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# Measurement, reporting, and verification for novel carbon dioxide removal in US federal policy

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## HIGHLIGHTS

- Consistent and credible measurement, reporting, and verification (MRV) is critical to providing transparency and accountability for the diverse array of novel carbon dioxide removal (CDR, or carbon removal) approaches.
- The United States lacks a comprehensive oversight mechanism to ensure that MRV efforts for carbon removal are rigorous, standardized, and fit for purpose. Instead, different actors carry out MRV efforts in individualized ways, leading to a proliferation of standards following inconsistent methodologies.
- As federal investments into carbon removal grow, there is an opportunity for a federal MRV function to create oversight and set quality standards for federally supported CDR.
- A federal MRV function could involve different levels of effort from the federal government. Overall, it should build on existing efforts, set standards with the best available science, designate roles, manage incentives, centralize data and transparency, set an appropriate threshold for uncertainty, and address noncarbon impacts.
- MRV done to quantify tons of carbon removed will need to manage uncertainty to be credible and trusted. As part of a federal MRV function, government can play a key role in developing guidance, mechanisms, and best practices for managing measurability uncertainty and permanence risk.

# EXECUTIVE SUMMARY

## Context

Novel types of CDR will be needed alongside carbon removal from land sink enhancement and deep emissions reductions to reach national and global climate commitments (IPCC 2022). Over the past five years, the US federal government has increased funding for research, development, demonstration, and deployment of carbon removal approaches (US Congress 2021; US Senate 2022b) (see Appendix A for a description of carbon removal approaches). The vast majority of this investment has been directed at direct air capture with sequestration, which has the potential to provide highly measurable and permanent removal. However, other carbon removal approaches, both on land and in the ocean, can provide removal as well and are beginning to be incorporated into federal policies supporting CDR.

Because carbon removal provides a public good by removing carbon pollution, there is a distinct need for government to support research, development, and demonstration of these technologies and approaches. Like other innovations and technologies, government investment is needed to support early development, and for carbon removal in particular, government support is also needed to create a market since it is a public good that doesn't have built-in demand.

MRV techniques are being developed alongside the approaches themselves to understand how effectively they remove carbon and to measure noncarbon impacts to ensure they're operating safely. In the near term, MRV for CDR is needed to quantify carbon removal at the project level and support scale-up of the industry. However, in the long term, MRV will also be needed to incorporate CDR into national greenhouse gas inventories that track emissions, reductions, and removals. This paper focuses primarily on near-term needs to improve project-level MRV.

Currently, carbon credits generated by carbon removal projects are often sold through direct contracts between buyer and seller as well as within the voluntary carbon market (VCM). Companies producing carbon removal credits usually develop their own MRV protocols or work with credit issuers or consultants to do this on an individualized, bespoke basis. In the United States, there is currently no comprehensive oversight body or function for MRV for carbon removal, which means that this individualized approach is causing a proliferation of different standards (see Appendix B), sometimes for the same activity. As one contrasting example, the European Union is developing a Carbon Removal Certification Framework (CRCF) to define quality standards and address this need for MRV oversight.

Several US policies support the scale-up of carbon removal with a focus on quantifiable, ton-based outputs, including the 45Q tax credit, the direct air capture hubs, and the pilot procurement prize. These all include some elements of MRV, but it is not addressed consistently or comprehensively. As federal investment expands to support a broader range of CDR approaches, there is an opportunity to explore the potential role of a federal MRV function. Such a function could provide oversight to avoid a replication of the inconsistencies among standards already seen in the voluntary carbon markets, where carbon removal credits are being purchased.

The design and operation of a potential MRV function will determine the level of effort required by the federal government. Ideally, it should build on existing efforts, work to streamline data, ensure transparency, set standards with the best available science, designate roles, manage incentives, set an appropriate threshold for uncertainty, and address noncarbon impacts.

Creating a robust framework for MRV will be important for ensuring that CDR interventions are delivering claimed benefits, creating transparency and accountability around projects, building trust in the industry, and eventually enabling CDR to be counted toward national climate targets. Not all carbon removal approaches are equally permanent or measurable, so addressing uncertainty within MRV for CDR will be particularly important.

## About this working paper

This working paper lays out the current landscape of MRV efforts for novel carbon removal approaches, or those that are not yet providing large-scale removal. While our scope is MRV for CDR within US federal policy, we examine the challenges that have arisen in voluntary markets and MRV efforts in other regions that could inform potential directions forward. The paper aims to inform those working on project- and technology-level MRV for CDR within the federal government, federally funded efforts, and other stakeholders working toward improving the quality and consistency of MRV for CDR. Our focus is on federal policy that supports carbon removal in ways that prioritizes the quantification of tons removed. Policy can also support CDR in ways that incentivize CDR practices without prioritizing quantification of tons removed; however, these policies are beyond the scope of this paper.

## Findings and recommendations

This paper defines MRV, identifies challenges confronting MRV efforts for CDR, and examines the ways that MRV is currently included in US federal policy supporting CDR. We move from describing the landscape to examining two key questions that inform future action: What would an ideal MRV function for CDR look like as it pertains to federal policy? And how can quantification uncertainty and reversal risk best be addressed across CDR approaches?

We find that MRV is present to some extent in current and proposed US federal policies supporting CDR, but its role and requirements are not consistent or comprehensive. The European Union's approach to CDR policy provides a relevant counterexample. The European Union is focused on designing a CRCF that provides a cross-cutting standard for high-quality CDR, including MRV guidance, whereas the United States has focused more on funding the development and deployment of the technologies to scale the industry.

In the United States, the US Department of Energy set a Carbon Negative Shot goal of reducing the cost of carbon dioxide ($CO_2$) removal pathways to US$100 per metric ton of $CO_2$ equivalent ($tCO_2e$) net removed within a decade for approaches that can reach gigaton scale (DOE 2021). To meet this goal, federal policy will need to support a wide range of CDR approaches that will need to adhere to consistent and credible MRV standards. Challenges around consistency and credibility have emerged due to a lack of oversight in the voluntary market for carbon credits, and these challenges underscore the need for federal intervention. There is now an opportunity to consider what an MRV function could look like in the context of federal policy, including approaches to managing uncertainty. We recommend seven principles for consideration in the development of a federal MRV function:

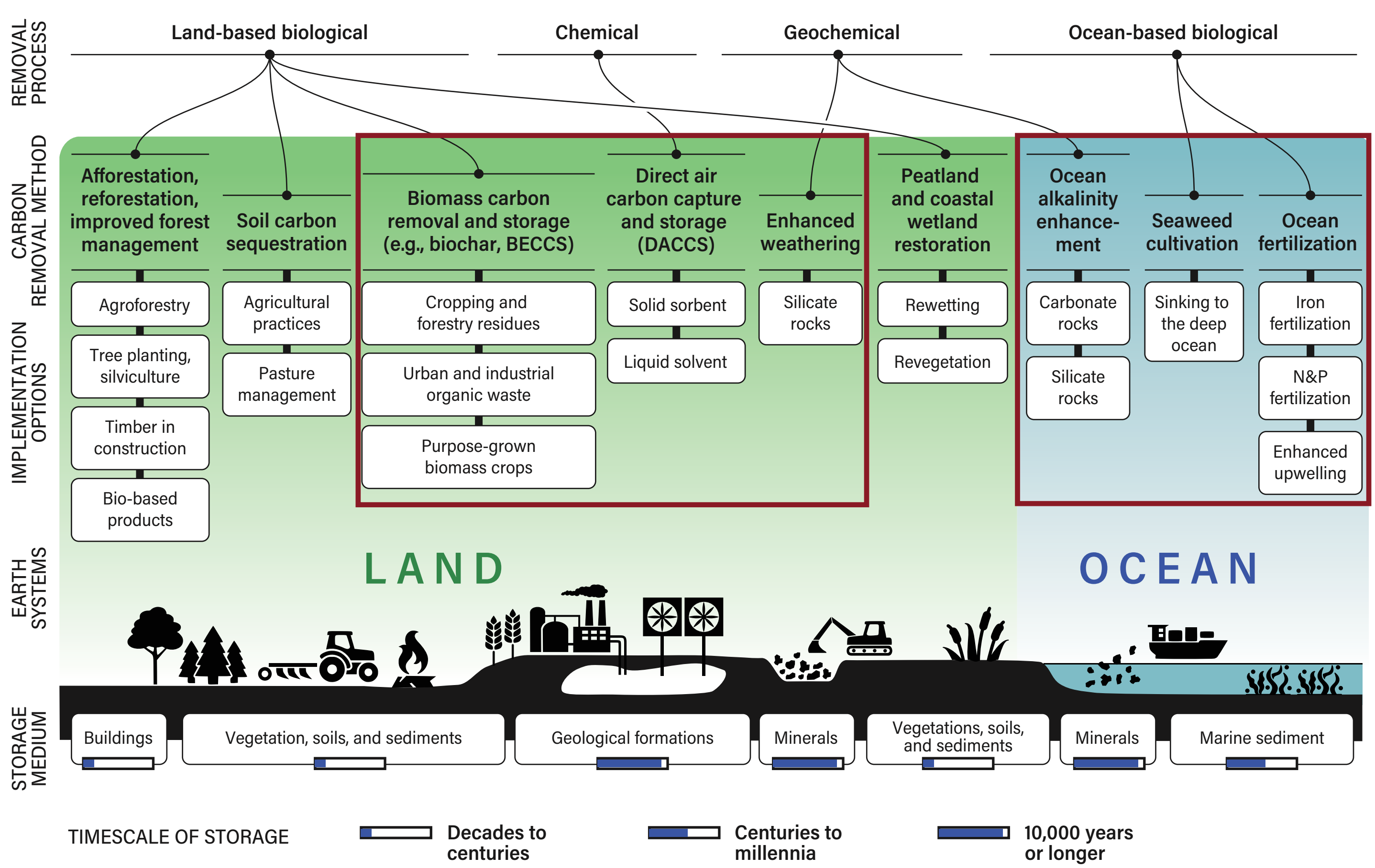
- **Build on existing expertise.** A federal MRV function should build on existing expertise and efforts in the private sector, in academia, and within the government to avoid duplication of efforts. A first step could involve a landscape assessment of existing efforts with identification of gaps, inconsistencies, and pain points.
- **Designate roles.** The government should determine roles and responsibilities within a federal MRV function, including delegating crucial functions that are outside of their capacities.
- **Manage incentives.** Part of the decision-making around roles and responsibilities will include determining an appropriate compensation framework for those designing and verifying MRV methodologies and protocols management to avoid overcrediting and fraud.
- **Set standards based on the best available science.** The federal government can create oversight by setting standards for CDR MRV with the best available science. At minimum, standards should address thorough and transparent life cycle carbon and greenhouse gas accounting, ongoing monitoring, and assessment of community and environmental impacts, which could also help raise quality standards for the VCM and increase buyer confidence in these markets.
- **Centralize data and maintain transparency.** Publicly and transparently reporting the outcomes of CDR projects is key for building trust in CDR and holding companies accountable for backing the claims that they make. In the near term, providing public information on projects in development and underway (to the extent practicable while considering confidential business information), reported levels of carbon removed and ongoing monitoring, and project details will be important to create transparency and credibility.
- **Set an appropriate threshold for uncertainty.** Policies designed to support carbon removal on a per-ton basis will need to set guidelines for acceptable levels of uncertainty related to the number of tons removed and specify ways to address the uncertainty that remains within that threshold. In the context of a ton-based policy support, uncertainty tolerance will differ depending on the CDR approach and how the removal is being used.
- **Address noncarbon impacts.** Carbon removal projects must not only remove carbon but also minimize negative impacts on the environment and people in order to be sustainable and scalable. Therefore, MRV frameworks should address noncarbon impacts, including impacts on air and water quality.

