Carbon Direct Microsoft

2024 EDITION

Criteria for High-Quality Carbon Dioxide Removal

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Introduction

The science is clear. Ambitious action is needed to reduce greenhouse gas (GHG) emissions while also rapidly scaling carbon dioxide removal (CDR). Effective and equitable climate action can both reduce climate loss and damage and provide wider benefits to society. The AR6 WIII report from the Intergovernmental Panel on Climate Change (IPCC) estimates the global community must remove 100–1000 billion metric tonnes of carbon dioxide ($GtCO_2$) by 2100 to limit warming to no more than 1.5°C. To reach this goal, large-scale CDR projects must annually remove 5–10 $GtCO_2$ by midcentury. Achieving this goal will require rapid scale-up and deployment of all viable CDR methods.

Microsoft and Carbon Direct are committed to the development of this critical market.[1]

Carbon Direct

Carbon Direct helps organizations go from climate goal to climate action. Carbon Direct combines technology with deep expertise in climate science, policy, and carbon markets to deliver carbon emission footprints, actionable reduction strategies, and high-quality CDR. With Carbon Direct, clients can set and equitably deliver on their climate commitments, streamline compliance, and manage risk through transparency and scientific credibility.

Microsoft

Microsoft plans to be carbon negative by 2030. By 2050, Microsoft aims to remove the equivalent of all cumulative GHGs emitted since Microsoft was founded. In January 2021, Microsoft announced our first portfolio of 1.3 million tonnes of CDR. In March 2022, Microsoft announced an additional 1.5 million tonnes purchased. Last fiscal year 2023, Microsoft contracted more than 5 million tonnes of high-quality CDR.

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Over the past four years, Microsoft and Carbon Direct observed a critical challenge in the emerging CDR industry: while there are many CDR projects on the market, few meet our criteria for high quality. A major contributing factor to this challenge is that CDR project developers and purchasers lack a common framework for determining what constitutes a best-in-class project. Microsoft elaborated on the need for a common framework in our 2021 whitepaper, noting the need for clear carbon accounting standards and the development of rigorous guidelines for additionality, durability, and leakage. Microsoft updated these insights in our 2022 whitepaper, where we discuss the lack of common standards, high prices, and insufficient supply of high-quality CDR credits. In our 2023 briefing paper, Microsoft demonstrated our commitment to signing long-term CDR offtake purchase agreements to help accelerate development of large-scale, quality CDR projects while progressing toward our 2030 goal.

Recent policy announcements also highlight the pressing need for evidence-based CDR criteria to guide action by both public- and private-sector actors. In the United States, the Inflation Reduction Act and the Infrastructure Investment and Jobs Act provide new funding for CDR project development. The White House Joint Statement of Policy and new Principles for Responsible Participation in Voluntary Carbon Markets sets the stage for broad national voluntary carbon market participation. In the European Union, the provisional Carbon Removal Certification Framework aims to set a high regulatory bar for voluntary CDR credits. Globally, as of June 2024, 72 countries have submitted long-term decarbonization strategies to the United Nations Framework Convention on Climate Change (UNFCCC), many of which include nature-based and engineered CDR. Together, these developments underscore the urgency for just, scientifically grounded CDR principles that ensure effective climate action across sectors and borders.

Updates in the 2024 edition

To help rapidly scale high-quality CDR, we developed the inaugural *Criteria for High-Quality Carbon Dioxide Removal* in 2021. This 2024 update is intended to achieve two key objectives:

1. The updated criteria should support and guide submissions to Microsoft for CDR procurement.
2. More broadly, the updated criteria should help advance a common definition of high-quality CDR by providing widely applicable quality benchmarks. We hope to catalyze CDR market maturation that facilitates just, effective climate action at scale.

We emphasize that the following criteria are not a substitute for pre-purchase due diligence to demonstrate scientific efficacy and validation. Nor are they intended to replace existing industry standards, which provide important—though in some cases imperfect or underdeveloped—quality assurance. We encourage existing standard-setting bodies to consider how these criteria could inform their protocols and principles.

The science of CDR is evolving, and these criteria will progress with this evolution. The 2024 edition provides updates across the essential principles as well as each of the CDR methods. This document also introduces new guidance on environmental harms and benefits, while still emphasizing environmental justice, procedural equity, and social harms and benefits. Regardless of whether they are engineered, hybrid, or nature-based solutions, carbon projects are grounded in physical space and will have an impact on the environment in which they occur. While people and the environment are inextricably linked, it is essential to address environmental harms and benefits directly. We have also updated “Carbon accounting and monitoring, reporting, and verification” to “Measurement, monitoring, reporting, and verification” to avoid confusion with corporate carbon accounting. In subsequent iterations, we expect to develop additional guidance for nascent CDR pathways, potentially including peatland and freshwater wetland restoration, carbon dioxide utilization, and marine CDR pathways like ocean alkalinity enhancement. We look forward to collaboratively refining this guidance over the coming years.

