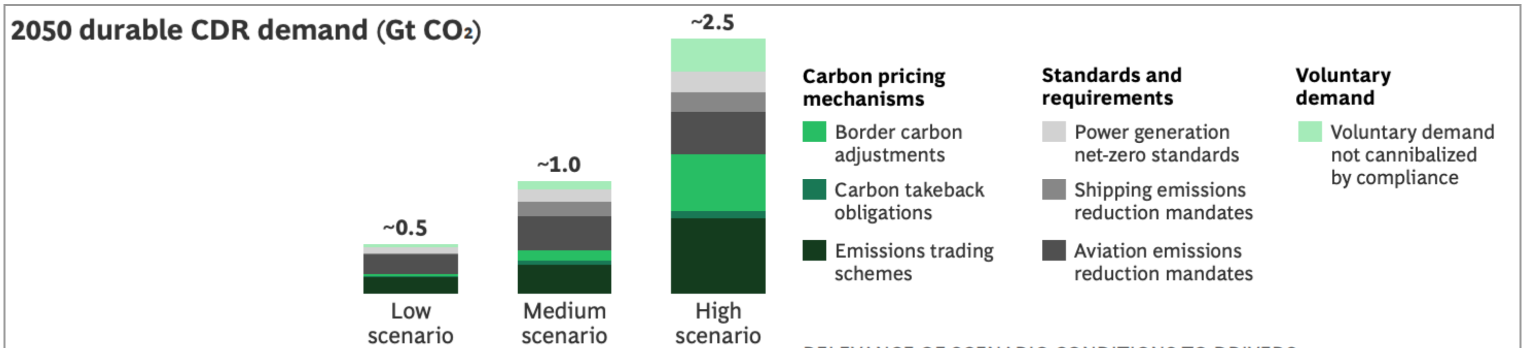


Figure 4: 2030-2040 durable CDR demand (Mt CO_2) and market size ($B) across scenarios, [*The Time for Carbon Removal Has Come, BCG (2023)*]()



RELEVANCE OF SCENARIO CONDITIONS TO DRIVERS

	Low scenario	Medium scenario	High scenario	Carbon pricing mechanisms	Standards and requirements	Voluntary demand
Strength of policy pressure to address emissions	Weak	Moderate	Aggressive	✓	✓	Some effect from increased compliance demand cannibalizing voluntary demand
Prioritization of durable CDR vs. non-durable, by governments	Low	Medium	High	✓	✗ “Like-for-like” approach requires durable only	
Average CDR portfolio price (including low durability CDR)	Moderate	Moderate	High	✓	✗	✓
Average durable CDR price per ton CO_2	~$200–$300	~$150–$250	~$100–$200	✓	✓	✓
Degree of demand reductions due to behavior change	Significant	Moderate	Minimal	✓	✓	✗

Figure 5: CDR Demand Will Ultimately Depend on Variations in Policy and Price,
Boosting Demand for Carbon Dioxide Removal. BCG (2024)