# INTRODUCTION

There is strong scientific consensus that along with deep economy-wide emissions reductions, the global community will also need to remove carbon dioxide ($CO_2$) from the atmosphere[1] to meet global and national climate goals (IPCC 2022). The Intergovernmental Panel on Climate Change (IPCC 2022) has made it clear that carbon removal—using both novel and conventional approaches (see Figure 1 and Appendix A)—will be needed at a scale of multiple billions of metric tons of removal annually by midcentury to limit temperature rise to 1.5°C. The US government's long-term strategy lays out a pathway to achieve net-zero greenhouse gas emissions by 2050. This strategy relies on roughly a gigaton of novel and conventional carbon dioxide removal, or CDR (US Department of State 2021). Around half of that gigaton, or 500 million metric tons, is expected to come from novel approaches—those beyond removals from enhancement of land carbon sinks.

Achieving this level of carbon removal scale-up requires government support from early-stage research to commercial deployment. Carbon removal is largely a public good that is providing atmospheric clean-up as a primary service. As a public good, it does not have a ready market of purchasers and instead relies on policy to drive demand. Furthermore, many CDR approaches are costly today because they are still in early

Figure 1 | **Taxonomy of carbon dioxide removal approaches**




*Notes:* Approaches outlined in red are within the scope of carbon removal approaches addressed in this paper. BECCS = bioenergy with carbon capture and sequestration. N&P = nitrogen and phosphorus.

*Source:* IPCC 2022.

development or demonstration. Like many types of innovation, government support for early research can help develop, derisk, and reduce costs of new technologies.

The government has directed billions of dollars in the past several years to support CDR development, demonstration, and deployment to reduce cost and scale the industry. This support will help meet the government-wide Carbon Negative Shot goal of reducing costs to US\$100/t$CO_2$ within the decade for approaches that can scale to gigaton level (DOE 2021).

At the same time that these CDR technologies and approaches are being developed, methods to measure their effectiveness must also be devised. Measurement, reporting, and verification (MRV) is needed in the near term to measure efficacy, create transparency, and provide accountability around carbon removal claims to help grow the industry and build public trust. While project-level MRV is already used today in the voluntary carbon market (VCM), where carbon credits are bought and sold, it is less developed in the context of federal policy support for carbon removal.

As federal funding of carbon removal increases in scale and scope, development of a federal MRV function to guide and oversee MRV for CDR in federal policy will help build confidence in this growing industry. This paper lays out the landscape of MRV for CDR today and then explores what an MRV function and ecosystem for CDR could look like in the context of federal policy. A federal MRV function would help establish, coordinate, and improve a broader MRV ecosystem that would build on existing efforts and include government agencies, academics, nongovernmental organizations (NGOs), and other actors.

Among other things, an MRV function would need to manage quantification uncertainty and reversal risk associated with CDR approaches in different policy contexts. Creating a robust and credible MRV ecosystem that can consistently and credibly quantify carbon removal and account for uncertainty will be critical for building trust in this new industry. This paper focuses on novel CDR approaches, such as direct air capture with sequestration (DACS), carbon mineralization, biomass carbon removal and storage, and ocean alkalinity enhancement, among others, which are not removing carbon at a large scale today (see Appendix A).

Novel CDR will ultimately be needed to help achieve national and global climate goals but is generally in early development or demonstration today. Consequently, high-quality project- and technology-level MRV is key for assessing efficacy and enabling credible and transparent federal policy support—much of which is oriented around the number of tons removed by a given project. In the longer term, MRV will also be needed to track progress toward national and global climate goals.

Given this paper's focus on project-level MRV, it does not address questions related to inclusion of CDR into the national greenhouse gas inventory (NGHGI). Rather, it examines the successes and challenges of existing mechanisms to incentivize high-quality, project- and technology-level MRV and assesses the ways that federal policy could resolve key pain points to enable accelerated deployment of effective CDR through more consistent MRV. Even so, policy recommendations in this paper could help lay the groundwork for eventual inclusion in the NGHGI and would likely also improve confidence in voluntary carbon markets.

## METHODOLOGY

The field of novel CDR is relatively young, and the literature on MRV within the field is not well developed. We seek to further the discussion on MRV for CDR by building on existing work that explores high-accountability MRV practices (Khan and Minor 2022) and uncertainties tied to quantifying net carbon removal and storage durability (Chay et al. 2022).

We reference existing technology- and project-level work exploring MRV for CDR approaches published by nonprofits and NGOs working on CDR policy and research (e.g., Chay et al. 2022; Khan and Minor 2022; Mercer and Burke 2023), as well as academic researchers (e.g., Arcusa and Sprenkle-Hyppolite 2022). We also reference MRV standards and protocols for CDR that have been published by carbon removal suppliers, standard setters, and other actors in the VCM to understand the current MRV landscape and to inform recommendations for federal policy to build on what has already been done. We consulted a dozen experts from NGOs, officials from federal agencies, and academic researchers working on carbon removal and MRV.

# MRV FOR CARBON DIOXIDE REMOVAL

MRV is a process for tracking the outcomes of climate mitigation activities. It includes measurement, reporting, and verification to quantify and transparently share information on the outcomes of a variety of climate actions, as well as ongoing monitoring to ensure that outcomes are maintained over time.

## How is MRV done?

MRV can be applied in many contexts related to climate change mitigation to track outcomes and hold countries and organizations accountable for their claims and climate goals (see Table 1). This paper is focused on project-level MRV, where carbon removal projects can use MRV to demonstrate the quality and credibility of removals and how this is maintained over time.

MRV should be fit for purpose for these different applications. In other words, the way it is designed should reflect the type of activity it addresses and the intended outcomes of a project or policy. For example, MRV for a national GHG inventory involves measurement of all emissions and removals resulting from human activity, usually by economic sector, over a specific time period, generally a year. In contrast, MRV for a DACS project would measure carbon dioxide removed from the air and sequestered underground over a certain time period plus any GHG emissions associated with the capture and sequestration process to assess net tons of carbon dioxide equivalent removed.

The term *MRV* first emerged within the context of the United Nations Framework Convention on Climate Change and in the Bali Action Plan, which was adopted at the 13th session of the Conference of the Parties (COP 13) in 2007. The plan determined that national and international climate change mitigation actions must be implemented in a "measurable, reportable and verifiable" manner (UNFCCC 2007). The Bali Action Plan provided no clear definition of these processes; the specific definition was left intentionally ambiguous to include a wide range of activities and methods, with the idea that it would become clearer through practice (IGES 2013). MRV systems have since been better conceptualized and are the foundation of tracking climate action. MRV provisions were expanded on and further solidified at COP 26, where parties established that MRV systems would be an integral part of tracking the implementation of nationally determined contributions (Singh et al. 2016).

Table 1 | **General types of MRV for climate change mitigation**

| TYPE OF MRV | OBJECTIVE OF MRV |
|---|---|
| National | Quantify GHG emissions and removals for a national GHG inventory; based on guidance from the IPCC |
| Policy | Quantify the GHG impact of certain policies |
| Organization | Quantify entity- or organizational-level emissions for reporting under emissions trading schemes or to report for corporate/organizational GHG inventories |
| Project | Quantify GHG reductions or carbon removed associated with a specific project |

*Notes:* GHG = greenhouse gas. IPCC = Intergovernmental Panel on Climate Change.
*Sources:* IGES 2013; Singh et al. 2016.

In the context of carbon removal, the amount of carbon removed through a particular activity is *measured* over a specific time frame; *reported* to registries, regulators, or other relevant parties; and then *verified* by an accredited third party to ensure accuracy. Once the results have been verified, they can be certified by carbon crediting registries for purchase on voluntary or compliance markets or for trade or compensation in other contexts. MRV steps may be sequenced in different ways to accommodate project needs and must be iterative over time.

The following steps are part of the MRV process for CDR (see Figure 2).

### 1. Measurement of carbon removal

This step can include direct measurements of the amount of carbon removed or the measurement of changes from an established baseline to quantify removal. To evaluate net tons removed by a technology or project, emissions from other steps in the capture and sequestration process need to be measured as well. Measurement should be done in accordance with an MRV protocol, if one exists, and can involve data collection on-site, sometimes combined with modeling, depending on the type of approach and availability of data. For example:

- In the case of direct air capture (DAC), carbon dioxide removed from the atmosphere and sequestered underground can be directly measured with a flow meter prior to injection. To determine net tons removed, emissions associated with capture, transport, and storage need to be measured as well and subtracted from the amount sequestered. The boundaries defining the scope of the DAC process are defined by the MRV standard and/or protocol.

- In the case of ocean alkalinity enhancement (OAE), ground alkaline material is added to the ocean to react with dissolved $CO_2$, where it forms bicarbonates and carbonates. The amount of alkaline material added must be quantified, and changes in partial pressure of $CO_2$ and ocean pH can be measured to help estimate the efficacy of OAE. Other changes that would affect net removal must also be measured, including induced precipitation of calcium carbonate minerals, responses of calcifying organisms, and other ecosystem changes (Ho et al. 2023). Changes in the air-sea flux also need to be quantified. When the concentration of dissolved $CO_2$ is lowered in surface water, $CO_2$ moves from the atmosphere to the ocean to equalize the relative $CO_2$ concentrations, resulting in atmospheric $CO_2$ removal. Because the ocean is always circulating, ocean circulation models will need to be combined with direct measurements to estimate removal. To quantify net tons removed, offsetting emissions associated with the OAE process would need to be counted as well.