ESSENTIAL PRINCIPLES FOR

High-quality carbon dioxide removal

The following common set of shared principles are intended to help characterize high-quality CDR projects. Note that we distinguish between criteria that “must” or “should” be considered during project development and implementation. We use these terms to differentiate between minimum viable project characteristics (must) versus ideal project characteristics (should). These principles are not exhaustive but are intended to describe key considerations across all CDR pathways.

A “project” is a cohesive set of activities that are relevant to generating CDR credits. In some cases, CDR activities may be a part or extension of a larger body of activity. For these cases, the “project” refers to the component that is relevant to generating CDR credits. CDR developers and buyers typically evaluate the quality of individual projects. It is also important to consider potential environmental, social, and other impacts across a CDR portfolio. While impacts of individual projects are often relatively small, collective impacts from each CDR pathway at scale may be significant.

Effective project management is essential to deliver high-quality CDR projects. Project developers need to incorporate technical, environmental, commercial, operational, and political facets of project management to ensure the project meets relevant quality criteria. Fundamentally, the criteria are intended as guidelines for project developers as they pursue detailed project requirements. Successful project management involves comprehensive coordination of tasks and resources, adherence to project specifications and standards, economic optimization, skilled commercial negotiation, and smooth operational flows from ideation through handover to operations. High-quality project management navigates stakeholder expectations and political landscapes, uniting diverse stakeholder viewpoints to work toward common goals. Effective project management is requisite to translate the intent of “must” and “should” criteria into concrete product requirements and real-world applications, ensuring projects meet or exceed these foundational objectives. **The criteria for specific CDR pathways build upon the common principles described below.**

Social harms, benefits, and environmental justice

High-quality CDR projects minimize new **social harms** to people and communities, including economic and socio-political systems, and avoid exacerbating existing social harms. Because concerns vary by CDR pathway and project, the social harms that follow are not exhaustive, but are intended to describe some of the common negative impacts across all CDR pathways.

Beyond minimizing harm, high-quality CDR projects provide additional **social benefits** to local communities by advancing environmental justice, building climate resilience, and supporting alternative livelihoods.

Environmental justice involves the equitable distribution of environmental benefits and harms resulting from CDR project development, implementation, and ongoing MRV. Environmentally-just CDR projects facilitate meaningful participation with local communities throughout the project lifecycle. It is important that community involvement is inclusive, accessible, and centers perspectives from vulnerable or marginalized community members. This collaboration and shared project leadership starts by acknowledging past and present harms to communities of color, low-income communities, and other vulnerable communities affected by the intersecting crises of climate and racial injustice. This acknowledgment is also known as recognitional justice.

Social and environmental harms and benefits are closely interwoven. Harms and benefits that primarily impact ecosystems are discussed under the "Environmental harms and benefits" section. Impacts that have significant bearing on both ecosystems and communities are addressed in both sections.

PROJECT DEVELOPERS MUST

- Show that projects have a low risk of community health impacts and provide a strategy for monitoring, disclosing, and mitigating any such health risks.

- Adhere to any country, state, and/or local protocols of community consultation near the project area in the early stages of project development (e.g., Free, Prior, and Informed Consent, State of California Tribal Consultation Laws, Government of Canada Public Consultations, etc.).
- Assess the likelihood and severity of project activities negatively impacting local communities (including but not limited to increased risk of wildfire, food insecurity, or energy unaffordability) and provide a monitoring and mitigation strategy.
- Prevent community displacement.
- Demonstrate ongoing, direct, and transparent engagement with local communities, including Indigenous groups, throughout the project lifetime.
- Inform local communities, including Indigenous groups, through "outreach" as defined by the ATSDR community engagement continuum for evaluating procedural equity.
- Explicitly describe worker compensation in project proposals and commit to paying a living wage, at minimum.
- Explicitly describe any worker-related health and safety impacts and provide best-in-practice training and reporting channels.

PROJECT DEVELOPERS SHOULD

- Actively involve, collaborate, and/or build shared leadership with community members during project development, implementation, and subsequent monitoring (see the ATSDR community engagement continuum as a reference for evaluating procedural equity).
- Clearly articulate distributive equity of project benefits to ensure underserved, marginalized, and vulnerable populations are involved, economically empowered, and generating wealth during the lifetime of the project.
- Prioritize community needs and priorities when designing and implementing CDR projects.
- Delineate the percentage of project revenues or profits paid to community members and other local partners, the form of these payments (e.g., cash

payments, in-kind payments, or funding for community services), and the timing of these payments.

- Avoid developing, disturbing, or restricting access to land designated as culturally sensitive or ecologically important by community members or local stakeholders.
- Make and report progress on public carbon reduction targets and clean energy transition commitments.