Measurement of the amount of net carbon removed from the application of a CDR approach involves life cycle carbon accounting that measures emissions from all stages of that technology's production, use, and disposal, as well as the gross removal to determine the net negativity of the whole process. Accurate carbon accounting provides a baseline measurement of the level of net negativity of a certain carbon removal technology, which can be used in project-based MRV.

The *M* in *MRV* is often also understood to stand for "monitoring," which is often used interchangeably or in combination with "measurement." What was initially measured needs to be monitored over time to ensure that sequestered carbon is not released. How this is done, how frequently, and by whom should be specified in MRV protocols and will vary depending on the quantification standard applied, the objective of the MRV, and what the MRV is used for.

In addition to measuring and monitoring carbon and other emissions, there have been calls for monitoring environmental impacts—including on air and water quality and on public health—to demonstrate that negative impacts are being avoided where possible and actively minimized (Bryce and Faber 2023; ICVCM 2023; Khan and Minor 2022).

## 2. Reporting of the measured and monitored data

Reporting is the administrative aspect of the MRV process (Bellassen et al. 2015). The data compiled in the measurement stage is shared with third parties, regulators, other relevant authorities and/or the public. What, how, and when data is reported is purpose- and project-specific. Reporting data is integral to the MRV process, as it makes these data available for assessment and can help create accountability for project developers. Reporting is ideally standardized in order to allow for comparison across projects and over time (Breidenich and Bodansky 2009).

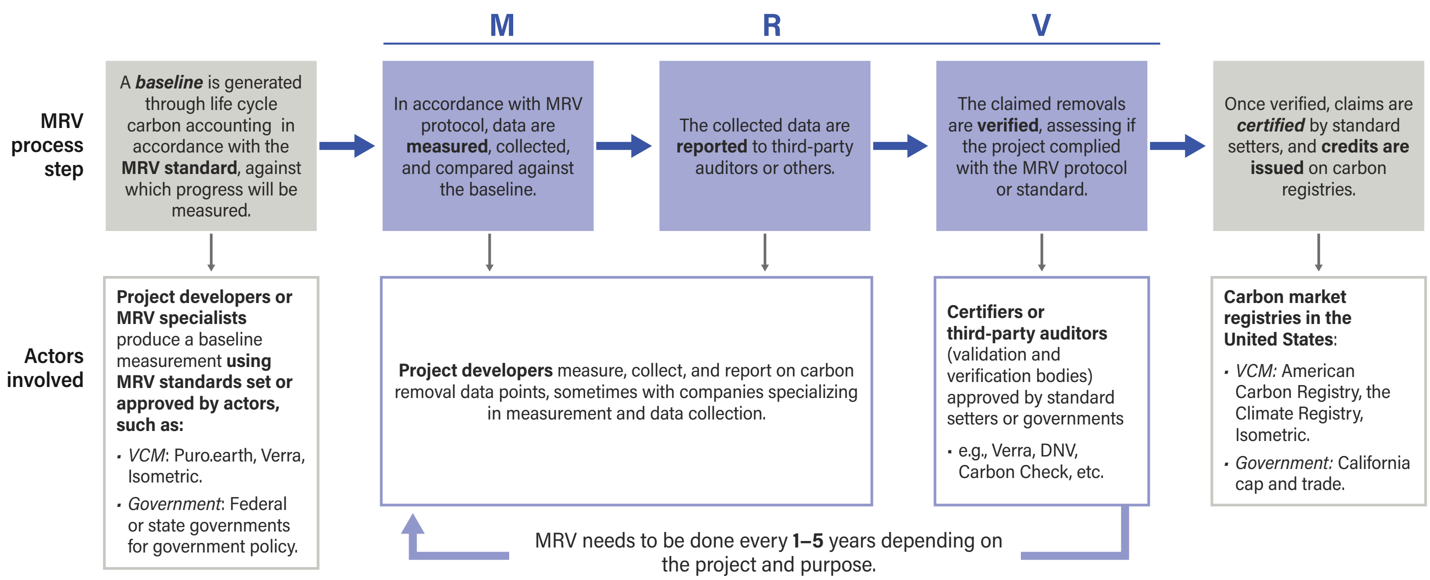
## 3. Verification of the reported data

The measured and reported data is then verified to ensure their accuracy and reliability. Verification is crucial to detect errors in reporting or measurement, including potentially fraudulent reporting (Bellassen et al. 2015). For carbon removal, verification is commonly carried out by accredited third parties, such as certified validation and verification bodies, which are accredited by a standards body such as the International Organization for Standardization. Verification entails the review of reported data, including through on-site inspections. Verifiers have discretion around some technical details of the verification process, which can also lead to inconsistency. If MRV is carried out for the purpose of generating a carbon credit, once the data are verified, they can be certified by a standard setter or registry that issues credits (World Bank 2022). Verification protocols should be open source and peer reviewed.

Development of and adherence to high-quality MRV for CDR (see Box 1) can provide accountability for carbon removal claims made, provide transparency around other impacts of a project, and build trust in the CDR ecosystem. This transparency and trust building is particularly important since carbon removal is a new industry that is already facing skepticism and distrust from various actors due to concerns about mitigation deterrence and equity (Carton et al. 2021; Grant et al. 2021; Lebling et al. 2023; Mace et al. 2021; McLaren 2020). Furthermore, other types of carbon credits, such as those from reduced emissions, have been found to be of poor quality and not producing the promised outcomes.[2]

If MRV is done poorly,[3] there are limited ways to hold project developers accountable for their claims, and trust in the sector is likely to erode, potentially undermining the role of CDR in contributing to climate goals. Federal deployment support will be necessary to scale carbon removal, and robust MRV systems will be needed to underpin the efficacy of these investments.

## Figure 2 | How MRV is done today for the generation of carbon removal credits




*Notes:* This is a simplified version of the MRV process for CDR today and actors involved; other actors such as ratings companies, insurance providers, and others can be involved at various steps. MRV = measurement, reporting, and verification. VCM = voluntary carbon market.

*Source:* Authors, based on Mercer and Burke 2023.

## Box 1 | Criteria for high-quality MRV for CDR

High-quality MRV frameworks for CDR should undertake the following:[a,b,c]

- **Prove additionality.** A CDR activity is *additional* when it can prove that it would not have otherwise happened. Such a hypothetical, no-intervention baseline scenario cannot be directly observed; it can only be inferred.[d]
- **Measure permanence.** Also referred to as *durability,* this is the duration for which carbon is safely sequestered, and the corresponding reversal risk of that sequestration. There are different definitions for what constitutes "permanent" sequestration, with most defining it as either more than 100 years or more than 1,000 years.[e,f,g] While CDR approaches involve different levels of risk of nonpermanence, or $CO_2$ reversal, this risk is generally lower for novel types of CDR, compared to conventional CDR, such as land sink enhancement. CDR projects with a higher risk of reversal must have measures in place to address this risk (see Appendix D).
- **Provide quantification to prove net negativity and account for uncertainty.** Quantification of carbon removed must be done with the best available science to prove and quantify net negativity on a life cycle basis of a project or technology. Quantification must also measure and account for different sources of uncertainty that could lead to under- or overestimation of carbon removed.
- **Address leakage.** When projects or activities are deployed in one location, this may lead to an increase in GHG emissions at another location because of market shifts. DAC projects could experience leakage if the energy used creates new energy demand elsewhere, especially if that demand is fulfilled with more emissions-intensive sources.[h] Leakage in this context is not to be confused with physical leakage, also known as $CO_2$ reversal.
- **Ensure transparency.** The way data are measured, collected, reported, and verified must be publicly accessible to the amount practicable, so project developers and others can be held accountable and trust can be built.
- **Track environmental and social impacts.** Beyond carbon accounting, impacts on the environment and people should also be measured and monitored to account for and minimize potential negative impacts. Projects should adhere to guidance on social and environmental safeguards in order to minimize negative externalities.

*Sources:* a. Carbon Direct 2023; b. Isometric 2023; c. Khan and Minor 2022; d. Wilcox et al. 2021; e. Chiquier et al. 2022; f. Hausfather et al. 2022; g. Weiss 2022; h. Carbon Direct 2023.

# MRV IN FEDERAL POLICY SUPPORT FOR CDR

As recognition of the need for CDR to meet climate goals has grown (IPCC 2022), the US government has provided historic levels of funding for research, development, and demonstration of CDR through the 2021 Bipartisan Infrastructure Law (BIL) and the 2022 Inflation Reduction Act (IRA), as well as through annual budget appropriations (US Congress 2021; US Senate 2022a, 2022b). Government policy for CDR can be categorized into three general types: research and development funding, demand-side policy, and regulatory policy (Jones et al. 2024). The policies we will focus on are generally meant to drive demand, support market development, and involve quantification of tons removed.

These policies include the 45Q tax credit, which was enhanced in the IRA; the CDR Purchase Pilot Prize, which was directed in fiscal year 2023 appropriations; and the Regional Direct Air Capture Hubs program, which was included in the BIL. In addition, there are two proposed CDR-specific policies; namely, the Federal Carbon Dioxide Removal Leadership Act and the Carbon Removal and Emissions Storage Technologies Act (CREST), which would both require multiyear government procurement of carbon removal.

All of these policies include MRV provisions to some extent (see Table 2) but not in a consistent or harmonized way, and most do not indicate how they will address quantification uncertainty or risk of $CO_2$ reversal associated with many CDR approaches within the MRV process. Federal policy in the United States has focused more on providing incentives for scaling CDR than on developing and adopting rules for quantification and reporting. The latter has been more of a focus in the European Union through the Carbon Removal Certification Framework (see Appendix C).