Environmental harms and benefits

Minimizing **environmental harms** involves avoiding negative impacts on environmental systems. Common classes of environmental harms seen across multiple CDR project types include release of pollutants into air and water, thermal pollution, disruption of nutrient cycling, and habitat fragmentation. Because concerns vary by CDR pathway and context, the environmental harms that follow are not exhaustive, but are intended to describe some of the common potential negative impacts across all CDR pathways. In addition to mitigating harms, high-quality projects should strive to promote **environmental benefits** by enhancing ecosystem services and underlying ecological and environmental functions, such as biodiversity.

Social and environmental harms and benefits are closely interwoven. Harms and benefits that primarily impact communities and people are discussed under the "Social harms, benefits, and environmental justice" section. Impacts that have significant bearing on both ecosystems and communities are addressed in both sections.

PROJECT DEVELOPERS MUST

- Obtain all necessary legal permits and operating permissions from the appropriate local, state/providence, and federal authorities.
- Assess and document the likelihood and severity of project activities that may negatively impact surrounding ecosystems (including but not limited to soil health, biodiversity, and water resources).
- Provide a mitigation strategy for any identified negative impacts.
- Provide a plan to monitor potential harms from acute impacts, such as fires and spills, and from chronic or accumulated impacts, such as land-use change or

ongoing pollutant discharge.

- Provide a remediation plan for projects with risk of material negative impacts.
- Transparently report any use of toxic and/or persistent environmental pollutants, including agrochemicals, and the risk of their release into the environment.
- Assess air, water, and land impacts that may occur in the supply chain, including waste handling and disposal activities associated with the project.
- Avoid using industrial chemicals and pesticides banned in the United States or the European Union, unless a comprehensive, public risk management plan accompanies the proposed chemical's use in the project.

PROJECT DEVELOPERS SHOULD

- Identify ecosystem services that could be promoted through project activities, such as clean air, water, or habitat restoration.
- Provide a strategy for promoting identified ecosystem services and the ecological and environmental functions that underpin them.
- Provide a plan for monitoring and reporting against targeted benefits.
- Regularly inform the local community of any identified environmental risks along with plans to monitor and mitigate them.

Additionality and baselines

Removals are **additional** if they would not have occurred without carbon finance. The **baseline** of a project is a conservative estimate of the carbon and other GHG impacts that would have occurred without carbon finance (the "counterfactual").

PROJECT DEVELOPERS MUST

- Show that they require carbon finance to implement the project.
  - When multiple finance streams support a project, projects are considered additional if revenue from the sale of carbon credits is required to initiate project activities.
- Show that the project is not required by existing and enforced laws, regulations, or other binding obligations.

- Show that project activities are not “common practice,” even in the absence of financial or regulatory incentives.
- Quantify the removals claimed relative to the most plausible baseline for carbon stocks and flows, i.e., the counterfactual in the absence of carbon finance.
  - Baselines must account for both recent and projected changes in carbon and other GHG stocks and flows.
  - Baselines must be conservative and site specific.

PROJECT DEVELOPERS SHOULD

- Provide full project financial information to demonstrate financial additionality, particularly where multiple revenue streams are present.

Measurement, monitoring, reporting, and verification

Carbon **measurement**, or project-level carbon accounting, reports all GHG emissions associated with a CDR project using repeatable and verifiable GHG quantification methods. In general, this requires the use of cradle-to-grave life cycle assessments (LCAs) and/or models that accurately estimate CDR, calibrated by periodic direct measurement.

Monitoring, reporting, and verification (MRV) involves developing and adhering to a plan for long-term monitoring of the project. Measurement and MRV are often closely linked. Developers should consider the interactions between these two criteria during project planning and execution.

PROJECT DEVELOPERS MUST

- Develop a credible MRV plan prior to the start of the project.
- Adapt the MRV plan throughout the project by incorporating the best available science and evolving industry practices.
- Use peer-reviewed and scientifically supported measurement methods to quantify the net volume of removals claimed and disclose the specific methods used.

- Where an LCA is provided, use a cradle-to-grave LCA and specify the use of either attributional or consequential LCA.
- Conservatively incorporate uncertainty to avoid overstating the estimated CDR from a project.
- Separately quantify removed, reduced, and avoided emissions, including delineating by GHG type.
- If applicable, use models that are calibrated and validated for the specific conditions in which the project will operate.
- If applicable, specify model assumptions that cannot be calibrated or revised due to practical constraints. Developers should periodically review MRV measurements and other scientific advancements to revise all other assumptions.
- Avoid double issuance and double use of credits by following best-in-class carbon accounting guidelines.

PROJECT DEVELOPERS SHOULD

- Use regionally appropriate sampling and data collection methods to quantify the emissions and removals associated with a project instead of solely using model-based or statistical methods.
- Ensure that the project's MRV plan is certified or endorsed by a third party (e.g., via a registry).
- Obtain third-party verification of calculated net removal volumes (e.g., via a registry).
- Directly measure carbon removed and stored throughout the duration of the project to the maximum practical extent possible. Store this data in a shared repository or facilitate data access to advance CDR MRV and accelerate market development.
- Contribute data and/or project learnings toward the development and improvement of robust global datasets and models.