Consistent and credible MRV standards that can be applied across policies will be necessary to support scaling of a diverse range of carbon removal approaches. This will ultimately help the United States meet its 2050 climate goal of net zero GHG emissions (US Department of State 2021). Otherwise, there is

Table 2 | **The MRV and uncertainty approaches of CDR-related enacted policies and proposed legislation**

| ENACTED POLICY | | |
|---|---|---|
| **45Q tax credit** | Policy summary | 45Q provides a tax credit for geologic sequestration or utilization of captured carbon oxides. $CO_2$ captured with DAC receives \$180/t$CO_2$ for geologic sequestration (and \$85/t$CO_2$ for BECCS) and does not require an LCA to determine net tons removed. $CO_2$ captured with DAC receives \$130/t$CO_2$ for utilization (and \$60/t$CO_2$ for BECCS) and requires an LCA to determine net tons utilized. |
| | Approach to MRV | Under 45Q, the MRV requirements address the sequestration component of the process, rather than the capture of $CO_2$. To receive a Class VI permit[4] for geologic sequestration, project developers need to submit data to the EPA on the planned amounts of $CO_2$ sequestered at their site. Subpart RR of the GHGRP determines that projects submit a proposed MRV plan that follows EPA requirements and be approved by the agency (EPA 2011). Among many requirements, the program determines what is to be measured and monitored as part of the EPA-approved MRV plan, what information is to be reported to the EPA on an annual basis, and how GHG data is to be calculated (EPA 2011). EPA Class VI permit rules also determine that once the injection of $CO_2$ has stopped, the operator must continue to monitor the site for 50 years to ensure $CO_2$ reversal is not happening. Facilities are responsible for establishing a strategy to detect and quantify $CO_2$ reversal (Congressional Research Service 2021).<br><br>For the utilization credit under 45Q, an LCA is required to demonstrate how much carbon oxide is captured and permanently removed from the atmosphere (in the case of DAC) or displaced from being emitted (in the case of BECCS). The DOE's National Energy Technology Laboratory has developed LCA guidance for use by project developers, who must submit the LCA to the IRS and DOE for preapproval, where it can be reviewed for adherence to international standards (e.g., ISO 14044). |
| **CDR Purchase Pilot Prize** | Policy summary | The DOE announced a \$35 million procurement prize in September 2023, which is the first government initiative to purchase high-quality carbon-removal credits directly from project developers. Eligible approaches include DACS, BiCRS, enhanced mineralization, and other carbon sink projects. Companies compete over 3 phases and several years for selection by the DOE for prizes of increasing dollar amounts in each phase. Projects must deliver at least 3,000 t$CO_2$ at the end of the 3-year contract for a value not exceeding \$3 million. |

Table 2 | **The MRV and uncertainty approaches of CDR-related enacted policies and proposed legislation (cont.)**

| | | |
|---|---|---|
| **ENACTED POLICY (CONT.)** | | |
| **CDR Purchase Pilot Prize (cont.)** | Approach to MRV | MRV requirements are outlined in Appendix 11 of the prize's official rules (DOE 2023a). The program requires competitors to submit an MMRV plan, and proposals with the most comprehensive MMRV plans will be prioritized. Competitors must provide details of measurement tools and models used to quantify $CO_2$ fluxes, emissions, $CO_2$ stored, and $CO_2$ reversal. Potential quantifiable environmental harms must also be identified. Reporting requirements include LCA results, uncertainty associated with $CO_2$ flux estimates, and the subsequent storage permanence. Applicants must outline how the uncertainty affects the net tons delivered and must obtain at least 2 independent reviews by third-party verification bodies, discuss transfer of responsibility for stored $CO_2$ after the completion of the project, use relevant insurance mechanisms, and ensure that $CO_2$ storage is compliant with the EPA's Class VI requirements (DOE 2023a). |
| **Regional Direct Air Capture Hubs** | Policy summary | The federal BIL provided \$3.5 billion to build 4 DAC hubs. Each hub must have capacity to capture and sequester, or use, 1 million metric tons of $CO_2$ per year. |
| | Approach to MRV | Although no official MRV plan is required, the program requires an LCA to be submitted in the application. If the $CO_2$ is stored in saline aquifers for permanent geologic storage, the inputs for the LCA are to be conducted in accordance with the DOE's Office of Fossil Energy and Carbon Management's best practices for LCA of DACS (Cooney 2022). An uncertainty analysis is included in the LCA, which pertains to measurement uncertainties. |
| **Carbon Negative Shot Pilots** | Policy summary | The Carbon Negative Shot Pilots are meant to support the development of BiCRS and $CO_2$ mineralization pilots, as well as other multipathway CDR test bed facilities to reach the DOE's Carbon Negative Shot target of \$100 per net metric ton of $CO_2$ within a decade (DOE 2024). |
| | Approach to MRV | Appendix E of the DOE's Funding Opportunity Announcement sets out guidelines for the LCA required, based on whether the captured $CO_2$ will be used in a marketable product or not. |
| **PROPOSED OR UPCOMING POLICIES** | | |
| **Federal CDR Leadership Act** | Policy summary | If passed, this act would direct the DOE to purchase increasing amounts of carbon removal over 10 years at a decreasing price, while supporting a diverse portfolio of CDR approaches. It would require purchase of up to 10 million net metric tons of $CO_2$ in the program's 10th year. |
| | Approach to MRV | The DOE would be required to coordinate with other relevant agencies to "establish standards for the moniroting, reporting, and verification of the net metric tons fo carbon dioxide removed" (US Senate 2024). |
| **CREST Act** | Policy summary | If passed, the CREST Act would provide funding for research and development of carbon removal as well as a 5-year purchasing program, structured as a reverse auction, with allocations of 70% of total purchase for approaches with 1,000 years' or more permanence and 30% for approaches with 100–1,000 years' permanence. |
| | Approach to MRV | Bids that are submitted in the reverse auction must include an LCA that includes operation, storage, and production inputs. |
| **DOE August 2023 announcements** | Policy summary | In August 2023, the DOE announced funding expected in FY2024 to support project development and commercializing protocols, technologies, and methods to improve MRV approaches for terrestrial or marine CDR pathways. |
| | Approach to MRV | More information is expected sometime in FY2024. |

*Notes:* MRV = measurement, reporting, and verification. CDR = carbon dioxide removal. $CO_2$ = carbon dioxide. DAC = direct air capture. $tCO_2$ = metric tons of carbon dioxide. BECCS = bioenergy with carbon capture and sequestration. LCA = life cycle assessment. EPA = US Environmental Protection Agency. GHGRP = Greenhouse Gas Reporting Protocol. GHG = greenhouse gas. DOE = US Department of Energy. IRS = Internal Revenue Service. DACS = direct air capture with sequestration. BiCRS = biomass carbon removal and storage. MMRV = measurement, monitoring, reporting, and verification. BIL = Bipartisan Infrastructure Law. CREST = Carbon Removal and Emissions Storage Technologies Act.

a risk of different standards being referenced under different federal policies, which could cause confusion, contributing to the proliferation of efforts and undermining trust in this new industry. This risk also exists at the international level.

## Challenges facing MRV for CDR today

The carbon removal industry has grown rapidly over the past five or so years. So far, the industry has emerged without much oversight, meaning that carbon removal companies are entering a space without consensus standards or protocols for how to consistently and credibly measure and report removals. The lack of consensus standards can lead to inconsistency in measurement methodologies. The measurement of removal from some approaches is also more difficult than for others, and some approaches present a bigger reversal risk than others (see Table 3).

These challenges are predominantly arising in the VCM today, as carbon removal projects and their associated credits have primarily been traded there. However, federal policy for CDR, which only emerged in recent years, is increasing, with billions of dollars of public investment (Stripe 2021; US Congress 2021; US Senate 2022b). There is no comprehensive federal oversight for MRV, indicating that the challenges that have emerged in the VCM may also arise in the federal policy context if they are not proactively addressed.

Proactively addressing these challenges will also be crucial if and when CDR policy moves toward compliance instruments, which will play an important role in scaling up carbon removal in the long run.

These key challenges are outlined below.

### Lack of standardized rules for quantification

The development of carbon removal quantification standards today (see Appendix B) is generally being done by carbon removal companies, sometimes in collaboration with consultants or standards bodies, and often on an individual, bespoke basis. While this approach is understandable in the context of a relatively new industry, it also creates challenges, such as the proliferation of standards and lack of consistency. The rules governing the quality and integrity of these protocols, which are created by standard setters and/or credit issuers (see Appendix B), are similarly being developed in inconsistent ways.

Without consensus on quantification standards, companies can measure carbon removal from one type of activity in different ways. This can cause confusion for buyers and enable forum shopping and potential races to the bottom on quality.

Such inconsistencies also burden CDR suppliers who would need to meet different standards and follow different protocols under different types of policy support. Consistent quantification standards could help companies understand where their money is best spent to improve measurement infrastructure or technology.

As federal policy support for carbon removal increases, there is a similar risk that different policy mechanisms reference different MRV standards and protocols, creating inconsistency and confusion. However, the CDR sector is still in the early stages of development, presenting an opportune moment for improving consistency and oversight.

There have already been calls for stronger oversight domestically and globally as well as some steps in that direction:

- In the United States, four national laboratory-led teams have been selected for $15 million in federal funding from the DOE's Office of Technology Transitions, Office of Fossil Energy and Carbon Management, and Office of Clean Energy Demonstrations to advance best practices and capabilities for MRV across several CDR approaches. Three national labs are developing MRV best practices for biomass CDR, cement and concrete, and mineralization-based CDR pathways, while the fourth is working on an umbrella MRV framework across CDR approaches to advance technical foundations and provide guidance on how to harmonize existing standards and protocol efforts (DOE 2023b).
- CarbonPlan and a group of carbon removal suppliers, nonprofits, and others have called for the creation of an independent, internationally oriented standards initiative that would provide scientific guidelines and protocols for CDR to ensure that MRV is done consistently and robustly and harmonize existing MRV approaches (Hausfather et al. 2023). The initiative would review and approve quantification protocols, establish guidelines for independent third-party verification, and update guidelines and protocols transparently so that they can always be based on best available science.
- In the European Union, the Carbon Removal Certification Framework (see Appendix C) is in development to establish criteria for high-quality MRV for CDR (Mitchell-Larson et al. 2022). The European Commission (2022) will establish detailed certification methodologies for three types of carbon removal activities (novel approaches, conventional approaches, and carbon stored in products) based on best available scientific evidence, in cooperation with expert groups and building on existing public and private schemes and methodologies.

- There are also efforts to improve credit quality (relevant to both reduction and removal credits) and foster consistency across MRV efforts in the VCM, such as the Core Carbon Principles established by the Integrity Council for the Voluntary Carbon Market. They aim to provide a high-level quality standard for standard setters to voluntarily adhere to (ICVCM 2022).
- The Paris Agreement's Article 6.4 will also help establish comprehensive MRV guidelines at the international level. The Supervisory Body overseeing the crediting mechanism's implementation will set practical standards for carbon crediting methodologies and has established CDR methodology guidelines, the negotiations around which are to resume at COP29 (IISD 2024; IPCC 2024).

## Quantification uncertainties

There are several types of uncertainty related to quantifying carbon removed, which differ depending on the CDR approach and its stage of development.

There can be uncertainty associated with the scientific underpinnings of the carbon removal approach, making it difficult to accurately quantify carbon removal even using the best available science. Methodology can also be a source of uncertainty if the methodology used to measure removals is not sufficiently rigorous or if inconsistent methodologies mean that identical projects are measured differently. For example, different bioenergy with carbon capture and sequestration (BECCS) methodologies may identify different counterfactual uses for the same feedstock, or different enhanced rock weathering protocols may require differing sampling methods. There may also be uncertainty regarding the timeline for the removal to happen and the durability once removal occurs (Chay et al. 2022). When considering federal policy supporting carbon removal on a per ton basis, measurability of net[5] carbon removed is critical.

Uncertainties around measurement can come from sampling and/or modeling uncertainties, as well as the lack of tools to collect data, especially for open-system approaches. Carbon removed through approaches that operate within a closed system can be easier to measure than carbon removed through approaches that seek to accelerate larger natural systems.

Generally, protocols that use physical measurements, or sampling, combined with modeling will lead to more robust quantification with lower uncertainty (Zelikova et al. 2021). However, for open-system approaches, measurement based on sampling will be more challenging, meaning that the MRV for these approaches will have to rely more on modeling. The reliance on models can make it more difficult to accurately quantify the level of uncertainty associated with the tons removed (Minor and Khan n.d.).

For example, with DAC, which is a closed-system approach, $CO_2$ can be directly measured before it's sequestered. When DAC or other approaches are combined with geologic sequestration, the amount of $CO_2$ injected into the ground can also be measured, and there is established guidance for monitoring sequestration over time (EPA 2023). On the other hand, open-system approaches like ocean alkalinity enhancement have lower measurability. Tracking the level of carbon removal in an open system like the ocean is costly and is more challenging from an engineering perspective.

While additional research, development, and demonstration can improve the ability to measure carbon removal (both through sampling and with improved models) and reduce the level of uncertainty, some approaches will always be easier to measure than others.

## Reversal risk

Reversal risk, also known as nonpermanence risk, refers to the risk that removed carbon will be rereleased back into the atmosphere. In some cases, this can be measured, while in other cases, it can be more difficult to detect reversals. If reversal can be measured, mechanisms can be established to address the reversal or mitigate risk; this is explored in the following section.

Carbon sequestered through biological processes is typically released during decomposition, so it is generally less permanent than carbon that is stored chemically or geologically (Ruseva et al. 2020). Novel approaches tend to have a higher permanence or longer storage duration and tend to have a lower reversal risk (see Table 3).

Table 3 | **Reversal risk tied to different novel CDR approaches**

| CDR APPROACH | | PERMANENCE (STORAGE DURATION) | REVERSAL RISK | CAUSE OF REVERSAL RISK |
|---|---|---|---|---|
| **Biomass carbon removal and storage (BiCRS)** | **Bioenergy with carbon capture and storage (BECCS)** | 1,000+ years | Low | If $CO_2$ is sequestered geologically, $CO_2$ reversal can occur when $CO_2$ escapes through nonsealed fractures in caprock or if a pressure buildup in the reservoir leads to caprock hydraulic fracturing. |
| | **Biochar** | Approximately 70% at 100 years; approximately 12% at 1,000 years in soil (Chiquier et al. 2022) | Medium-high, depending on the environment where biochar is applied or stored | Chemical composition and environmental conditions can have different impacts on the decay rate of biochar. |
| | **Biomass sequestration** | 100–1,000+ years | Medium, depending on how biomass is processed and contained | Decomposition of biomass over time. |
| **Direct air capture (DAC)** | **With geologic sequestration** | 1,000+ years | Low | Same as for BECCS, above. |
| | **With in situ mineralization** | 1,000+ years; time for removal to occur usually <2 years | Low | Once injected $CO_2$ has converted into carbonate minerals, there is effectively no reversal risk. |
| **Enhanced rock weathering** | | 1,000+ years; time for removal to happen initially highly variable (Deng et al. 2023) | Low | Once removal has happened and $CO_2$ has converted into carbonate minerals, there is effectively no reversal risk. |
| **Seaweed cultivation and sinking** | | Up to 100s to 1,000+ years | Medium | Since currents slowly circulate ocean water, carbon that is sunk to depth will eventually make its way back to the surface. The time period over which that happens depends largely on how deep and where the material has sunk (Siegel et al. 2021). |
| **Ocean alkalinity enhancement (OAE)** | | 1,000+ years; time for removal to happen initially variable, from days to >1 year | Low | Factors like pH gradients can impact efficacy, but once $CO_2$ reacts to form dissolved inorganic carbon, there is effectively no reversal risk. |
| **Electrochemical ocean CDR** | **Alkalinity creation** | 1,000+ years: time for removal to happen initially variable, from days to >1 year | Low | Causes of reversal would be the same as OAE, above. |
| | **Direct ocean capture with geologic sequestration** | 1,000+ years | Low | If $CO_2$ is sequestered geologically, causes of reversal would be similar to DACS and BECCS. |

*Sources:* Authors' synthesis, based on Chay et al. 2022; Chiquier et al. 2022; IPCC 2022; Mercer and Burke 2023; Wilcox et al. 2021.

# KEY CONSIDERATIONS FOR FEDERALLY SUPPORTED CDR MRV

Federal support for CDR scale-up today is generally available to technologies with high technology readiness and for which removal amounts are relatively easy to measure. As federal policy evolves to support a broader portfolio of emerging CDR technologies, more sophisticated MRV will be needed to address a wider range of approaches.

There are two key questions associated with growing federal support for carbon removal: what type of arrangement, or ecosystem, of federal agencies, civil society, and the private sector would best support credible and consistent MRV for CDR? And how can this MRV ecosystem manage the uncertainty that exists at different levels and from different sources for each type of carbon removal?

## MRV ecosystem

Effective MRV as part of US federal policy will require the involvement of federal agencies, the private sector, independent credit verification companies, scientists, and others to create a robust ecosystem to support high-quality carbon removal. Because the carbon removal industry is nascent, a fully fledged MRV ecosystem of actors and the rules they develop and follow will take time to develop and will require the buy-in and collaboration of all actors.

While federal agencies are responsible for implementing policies supporting CDR, they likely would not have the internal capacity to track and verify removal claims from every project. Third-party verifiers and standard-setting bodies already have expertise in this area, and companies developing CDR techniques have ultimate knowledge of their own technologies. While consistency and oversight are challenges, there is significant work ongoing in different contexts that can be brought together and built on.

The federal government can, however, play a critical role in creating a high-accountability MRV ecosystem in which project developers and third-party verifiers are required to adhere to best practices for measuring carbon removal and environmental and social impact, monitoring sequestered carbon to ensure permanence, and reporting methods and impacts transparently (Khan and Minor 2022). The European Union has taken first steps in this direction through the development of the Carbon Removal Certification Framework (CRCF), which could provide some lessons learned on what role governments can play in a broader MRV ecosystem for CDR (see Appendix C).

The following principles, which pertain to both the design and operation of an MRV function, should be considered as the federal government works to build an MRV ecosystem that requires high-quality MRV and supports the growing carbon removal industry.

**Build on existing expertise.** Verifying the impact of federal spending is the responsibility of federal agencies, but the private sector, academia, and third-party verification bodies have pioneered many of the approaches to measurement and modeling that will continue to be used for carbon removal supported through federal policy. Leveraging these existing efforts—as well as existing expertise across government agencies—as the MRV ecosystem continues to evolve with federal guidance, direction, and oversight will be important to save time and avoid duplication of efforts. A first step in this could involve a landscape assessment or stakeholder mapping of existing efforts for each type of CDR approach—both within and outside of the federal government—and then identifying gaps, inconsistencies, and pain points where the federal government could improve existing systems. An effort could then be made to create a central information hub to catalog what has been done already.

**Designate roles.** The government should determine roles and responsibilities within a federal MRV function, including delegating crucial functions that are outside of government capacities. The way an MRV function for federal policy is designed and operationalized could be done in different ways that imply different levels of effort for federal agencies. For example, agencies within the federal government could set standards and then delegate development of MRV methodologies and protocols and ongoing verification to other approved organizations rather than taking on that effort directly.

**Manage incentives**. Part of the decision-making around roles and responsibilities will include management of incentives to avoid overcrediting and fraud. Determining an appropriate compensation framework for those designing and verifying MRV methodologies and protocols will be critical. For example, compensation based on number of credits issued can drive the market toward overcrediting and low-cost, low-quality credits.

**Set standards based on the best available science.** The federal government can create oversight by setting standards (the high-level rules that approach-specific methodologies and protocols must adhere to) with the best available science. Scale-up of

CDR as supported by federal policy should source carbon removal tons from projects that are verified by standards and use protocols that reference the best available science.

At minimum, standards should address thorough and transparent life cycle carbon accounting, ongoing monitoring, and assessment of community and environmental impacts, which could also help raise quality standards for the VCM and increase buyer confidence in these markets.

Identifying the best available science would require federal funding for research, partnership with academic institutions, and review of existing protocols to identify the degree to which they align with best practices. It could also involve periodic publication of reports outlining what is determined to be the best available science.

**Centralize data and maintain transparency.** Publicly and transparently reporting the outcomes of CDR projects is key for building trust in CDR and holding companies accountable for their claims. In the near term, providing public information on projects in development and underway (to the extent practicable while considering confidential business information), reported levels of carbon removed and ongoing monitoring, and project details will be important to create transparency and credibility.

In the longer term, once inventory guidance is developed to incorporate CDR into the national inventory, this centralized data function can help serve that purpose as well. Currently, only removals from the land sector are included in the national greenhouse gas inventory (NGHGI) because IPCC guidance on inventory methodology does not yet exist for most types of novel carbon removal. While the IPCC's Task Force on National Greenhouse Gas Inventories will develop a methodology report on carbon removal technologies by 2027, the federal government should begin to collect and publicize removal data in the meantime (IISD 2024). Ultimately, developing a database of carbon removal projects that feeds into, but is separate from, the NGHGI[6] will help provide transparency around CDR projects and the level of removal relative to emissions reductions happening in the country.

**Set an appropriate threshold for quantification uncertainty.** Policies designed to support carbon removal will need to set guidelines for acceptable levels of uncertainty related to the number of tons removed and ways to address the uncertainty that remains within that threshold. Most existing and proposed demonstration and deployment support policy in the United States supports CDR on a per ton basis, which requires attention on the level of quantification uncertainty.