Durability

Durability is the capacity for stored carbon to withstand reversal, or re-emission, to the atmosphere. We use the term "durability" because it is less absolute than "permanence" and acknowledges the temporal variability inherent to most forms of carbon storage. The durability of stored carbon is limited by both natural and anthropogenic risks of reversal, which can prematurely release carbon from storage. Reversals can be either intentional (e.g., changing management practices) or unintentional (e.g., natural disturbances). Longer and more durable storage terms are preferable (until widely accepted methods enable comparison of varied durability terms).

PROJECT DEVELOPERS MUST

- Substantiate the projected duration (in years) over which removed carbon will be stored.
- Implement an MRV plan to monitor the stored carbon and reliably detect reversal events.
- Conservatively estimate a project's risk of reversal using the best available science, including planning for present and future climate change.
- Identify who is liable for remediating the reversal of stored carbon and the length of this liability (e.g., number of years).

PROJECT DEVELOPERS SHOULD

- Site projects in areas with low risk of reversal and implement ongoing risk mitigation measures to minimize the impact of future reversal events, including future risks associated with climate change.
- Ensure that agreements made during project execution include measures that mitigate the risk of reversals throughout and beyond the project's operational lifetime.
- Rely on insurance-type products, such as a buffer pool, to address the risk of reversal, which:
    - Reflect a scientifically substantiated, conservative risk of reversal, including possible increases in risks associated with climate change.
    - Dictate that intentional reversals must be entirely remediated, even exceeding all buffer pool contributions from the project.

- Retire a project's buffer pool credit contributions at the end of the project monitoring period.
- Wherever possible, draw upon like-for-like credits for compensation.

Leakage

Economic leakage ("leakage") is the displacement of GHG emissions from the project site to another geographic location. Economic leakage typically occurs because market demand for the output of the emitting activity is unchanged, while the CDR project decreases local supply. Leakage should not be confused with *physical leakage* of stored CO_2, which is discussed in the **Durability** principle.

There are two forms of economic leakage: activity-shifting and market. Activity-shifting leakage occurs when agents operating within a project boundary shift production to outside of the project boundary. Market leakage occurs when a project reduces the production of a good, and this local reduction induces increased production of that good elsewhere to meet demand. Market leakage can be very difficult to predict and measure.

PROJECT DEVELOPERS MUST

- Conservatively account for the carbon impacts of leakage caused by the project, accounting for both domestic and international leakage, or conclusively demonstrate the project avoids any leakage.

PROJECT DEVELOPERS SHOULD

- Diminish leakage risk in project design.

NATURE-BASED

Forestation and agroforestry

Forestation, including reforestation and afforestation, is the process of growing trees to establish forests or woodlands. **Agroforestry** integrates trees within agricultural production systems. Improved forest management (IFM) and mangrove forestation are included as separate sections below.

Given the large amount of degraded land globally, forestation and agroforestry offer substantial opportunities to remove carbon from the atmosphere while simultaneously providing important co-benefits to communities and nature. Forestation and agroforestry projects have complex and place-based social, ecological, and economic land-use dynamics. Given these dynamics, it is essential to site projects in socially as well as environmentally appropriate areas. The following principles for forestation and agroforestry projects build upon those described previously under the "Essential principles for high-quality carbon dioxide removal" section.

Tropical secondary forest in Peru (Source: Adobe Stock)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Avoid project development on land with unclear or insecure land tenure to reduce the risk of tenure disputes and disenfranchisement of local communities.
- Avoid violence when establishing or protecting forested areas.
- Respect local or traditional approaches to land ownership and management.

PROJECT DEVELOPERS SHOULD

- Work with experienced local partners to select project locations, species, and planting approaches.
- Proactively plan for the job security and economic stability of workers to mitigate the short duration of many forestation activities, e.g., through longer-term employment across multiple parcels in a region.
- Where existing activities are displaced, including activities deemed destructive or illicit, ensure alternative livelihoods to substitute for the displaced activities.
- Actively promote long-term sustainable livelihoods and economic opportunities for local communities (e.g., support local workforce development programs and initiatives).

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Avoid damaging, destroying, or harvesting existing trees during project site preparation.
- Avoid the destruction of native, non-forested ecosystems—such as wetlands, grasslands, and savannas.

- Prioritize local seed stock collection methods that do not harm natural forests, do not reduce the production of non-timber forest products, and utilize local infrastructure and seed supply chains, as per the "10 golden rules for reforestation" proposed by scientists from the Kew Royal Botanic Gardens and Botanic Gardens Conservation International.

PROJECT DEVELOPERS SHOULD

- Expand the volume of seeds available to ensure adequate supply for pre-existing demand and accommodate increased demand from new CDR project activity.
- Consider the impacts on biodiversity (both harms and benefits) when selecting species for forestation.
- Prioritize biodiversity and resilience by growing diverse, native species; pursuing ecological restoration or natural regeneration of formerly forested areas, where possible; and choosing species and seedling sources that can flourish under future local climatic conditions and maximize biodiversity.
- Use cost-effective forestation techniques such as applied nucleation, direct seeding, or assisted natural regeneration.
- Work to abide by the "10 golden rules for reforestation".