Policy can also be designed with less focus on tons of carbon removed. For example, approaches like enhanced rock weathering could be supported based on the amount of material added rather than the eventual outcome (known as "pay for practice"). While these types of policies are promising, they are beyond the scope of this paper.

In the context of a ton-based policy support, uncertainty tolerance will differ depending on the CDR approach and how the removal is being used. For example, policies may require lower levels of certainty for open-system CDR approaches than closed system approaches because reaching the same level of accuracy will require higher effort and cost—at least in the near term, and may simply not be possible. There is a trade-off between accuracy and effort, which will change over time as these approaches develop further. Similarly, tons of CDR being used in compensatory claims should require a higher level of certainty than those used for contributional claims.

Government agencies could be directed to develop—or approve others to develop—categories or assessments of uncertainty ranges as well as recommendations for uncertainty thresholds for eligibility associated with different carbon removal approaches. These could be periodically updated and adapted for use in different types of carbon removal policy and updated periodically based on the best available science.

**Address noncarbon impacts.** There are increasing calls (Bryce and Faber 2023; Holzer et al. 2023; Minor and Khan n.d.) for carbon removal projects not only to minimize harm to host communities and the local environment but also to provide benefits that can help address past harms of infrastructure build-out in the United States. Setting minimum thresholds for noncarbon impacts (e.g., on air quality, water quality, energy and water usage) and equitable distribution of harms and benefits will be important to signal commitment to high-integrity projects and to set this new industry on a responsible and sustainable trajectory. If a project produces a net carbon benefit but causes damage to the environment or livelihoods locally, it is likely to face community pushback and is not a model for sustainable and long-term scale-up.

Conversely, a project may have positive environmental impacts that might make it more attractive to a community. As mentioned previously, government agencies could be directed—or delegate to others—to establish appropriate approaches to measuring and setting standards for noncarbon impacts that could be incorporated into policy. Outside of the MRV process, other mechanisms such as community benefits plans and community benefits agreements can be used to codify engagement processes that can secure and ideally track social impacts (Said et al. 2023).

## Managing quantification uncertainty and reversal risk in MRV for CDR

The sixth principle discussed earlier—set an appropriate threshold for quantification uncertainty—is particularly important in the context of federal support for CDR today and on the horizon. With more policies in development supporting a diverse range of CDR approaches, the question of how to manage quantification uncertainty is key and will depend on the type of policy as well as the type of CDR approach. Ongoing monitoring to track any reversal of $CO_2$ sequestration will also be critical for policies focused on tons removed. Uncertainty management mechanisms can be used to manage remaining quantification uncertainty and reversal risk.

Uncertainty management mechanisms can only be applied in cases in which the level of uncertainty or reversal risk can be quantified with some level of confidence. In other words, you can't manage what you can't measure. For some CDR approaches, the level of quantification uncertainty or reversal risk is too high, making it impossible to set constraints that would enable management (see Appendix D).

This section lays out a few mechanisms that could help address remaining uncertainty and mitigate reversal risk, including their benefits and drawbacks (see Table 4). It also summarizes how current policies address uncertainty in MRV for CDR and how these mechanisms could be applied in the future.

**Uncertainty and risk management mechanisms**

Mechanisms to address remaining uncertainty include the following:

- **Uncertainty discount** involves the calculation of quantification uncertainty or reversal risk associated with each ton of removal, and then only crediting the amount left after the uncertainty percentage has been deducted. To reach the total contracted volume of removal, additional credits would need to be supplied to counterbalance uncertainty. So far, this type of discounting has not been widely applied within carbon markets (Arcusa and Hagood 2023). However, Frontier, an advance market commitment aimed at accelerating the development of CDR technologies, provides one example of using this approach (see Appendix D). Uncertainty discounting is one of the few uncertainty management mechanisms that could address both permanence risk and measurement uncertainty ex ante.
- **Buffer pools** are a type of self-insurance mechanism, or risk management approach, whereby a certain number of credits are set aside up front into a "pool" to account for the risk that some carbon removal may be reversed. To establish appropriate buffer pools, project risk factors are assessed to determine the reversal risk. Based on this assessment, a certain number of risk-prone credits per project are set aside into the buffer pool as a type of insurance contribution in case of a reversal, and these credits cannot be sold. If reversal occurs, the pool can be accessed, and those set-aside credits can replace the lost credits representing the amount of $CO_2$ that was rereleased (Repmann et al. 2021).
- **Insurance** for carbon removal will take different forms depending on what specifically is being insured—for example, failure to deliver removal credits, or reversal of sequestration. Insurance for CDR would operate in similar ways to insurance in other sectors: a carbon removal buyer would make regular premium payments to the insurance provider and would receive a payout if circumstances covered by the insurance policy occur. For example, if the insurance policy covers reversal and $CO_2$ were to leak back into the atmosphere, the insurance deductible would have to be paid (Galik et al. 2014). Carbon removal insurance is, however, still in its early stages; so far, there are only few companies providing insurance for novel CDR, and even fewer that cover the reversal risk.

Beyond these three mechanisms, policymakers could also consider an obligation to replace reversals. This is also known as required compensation and would only address reversal risk, not measurement uncertainty. If reversal is detected, project operators would have to buy or create certificates from other projects to make up for the tons released (Arcusa and Hagood 2023; Whitmore and Aragones 2022). A related mechanism, known as temporary crediting, can also help manage the reversal risk. This approach entails the generation of credits by projects, typically those with low permanence, which would have to be replaced with newly issued temporary credits after a certain time period, or a permanent credit from another project, to compensate for any reversal (Brander et al. 2021).

Table 4 | **Benefits and drawbacks of different uncertainty and risk management mechanisms**

| | TYPE OF UNCERTAINTY OR RISK ADDRESSED | WHO/WHAT IS COMPENSATED FOR THE UNCERTAINTY OR RISK | BENEFITS OF THIS MECHANISM | DRAWBACKS |
|---|---|---|---|---|
| **Uncertainty discount** | Measurability, permanence | Atmosphere | Addresses uncertainty up front rather than during or at the end of the project. | The accounting of various types of uncertainty associated with different steps in the process can be complex and difficult to apply at scale across many different pathways and project types. |
| **Buffer pool** | Permanence | Atmosphere | Common mechanism to address reversal risk; many lessons learned from conventional CDR to build on and improve. | If not designed well, and risk rating is not based on sound modeling, the projects' contribution to the pool could be too low, resulting in the pool being undercapitalized and depleted too soon and rendering the mechanism ineffective. |
| **Insurance** | Permanence | So far, carbon removal buyers | May be an effective mechanism to protect carbon removal buyers against the risk of $CO_2$ reversal.<br>If applied together with a buffer pool, could increase financial resilience and create a backstop in case of significant reversal. | Private sector insurance is unlikely to cover long-term liabilities. Private-public partnerships could help address this (Repmann et al. 2021). More data is also needed to better understand the performance of specific CDR approaches, as well as $CO_2$ reversal history, in order to create appropriate insurance policies (Repmann et al. 2021). |

*Notes:* CDR = carbon dioxide removal. $CO_2$ = carbon dioxide.

*Sources:* Authors' analysis, based on Badgley et al. 2022; CarbonPlan 2022; Frontier 2022; Indigo Ag, n.d.; Kita Earth, n.d.; Repmann et al. 2021.

## How current policy addresses quantification uncertainty and reversal risk in MRV for CDR

Federal CDR policies in the United States have addressed uncertainty to varying extents (see Table 5). They have primarily addressed reversal risk, while measurement uncertainty remains largely unaddressed. The way uncertainty is addressed differs based on the policy objective, the design, and how the policy is administered. Even within policies that support CDR on a per ton basis (e.g., procurement and tax credits), the way uncertainty is addressed can differ.

For example, MRV done to track the role of carbon removal in meeting US climate goals will need to reduce uncertainty as much as possible. If MRV is being done for earlier-stage demonstration projects that are not being claimed toward climate targets, greater leniency around the accuracy and certainty of the removal can reduce costs for companies as they scale and encourage innovation. However, if policies are supporting CDR that is used for compensatory or offsetting claims, tolerance of uncertainty may be lower.

For ton-based policies, uncertainty discounting can help manage both measurement and permanence uncertainty up front and could be adopted as a standard approach across policies. So far, ton-based federal CDR policies have not included an uncertainty discount approach and have deferred to project operators to apply private buffer pools and/or other insurance mechanisms to address any remaining measurement or permanence uncertainties. Insurance for novel CDR approaches is, however, still in its early days and might not be easily accessible to project developers.

Table 5 | **Federal CDR policies and their approach to managing uncertainty**

| POLICY | UNCERTAINTY MANAGEMENT MECHANISM | APPROACH TO MANAGING UNCERTAINTY |
|---|---|---|
| **45Q tax credit** | Credit recapture | The mechanism under the 45Q tax credit that addresses $CO_2$ reversal is known as credit recapture. Under this mechanism, taxpayers must repay the originally claimed tax credit to the US Department of the Treasury if the $CO_2$ is released back into the atmosphere. For utilization credits, measurement uncertainty is addressed through an LCA, which is subject to review and approval by the DOE, EPA, and IRS. |
| **CDR Purchase Pilot Prize** | Buffer pool, insurance, or others | The MRV plan should include mechanisms for long-term storage oversight of the stored carbon. Mechanisms *may include* buffer pools, which would provide financial repayment to compensate the DOE in case of storage reversal, or insurance, claw-back mechanisms, or other financial mechanisms to redress storage reversal. |
| **Regional Direct Air Capture Hubs** | None mentioned | Although the program requires an LCA to be submitted as part of the application process, no specific mechanisms that would manage uncertainty are mentioned in the respective Funding Opportunity Announcements. |
| **Carbon Negative Shot Pilots** | None mentioned | |

*Notes:* CDR = carbon dioxide removal. $CO_2$ = carbon dioxide. LCA = life cycle assessment. DOE = US Department of Energy. EPA = US Environmental Protection Agency. IRS = Internal Revenue Service. MRV = measurement, reporting, and verification.

*Source:* Authors' analysis.

For CDR to scale up responsibly, the government should consider the development of guidance and best practices for both detecting and measuring $CO_2$ reversals and uncertainties for different approaches. Best practices should also include monitoring guidance and guidance on implementing mechanisms to minimize uncertainty upfront and address any remaining uncertainty. Although uncertainty discounting can be complex, the establishment of guidance, best practices, and verification can be delegated across government agencies or independent, third-party actors. The consistent application of such a mechanism will be crucial, as buffer pools run the risk of being undercapitalized and insurance is underdeveloped for CDR. These two mechanisms can therefore play supporting roles to a discounting mechanism but do not address uncertainties entirely on their own.