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Determine the natural regeneration baseline using the best available science to predict natural seedling establishment and forest growth in the absence of tree planting.
- Ensure pre-project trees are excluded from crediting and monitored throughout the crediting period.
- If using dynamic baselines with control plots, use remote sensing protocols that ensure quality in both the selection of control plots that are adequately matched to project plots and in the measurement of biomass accrual in control plots.

PROJECT DEVELOPERS SHOULD

- Establish control plots to directly measure natural regeneration or other growth in comparable parts of the surrounding landscape throughout the project.
- Use historical time series of remotely sensed data sufficient to show that natural forest recovery is unlikely to occur when claiming a negligible natural regeneration baseline.
- Use a crediting approach that adjusts dynamically if legal compliance or other land-use dynamics change over time—especially where the project area is legally supposed to be forested, but generally is not, or there is other uncertainty about evolving land use.

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Justify the models and assumptions used to quantify carbon accumulation in above-ground biomass, below-ground biomass, and (when included in the project) organic soil pools.
- Specify key assumptions that materially affect modeled carbon accumulation rates, such as geographic and environmental variables, species-specific allometric models, and expected seedling survival rates.
- Use statistical samples and best-available models (for example, species-specific and region-specific allometric equations) to quantify above-ground carbon.
- Use data from in situ sampling or conservative root:shoot ratios (that is, use smaller ratios to mitigate uncertainty) to quantify changes in below-ground carbon, where this pool is included.
- Measure and monitor changes in soil carbon when claiming removals in soils, using the criteria listed in the "Soil carbon" section.

PROJECT DEVELOPERS SHOULD

- Use ground inventories whenever feasible to validate remotely sensed measurements of above-ground biomass changes.
- Use site-specific data and/or collect data needed to parametrize the models used to estimate biomass changes (such as species-specific allometries and wood densities measurements).
- If soil carbon is not directly measured, establish projects on lands where the net impact of forestation or agroforestry on soil carbon is expected to be positive (e.g., degraded lands).
- Quantify any GHG fluxes associated with site preparation including removal of existing vegetation. If GHG fluxes are determined to be de minimis, the project developer should articulate why.
- Include an LCA of harvested products for agroforestry and plantation projects.
- Account for applicable and appreciable indirect climate impacts. For example, projects occurring in high altitude or high latitude areas should account for changes in albedo due to establishment of tree cover.

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Actively mitigate identified risks throughout the project duration (e.g., forest thinning in fire-prone areas).
- Where appropriate, select species adapted to future climate conditions and apply planting patterns that foster resistance to disturbance.
- Develop seedling planting and monitoring plans to maximize the probability of tree survival during the critical three- to five-year establishment period, factoring in physical infrastructure and human capacity needs.

PROJECT DEVELOPERS SHOULD

- Use the best available information to forecast future risks of disturbance to planted forests and situate projects in areas of lower risk. Salient disturbance risks include, but are not limited to, direct and indirect impacts of climate change, drought, fire, insects, disease, financial insolvency of the project operator, land theft, timber theft, and social disturbances.
- Use resilient plant material with appropriate genetic variability and provenance.
- Incorporate harvested timber or biomass into long-lived wood products, either traditional (e.g., lumber, oriented strand board) or emerging (e.g., biochar, cross-laminated timber).
- Encourage additional productive uses of land such as sustainable wood production, non-timber forest products production, and ecotourism to ensure that forests are protected and maintained over time.
- Leverage early-warning systems to detect and respond to reversals, particularly wildfire.
- Pilot restoration in small areas before scaling when restoration is first-of-a-kind locally.

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Provide robust and conservative estimates of leakage rates and justify the methods used to quantify the leakage rate.
- Quantify two types of leakage deductions: when project activities displace any existing economic activities and when these existing economic activities shift to outside of the project boundaries.

- When claiming low leakage rates, provide evidence that project lands are degraded, have low economic value, or that project activities do not significantly displace existing land uses. Evidence must show that one of the following two scenarios is true.
  - There has been minimal agricultural land cover over the preceding decade, the project is not sited in an area of active land cover change, and that the lands are predicted to have a low likelihood of future use for agriculture.
  - Tree planting is integrated into ongoing agricultural practices using sustainable agroforestry systems.

PROJECT DEVELOPERS SHOULD

- Use remotely sensed land-use data to determine leakage estimates, especially when coupled with land-use change models.
- Establish contractual agreements that prevent activity leakage.

NATURE-BASED

Mangrove forestation

Mangrove forestation, including reforestation and afforestation, is the process of growing mangrove tree species to establish forest cover. Located within the intertidal zones of tropical and subtropical coastlines, mangrove forests are highly productive, capable of stocking large amounts of carbon in their biomass and soils. However, intertidal ecology also necessitates specific forestation considerations, such as potential hydrological restoration of the site. Given the unique ecology of mangrove forests, we provide specific guidance for mangrove forestation here. The following principles build upon those described previously under the "Essential principles for high-quality carbon dioxide removal" section.