## CONCLUSION

The federal government can and should play a leading role in creating a credible and consistent MRV ecosystem for CDR supported by federal policy. As federal support for CDR continues to grow and expand in scope, the timing is right for the establishment of a federal MRV function that could create oversight and help avoid challenges around consistency and credibility that have arisen in the voluntary carbon market.

Because the carbon removal industry is growing quickly, and because more carbon removal expertise is being developed with each new approach and project that is established, it is critical that federal agencies collaborate with and build on expertise and experience in the private sector and in existing voluntary and compliance markets. The urgency of scaling CDR to address the growing threat of climate change requires the development of a cohesive and widely accepted MRV ecosystem, which must be done with consideration and planning so that it is durable and provides the foundation for responsible and impactful scaling of CDR approaches. This approach will allow a federal MRV function to be synergistic with existing expertise and to achieve the ultimate goal of enabling CDR to make its necessary contribution to US and global climate targets.

# APPENDIX A: DESCRIPTIONS OF NOVEL CARBON REMOVAL METHODS

Below are brief descriptions of prominent types of novel carbon dioxide removal. These approaches are not yet providing large-scale carbon removal and need further investment in research, development, and demonstration. This is in contrast to conventional or natural CDR approaches, such as tree restoration and soil carbon sequestration, which are providing large-scale removal and are not the focus of this paper.

- **Direct air capture and sequestration (DACS).** DACS involves the use of certain chemicals that selectively react with $CO_2$ in the air to capture it. That captured $CO_2$ can then be permanently sequestered underground or used in long-lived products, such as concrete, which also provide permanent sequestration.
- **Biomass carbon removal and storage (BiCRS).** BiCRS includes approaches that use biomass, which naturally removes $CO_2$ from the air, coupled with different types of sequestration that store the embodied carbon in the ground or in long-lived products.
  - **Bioenergy with carbon capture and sequestration (BECCS).** Biomass is combusted for energy production, and its emissions are captured before they are released into the atmosphere; captured $CO_2$ is stored underground or in long-lived products.
  - **Biochar.** Biochar is produced by heating biomass without oxygen to turn embodied carbon within the biomass into a kind of charcoal that resists decay and can be used as a soil additive.
  - There are other conceptions of biomass-based CDR, including making bio-oil with residual biomass and injecting it into the ground for sequestration.
- **Carbon mineralization.** A range of applications that use reactive minerals in rocks to chemically bind with and store $CO_2$ as a solid. Mineralization can happen through enhanced rock weathering, where ground alkaline material is spread on agricultural land; letting suitable types of mine tailings react with ambient $CO_2$; or injecting captured $CO_2$ into suitable geologic formations, where mineralization happens underground as a form of secure storage; among others.
- **Seaweed cultivation.** Growing seaweed, which sequesters carbon through photosynthesis, and then harvesting it and sinking it to the deep ocean, where the embodied carbon can be stored for long periods.
- **Ocean fertilization.** Adding nitrogen, phosphorus, or iron to areas where it is a limiting nutrient to phytoplankton growth—a portion of embodied carbon in the phytoplankton is then expected to naturally cycle to the deep ocean for sequestration.
- **Alkalinity enhancement.** Adding certain types of crushed rock that react with dissolved $CO_2$ in seawater and increase levels of dissolved inorganic carbon. Ocean alkalinity enhancement is a form of carbon mineralization.
- **Artificial upwelling.** Moving deep nutrient-rich water to the surface to spur phytoplankton growth; a portion of embodied carbon in the phytoplankton is then expected to naturally cycle to the deep ocean for sequestration.
- **Artificial downwelling.** Moving surface water to a depth where more dissolved inorganic carbon can be held.
- **Direct ocean capture.** Using electricity to rearrange ions in seawater to allow for direct extraction of $CO_2$ in the seawater. Captured $CO_2$ then needs to be transported and sequestered elsewhere.
- **Electrochemical alkalinity enhancement.** Using electricity to create alkaline seawater, which is added back into the ocean, mimicking the process of ocean alkalinity enhancement.

Many ocean carbon removal approaches seek to take up dissolved $CO_2$ in the surface waters of marine environments and then rely on an equilibration of relative $CO_2$ concentrations between the air and sea to result in atmospheric $CO_2$ removal.

# APPENDIX B: THE MRV ECOSYSTEM OF CDR STANDARDS AND CERTIFICATION

**Standards.** Standards provide the overarching set of rules, guidelines, and procedures to determine a minimum level of quality and rigor.

**Quantification standard.** This lays out requirements that a protocol must follow to accurately quantify removals from a specific carbon removal approach. Quantification standards detail how project developers are to measure and monitor carbon removal, as well as other potential controls. They may also issue guidance around challenges like permanence, additionality, and $CO_2$ reversal (Mercer and Burke 2023). Standards may include a set of protocols, each of which applies to a more specific type of project, that project developers must apply in order for their activity to be certified under the standard. Examples of quantification standards specific to or applicable to novel CDR include the Puro Standard, the Verra Verified Carbon Standard, and the Isometric Standard.

**Protocol.** An MRV protocol refers to a set of rules tied to how a project is to carry out the measurement, monitoring, reporting, and verification for a specific CDR approach or project type (Mitchell-Larson et al. 2022). Protocols detail what physical processes are to be measured and how, as well as how the carbon accounting for a specific method is to be carried out. Project developers generally develop protocols and methodologies for their project type and submit these for approval by a standard-setting organization. Once approved, a protocol can be used by any project that adheres to it. *Protocol* is often used interchangeably with *methodology*, but in some cases a protocol can be more detailed than a methodology.

As of May 2024, there were 35 MRV protocols for nine different types of novel CDR. Ten of the 35 focus on DAC or BECCS, and 11 of the 35 were developed by Isometric or Puro.earth (Chen and Walsh 2024). In some cases, protocols can specify high-level methodologies for MRV, but the specific methods and datasets used to carry out accounting can differ from project to project. These slight differences in methodology can make it difficult to compare the effectiveness of different projects and the quality of different credits.

**Certification.** Once MRV has been carried out, certification can be done on the basis of a certain standard and the protocol or methodology tied to it. Certification provides a "stamp of approval," indicating that the CDR activity successfully followed the specified methodologies and truly removed the amount of carbon that it claimed to have removed (Arcusa and Sprenkle-Hyppolite 2022). Often, the same organizations that provide the standard and protocol are also certifying the activities.

Among NGOs that develop and certify CDR activities, Verra has nine registered protocols for which it certifies, followed by Puro.earth, the American Carbon Registry, and the Climate Action Reserve. Government agencies that certify include the European Union's Competent Authority, which certifies MRV credits for BECCS and direct air carbon capture and storage under various EU directives, as well as the EPA, which provides MRV for the same approaches (Mercer and Burke 2023).

**Credit issuers.** These include organizations that have established standards under which carbon credits are issued. The credits are issued against protocols that are compliant with the quantification standard. Once the carbon removal activity has been certified on the basis of a standard, the certificate is recorded within "registries," an electronic ledger, for transparency purposes and to avoid other organizations claiming the same carbon credit. The credits are tracked, traded, and eventually retired within the realm of the registry.

**Standard-setting organization.** MRV standards are developed by both governments (e.g., California Air Resources Board, Australian government) and NGOs (e.g., Verra, Gold Standard) to certify carbon reduction and removal-based credits. As of 2022, there were 30 standard-setting organizations,[7] covering 23 CDR approaches (Arcusa and Sprenkle-Hyppolite 2022). So far, existing standards mostly focus on conventional approaches, such as soil carbon, land management, and afforestation approaches. Examples of organizations that have developed standards for novel CDR approaches include Puro.earth, Verra, and Isometric.

# APPENDIX C: THE EUROPEAN UNION'S CARBON REMOVAL CERTIFICATION FRAMEWORK'S MRV ECOSYSTEM

The Carbon Removal Certification Framework (CRCF) was proposed by the European Commission in 2022 to establish an EU-wide voluntary regulatory framework for the certification of carbon removal. The framework will cover permanent carbon removal, temporary carbon storage in long-lasting products, temporary carbon storage from carbon farming (referring to $CO_2$ sequestration through conventional approaches like afforestation or soil sequestration), and soil emission reduction ($CO_2$ emission reduction resulting from soil management practices).

A provisional agreement was reached in February 2024, with the framework expected to enter into force later in 2024. The objective of the framework is to minimize the proliferation of efforts within the VCM, as the varying standards, protocols, and methodologies make it challenging to accurately compare removals, risking diminishing transparency and lowering credibility of certified removals (Jensen 2024).

The framework will involve the development of certification methodologies with an expert group, including mechanisms that could address and minimize uncertainty. The expert group is made up of 70 members, including independent experts, national authorities, public entities, businesses, industry, NGOs, certification bodies, and research institutions in the field of carbon removal. Independent third-party certifiers, hired by project developers, are to carry out periodic audits of the carbon removal activity and verify compliance with the quality principles.

The CRCF can provide lessons for the design of a robust MRV ecosystem for CDR in a US policy context.

**Setting standards for the quality of certification.** Certification methodologies are to comply with four QU.A.L.ITY criteria, while acknowledging that the certification approach will differ across CDR activities. This will help guarantee the quality across removal activities, while ensuring their comparability (European Commission 2022). The four high-quality criteria include quantification, additionality and baselines, long-term storage, and sustainability.

**Establishing a robust MRV ecosystem for certification.** Together with an Expert Group, the European Commission is developing detailed methodologies for several CDR approaches (ICF 2023). The European Commission has also tasked the Expert Group to identify best practices and determine to what extent existing methodologies address the QU.A.L.ITY criteria that the CRCF proposal outlines (European Commission 2023; ICF 2023).

The European Commission will officially recognize and approve existing standards if they meet the commission's criteria. If a project wishes to comply with the criteria set by the European Union, its removals must be certified under a standard that has been approved and recognized by the European Commission. The standard must then list the removals that the European Commission has certified within interoperable public registries that are managed by it. Whether operators comply with the commission's standard and quality criteria will be verified regularly by independent certification bodies that are supervised by member states (Carbon Gap 2023).

**Uncertainty mechanisms.** The framework points to a handful of uncertainty management mechanisms, including discounting of carbon removal units, collective buffers or carbon removal accounts, and up-front insurance mechanisms to help address $CO_2$ reversal.

# APPENDIX D: EXAMPLES OF THE APPLICATION OF UNCERTAINTY MANAGEMENT MECHANISMS

## Uncertainty discounts

**Frontier's approach.** Frontier, an advance market commitment to purchase $1 billion worth of carbon removal by 2030, asks CDR suppliers to estimate the uncertainty associated with different steps and components in their CDR approach, using guidelines based on the CDR Verification Framework, which was codeveloped by Frontier and CarbonPlan (Chay et al. 2022; Klitzke et al. 2022).

It offers an interactive tool that allows users to set expected levels of uncertainty to calculate the number of delivered tons (CarbonPlan 2022; Klitzke et al. 2022). Based on that estimate, the supplier is then expected to apply the uncertainty discount to the total volume of tons delivered. For example, if there is a total uncertainty of 30 percent across all the pathway components, 100 proposed tons would be reduced to 70 delivered tons.

The tool categorizes uncertainty for each type of approach, certifying those with lower uncertainty as suitable for ton-based purchasing, while others that do not have sufficient certainty for ton-based purchasing are considered to be in "exploration mode" (Chay et al. 2022).

These respective uncertainty ranges are called Verification Confidence Levels (VCLs) (see Table D-1), indicating the level of confidence for each approach that the amount of removal and permanence can be accurately quantified.

Each VCL has a different percentage level of total uncertainty. Important to note is that the uncertainty tied to each approach is not only linked to uncertainty from $CO_2$ reversal. Some of the overall uncertainty could stem from uncertainties around $CO_2$ reversal, or incomplete measurement or monitoring data. It could also stem from an incomplete scientific understanding of ecosystem responses tied to the deployment of a CDR approach; for example, the amount of alkalinity that is transferred to the deeper ocean before resulting in atmospheric $CO_2$ removal (Chay et al. 2022). For example:

- A VCL 5, where some DAC projects would fit, has higher certainty than a lower VCL, and therefore applies a lower discount—for example, around 5 percent. Once the discount is applied to the tons removed, only 95 of 100 tons, for example, count as delivered. In the case of DAC, that uncertainty could come from uncertainty about whether the introduction of the project would displace the use of renewable energy for other demands (Klitzke et al. 2022).
- A VCL 3, such as an enhanced rock weathering project, may end up with an uncertainty discount of 34 percent, in which case only 66 of 100 tons would count as delivered. Much of the uncertainty in this example would come from project-level uncertainty, given the measurement uncertainties tied to field sampling and modeling in an open system, as well as the existing

Table D-1 | **Verification confidence levels**

| VCL # | DESCRIPTION | MINIMUM UNCERTAINTY DISCOUNT (PERCENTAGE OF NET REMOVAL VOLUME) | ELIGIBILITY FOR PURCHASE | EXAMPLE |
|---|---|---|---|---|
| 1 | Current quantification capacity is unlikely to establish permanent carbon removal with confidence. | Too uncertain to measure carbon removal | R&D grants | Ocean biomass sinking (VCL range 1–3) |
| 2 | Current quantification capacity may be able to establish that permanent carbon removal occurred. | 40% or greater | Prepurchase agreements | Ocean alkalinity enhancement (VCL range 1–3) |
| 3 | Current quantification capacity can establish that permanent removal occurred, but significant uncertainties remain. | 20% or greater | Offtake eligible (medium certainty) | Enhanced rock weathering (VCL 3) |
| 4 | Current quantification capacity can establish permanent removal with confidence, and medium uncertainties remain. | 10% or greater | Offtake eligible (medium certainty) | Biomass with carbon removal (VCL range 3–5) |
| 5 | Current quantification capacity can establish permanent carbon removal with confidence. Only small sources of uncertainty remain. | 0% or greater | Offtake eligible (high certainty) | Direct air capture (VCL range 4–5) |

*Notes:* VCL = Verification Confidence Level. R&D = research and development.

*Sources:* Authors, based on Frontier 2022; Klitzke et al. 2022.

knowledge gaps around $CO_2$ reversal from the ocean back into the atmosphere (Klitzke et al. 2022).

- Lower VCLs, such as VCL 1, are too uncertain to even allow for uncertainty measurement, whereas VCL 2 approaches (e.g., some ocean alkalinity enhancement projects) could be measured to an extent, although Frontier recommends that the uncertainty discount be 40 percent or greater. These low VCLs are not eligible for offtake agreements but could be candidates for research and development funding or small prepurchase agreements. Higher VCLs, on the other hand (e.g., DAC), have limited sources of uncertainty (20 percent, 10 percent, or 0 percent or greater uncertainty discount for VCL 3, VCL 4, and VCL 5, respectively) and are eligible for offtake agreements (Frontier 2022).

**Conservativeness deduction in the VCM.** Registries, or standard-setting organizations, tend to provide requirements for uncertainty management and accounting. To account for measurability uncertainty of the projects whose removal activity they are certifying, these organizations often apply an uncertainty deduction when issuing credits (Indigo Ag, n.d.). For example, the Verra Verified Carbon Standard methodology requirements asks for developers to follow IPCC guidance when applying methods to estimate errors and include an assessment of uncertainties that could result from the applied methodology. Through the assessment, project developers must "conclude whether there is a significant risk that the uncertainty for estimating . . . removals could exceed 10 percent of the estimated value" (Verra 2023, 10). If this is the case, the developer must follow a set procedure to calculate the appropriate conservativeness deduction.

## Buffer pools

**California's Low Carbon Fuel Standard (LCFS).** Buffer pools are a common mechanism to protect against reversal, having been applied by many standard-setting organizations within the VCM and in compliance markets like the LCFS in California. California's LCFS applies a "buffer account" to DAC projects, among other projects, to account for the risk of $CO_2$ reversal. Projects have to contribute a specific percentage of LCFS credits to the LCFS Buffer Account to account for several types of risk associated to the project. If the $CO_2$ sequestration well meets the EPA's Class VI well requirements, it is considered to be a low well integrity risk, with a risk rating contribution of 1 percent. However, if it does not meet the requirements, it has a higher risk status and therefore a risk rating contribution of 3 percent (California Air Resources Board 2018). Projects also have to account for other risks, including management, financial, social, and site risks. When $CO_2$ reversal occurs, the LCFS credits from the buffer account will be retired.

**California's Compliance Offset Program.** The Compliance Offset Program under the Cap-and-Trade scheme in California uses a buffer pool for forest credits to account for reversal risk through wildfires or disease. However, this has been an unsuccessful example of buffer pool implementation. Credit-generating projects only had to contribute 2 to 4 percent of insurance contribution to account for the risk of wildfire, a risk rating that wasn't precise nor based on a rigorous analysis (Pontecorvo and Osaka 2021). In 2020, only 10 years after the start of the program, severe $CO_2$ losses caused by wildfires depleted 95 percent of the buffer pool's contributions for wildfire risk, which were meant to provide insurance for 100 years (Badgley et al. 2022). Although the reversal risk for conventional CDR is much higher than for novel CDR, this example still underscores the need for robust and scientifically sound risk rating when designing buffer pools. The depletion of the buffer pool highlights the likely inability of the program to guarantee climate benefits and the integrity of credits and provides lessons learned for other compliance markets on adequately factoring in nonpermanence risks. If project-level risk does not match the project-level insurance contribution, this could result in the pool being undercapitalized and depleted too soon (Badgley et al. 2022).

## Insurance

**Private insurance.** Kita is one of the few examples of companies that have created insurance policies for CDR. Its main policy, Carbon Purchase Protection Cover, protects carbon removal buyers against delivery risk of forward-purchased carbon credits. Claims are paid for underdelivery at the verification stage of the process and cover avoidable loss, unavoidable loss, and carbon risk but do not cover political risk. Kita has noted that it's working on releasing further insurance policies that would cover the reversal or durability risks associated with different CDR approaches (Institute for Carbon Removal Law and Policy 2023). Kita has also highlighted that insurance could serve a supportive role to buffer pools in order to manage reversal risk. The incorporation of insurance into buffers would provide "a protective wrapper around the buffer to increase financial resilience and a backstop in case of catastrophic loss" (Kita Earth n.d., 20) of carbon back into the atmosphere.

On its own, insurance might not be the most adequate mechanism to manage uncertainty tied to $CO_2$ reversal in the case of permanent CDR approaches, as long-term risks—such as those tied to the long-term sequestration of $CO_2$ in geologic reservoirs—are unlikely to be covered by a private insurance policy in the long run and are more likely to be covered by public-private partnerships (Kita Earth n.d.; Swiss Re 2019). In the long run, insurance is therefore better applied in combination with other mechanisms like buffer pools to manage reversal risk.

## ENDNOTES

1. Carbon removal is separate and distinct from carbon capture and storage (CCS), which captures emissions at a source and is a type of emissions reduction.

2. An independent analysis by *The Guardian*, *Die Zeit*, and Source-Material found that Verra, a leading carbon standard, had issued "phantom" credits, with only 10 percent of issued credits representing real emission reductions (Greenfield 2023).

3. MRV is of poor quality if it fails to follow consistent and high-quality standards and methodologies that are open to the public for transparency and verification purposes. Poor-quality MRV will prevent the verification of data, including assessment of the accuracy of removals.

4. The US Environmental Protection Agency regulates Class VI wells, which involve the underground injection of $CO_2$ into deep rock formations. For project operators to be able to inject and permanently sequester $CO_2$, they must obtain a Class VI permit to construct and operate the well through to site closure.

5. The net removal of carbon refers to the total amount of carbon that has been removed, after accounting for potential $CO_2$ leakage back into the atmosphere and deducting project-specific emissions resulting from the removal activity, transport, and storage of $CO_2$. For example, a DAC project that uses nonrenewable energy sources to operate the DAC plant will have higher project-related emissions than a DAC project that relies on renewable energy, so although the amount of $CO_2$ they remove from the atmosphere might be same, their net negativity and therefore climate impact will differ.

6. Important to note is that CDR projects will only be able to feed into the NGHGI and therefore count toward a country's nationally determined contributions (NDCs) once there is IPCC guidance on these approaches, which can then be adopted by national-level inventory guidance. The IPCC's Task Force on National Greenhouse Gas Inventories will prepare a Methodology Report on CDR Technologies for the Seventh Assessment Report cycle by the end of 2027 (IISD 2024; IPCC 2024). The report will provide guidelines for the preparation of GHG inventories for the inclusion of CDR approaches.

7. These numbers do not exclusively focus on CDR but also include emissions reductions and avoidance.

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# ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

**Our challenge**

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

**Our vision**

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

**Our approach**

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.