Fish and jellyfish swim among mangrove roots in the Caribbean (Source: Adobe stock)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Prioritize mangrove forestation in areas that protect communities from storm surge, prevent coastal erosion, and support fish nursery habitat.
- Use cost-effective and equitable forestation techniques such as Community-Based Ecological Mangrove Restoration, which engages local communities to remove barriers to natural regeneration.
- Avoid project development on land with unclear or insecure land tenure. Mangroves commonly exist on public land with customary tenure, raising the risk of tenure disputes and disenfranchisement of local communities.
- Respect local or traditional approaches to land ownership and management.

PROJECT DEVELOPERS SHOULD

- Proactively plan for the job security and economic stability of workers to mitigate the short duration of many forestation activities, e.g., through longer-term employment across multiple parcels in a region.
- Include alternative livelihood activities in projects to replace foregone aquaculture income or nutrition if mangrove forestation reduces aquaculture production.
- Actively promote long-term sustainable livelihoods and economic opportunities for local communities (e.g., support local workforce development programs and initiatives).

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Avoid the destruction of non-vegetated coastal ecosystems, such as natural tidal mudflats, which are important and threatened ecosystem types across the globe.

- Avoid damaging, destroying, or harvesting any existing mangroves during project site preparation activities.
- Prioritize forestation of biodiverse mangroves by supporting natural regeneration processes or planting a variety of native species that are resilient to current and future environmental conditions. Avoid planting monocultures of generalist species, such as *Rhizophora* spp.
- Consider the impacts on biodiversity (both harms and benefits) when selecting species for mangrove forestation.

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Identify the human and/or environmental drivers of mangrove loss or degradation and plan to mitigate these impacts in the future, including impacts of climate change.
- Ensure pre-project mangroves are excluded from crediting and their continued existence is monitored throughout the project crediting period.
- Determine the natural regeneration baseline using the best available science to predict natural seedling establishment and forest growth in the absence of tree planting.

PROJECT DEVELOPERS SHOULD

- Establish control plots to directly measure natural regeneration over the course of the project.
- Use historical time series of remotely sensed data when claiming a negligible natural regeneration baseline to show that natural recovery of mangrove forest is very unlikely to occur.

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Justify the models and assumptions used to quantify expected carbon accumulation in the above-ground biomass, below-ground biomass, and organic soil pools. Include key determinants of carbon accumulation such as environmental setting of forestation areas (e.g., fringe vs. deltaic settings), species-specific allometries, and survival rates of seedlings.
- Use statistical samples and best-available models (for example, species- and region-specific allometric equations) for quantifying above-ground carbon, including stratifying by site hydrogeomorphology (e.g., fringe vs. deltaic settings).
- Use data from in situ sampling or conservative root:shoot ratios (that is, use smaller ratios to mitigate uncertainty) to quantify changes in below-ground carbon, where this pool is included.
- Measure and monitor changes in soil carbon when claiming removals in soils, using the criteria listed in the "Soil carbon" section and stratifying by site hydrogeomorphology (i.e., project developers must rely on empirical site-level data or models, not default soil carbon factors).
- Develop monitoring plans that account for changes in carbon stocks using some or all of these approaches: mapping, remote-sensing, long-term field plot measurements, relative sediment elevation table methods, and/or field-validated modeling.

PROJECT DEVELOPERS SHOULD

- Compare and justify expected carbon accumulation numbers against benchmark figures, such as standing carbon stocks in proximal mature mangrove stands, global maps of mangrove carbon, or meta-analyses of carbon accumulation in planted mangroves from scientific literature.
- Employ validated and regionally calibrated methods and/or use ground inventories to validate remotely sensed measurements of above-ground biomass changes.

- If soil carbon is not directly measured, establish projects on lands where the net impact of forestation or agroforestry on soil carbon is most likely to be net positive.
- Quantify any GHG fluxes associated with site preparation including removal of existing vegetation. If applicable, explain why any GHG fluxes are expected to be de minimis.
- Account for any indirect climate impacts, for example, methane emissions potentially resulting from hydrologic restoration.

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Plant mangroves in appropriate locations with site-appropriate species where mangroves are likely to persist and flourish.
- Integrate projections of sea level rise when choosing sites for forestation and species stratification.
- Implement active and ongoing measures (i.e., adaptive management plans) to mitigate identified risks to the durability of carbon held in mangrove forests (e.g., direct and indirect impacts from sea level rise, storm surge, or watershed management).
- Determine the hydrological status of the site and address any impacts to site hydrology that might prevent successful mangrove forestation.
- Identify and mitigate human drivers of mangrove loss throughout the project life.
- Develop seedling planting and monitoring plans to maximize the probability of seedling survival during the critical three- to five-year establishment phase, including physical infrastructure and human capacity considerations.

PROJECT DEVELOPERS SHOULD

- Identify potential policy conflicts for long-term management of forests due to unclear demarcations of intertidal zones and overlapping jurisdictions of national or local governments (e.g., Ministry of Marine Resources and Ministry of Forests).
- When initiating projects that involve harvesting, incorporate harvested biomass into long-lived wood products, either traditional (such as lumber or polewood) or emerging (such as biochar).
- Plant species adapted to future conditions and apply planting patterns that foster resistance to disturbance, including plans to mitigate "coastal squeeze," i.e., the phenomenon by which mangroves cannot migrate landward with sea level rise due to impermeable surfaces such as paved urban areas.
- Monitor and report seedling survival at multiple time points after planting (e.g., 1, 3, and 5 years), as well as any additional planting needed to replace dead seedlings in subsequent years.

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Quantify leakage deductions when project activities displace any existing economic activities that could be shifted to outside of the project boundaries and result in higher emissions.
- When claiming low leakage rates, provide evidence that project lands have low economic value, or that project activities do not significantly displace existing land uses.

PROJECT DEVELOPERS SHOULD

- Demonstrate low leakage rates by showing minimal land use for agriculture or aquaculture over the preceding decade and minimal expected future land-use change, including a low likelihood of future land use for agriculture or aquaculture.
- Use remotely sensed land-use data to determine leakage estimates, especially when coupled with models of land-use change.

NATURE-BASED

Improved forest management

Improved forest management (IFM) involves management changes that increase carbon stocks in forests and in harvested wood products. IFM projects are hampered by uncertainty in project baselines, additionality, and market leakage. These uncertainties make accurate quantification of CDR from IFM challenging and have tended to result in overestimation of carbon benefits. Best-in-class IFM projects minimize uncertainty and conservatively estimate carbon sequestration. The following principles for IFM build upon those described previously under the "Essential principles for high-quality carbon dioxide removal" section.

Forest near Las Animas, a town in the Oaxaca highlands, Mexico (Source: Adobe Stock)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Ensure that the project minimizes major risks to the health and safety of workers, especially risks present in forest management operations.
- Ensure that when projects occur on public lands, communally owned lands, or lands with customary tenure, and the carbon rights are transferred to a third party, the benefits of the project are shared among members of the community by actively including land stakeholders in planning, execution, and operation.

PROJECT DEVELOPERS SHOULD

- Prioritize IFM projects that support local and regional industry, livelihoods, and sustainable forestry over the long term.
- Avoid increasing natural disturbance hazards that may directly or indirectly impact local communities.

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Transparently report any use of toxic and/or persistent environmental pollutants, including agrochemicals used for suppression of non-crop plants, and the risk of release into the environment.

PROJECT DEVELOPERS SHOULD

- Implement forestry practices that are regionally appropriate and designed to foster habitat for indicator species and encourage biodiversity broadly.
- Avoid increasing natural disturbance hazards that may directly or indirectly impact local ecosystems.

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Implement conservative baselines as defined by the following three criteria.
  - Baselines must reflect initial carbon stocks and trends in carbon stocks over at least the past decade or reflect typical management on similar parcels in the region.
  - Baselines must be informed by previous forest management practices, as documented in previously written management plans, or observed in historical remote sensing data (in the absence of a management plan or previously observed management activity, developers must provide evidence that the baseline is realistic for the owner and property in question).
  - Baselines must account for recent or projected changes in forest product demand. For example, projects located in regions with decreasing harvesting trends, such as due to closed mills, can be expected to have increasing baseline stocks.

PROJECT DEVELOPERS SHOULD

- For projects with multiple revenue streams, such as timber harvest or conservation investments, demonstrate that IFM activities are unequivocally a result of carbon finance by documenting inputs to financial models (e.g., those used to calculate net present value).

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Use the best available tools to measure and verify changes in carbon storage.
  - Use statistically representative field inventories and/or remote sensing.
  - Utilize allometry based on published regional- and species-specific data.

    - Include reporting on carbon pools with increased storage only where data and measurements can be well substantiated (e.g., ignoring increases in soil carbon when uncertainty is high).
    - Include reporting on all carbon pools with decreased storage resulting from project activities.

PROJECT DEVELOPERS SHOULD

- Validate measurements with field inventories when using remotely sensed data.

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS SHOULD

- Maximize the durability of carbon storage.
    - Improve forest health and reduce disturbance hazards (e.g., wildfire and insects) on project lands, including by decreasing the risk of disturbance-induced mortality associated with historical management practices such as fire suppression and adverse species selection.
    - Incorporate harvested timber or biomass into long-lived wood products, either traditional (e.g., lumber, oriented strand board) or emerging (e.g., biochar, cross-laminated timber).
    - Include forward-looking projections of climate risk when accounting for reversal risks.

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Establish contractual agreements or use certification schemes that prevent activity leakage.

PROJECT DEVELOPERS SHOULD

- Deduct market leakage at the same time as when increased stocks are credited, even if existing offset protocols do not require this standard.
- Design projects that minimize leakage risks by avoiding large reductions in counterfactual products (e.g., harvested wood products) relative to the baseline.
- Ensure that leakage risks are properly quantified, particularly in high-risk situations as described below.
    - Leakage risks are likely high in regions where mills are running at capacity due to high demand from wood product markets and where timber supply is responsive to price changes.
    - Regions where large amounts of non-participating lands can produce similar timber products also represent a high risk of leakage.
    - Where the wood products that would otherwise be produced on the project lands are highly substitutable, high leakage risk likely exists.

Other considerations

Project types

PROJECT DEVELOPERS SHOULD

- Consider IFM project types that may be of higher quality, including:
    - Forest restoration with little decrease in timber harvesting
    - Reduced impact logging
    - Increased stand productivity through better stand management (such as thinning)
    - Increased forest fiber utilization
    - Extended rotation lengths on commercial timberland in projects that employ very conservative leakage rates

NATURE-BASED

Soil carbon

Soil carbon CDR involves adoption of new conservation and/or regenerative agricultural management practices and soil inocula that increase the amount of carbon stored in soil. Agriculture both contributes to GHG emissions and is especially vulnerable to the impacts of climate change. Soil carbon projects can minimize these adverse climate change impacts by improving long-term sustainability and increasing the climate resilience of agricultural operations. While the on-farm implementation of management practices that sequester carbon in soils is well understood, the precise impact these practices have on soil carbon stocks is dependent on site-specific considerations such as soil type, crop, and climate. The scalability of soil carbon as a CDR pathway depends on a complex set of factors that include producer behaviors and preferences, cultural context, and access to technical assistance. The following principles for rigorous and credible soil carbon projects build upon those described previously under the "Essential principles for high-quality carbon dioxide removal" section.

Freshly plowed soil (Source: Adobe Stock)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Show that projects have a low risk of community health impacts from changing agricultural practices and inputs (fertilizer, herbicides, etc.), including the health and welfare of agricultural producers (e.g., farmers and ranchers).
- Articulate a strategy for mitigating impacts to air, water, and land quality from changes in agricultural practices (e.g., tillage, fertilizer, herbicide, etc.).

PROJECT DEVELOPERS SHOULD

- Equitably distribute benefits resulting from improved soil health to all project participants, including both landowners and operators.
- Allow flexibility for farmer practices given variable climate, environmental, and market conditions. Ensure contracts allow flexibility so producers are not locked into unadvisable practices.
- Design projects to accommodate participants who both own and lease land. This should include provisions to ensure that lessees do not inadvertently experience adverse financial effects by improving soil health through regenerative practices (i.e., higher rent for more desirable land).
- Actively promote long-term sustainable livelihoods and economic opportunities for local communities.
- Specify the percentage of project revenues or profits that are paid to farmers.
- Identify how project labor will be distributed and compensated, considering that farming and ranching operations often rely on migrant labor.

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Show that projects have a low risk of ecosystem impacts (e.g., negative impacts on air or water quality, land degradation, and/or sound pollution) from changing agricultural practices, including changes in inputs (fertilizer, herbicides, etc.).

PROJECT DEVELOPERS SHOULD

- Monitor co-benefits (e.g., soil health, biodiversity, water quality, and air quality, etc.).

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Document dynamic baseline emissions from business-as-usual management either by (1) using control plots to directly measure baseline fluctuations in soil carbon due to climate variability or other non-management drivers, or (2) using a model to estimate baseline fluctuations in soil carbon based on records of historical management practices and soil carbon measurements from a pre-project time period encompassing at least one full crop rotation or three years, whichever is longer.
- Demonstrate that any new practice is not already a common management practice across the farm or ranch.
- Use region-specific and agricultural-system-specific baselines to quantify the change in soil carbon resulting from the adoption of new management practice(s).

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Account for net project carbon removals factoring in any material emissions increase, including increased fertilizer applications.

- Document sampling design, including any stratification by practice, soil type, crop, and other relevant environmental factors.
- Describe the analytical and calculation methods used to assess soil carbon stock change, including the mass/depth basis and any correction applied.
- For projects that use modeling to estimate soil carbon changes, conduct project-specific direct soil sampling at the project's outset and at least once every five years thereafter to validate modeled estimates of soil organic carbon levels.
- Take soil cores to a sufficient depth to represent the impact of the implemented practice (e.g., a minimum of 30 cm depth below the organic layer for cover crops, minimum of 1 m or soil depth for some types of tillage change).
- Calculate carbon content using appropriate methods for bulk density measurement or an equivalent soil mass basis.
- Use models that have been developed and published in peer-reviewed literature for a specific soil, climate, and/or management context.
- Follow modeling best practices, including appropriate calibration and validation with region- and practice-appropriate independent datasets, and comprehensive assessment of model prediction uncertainty.
- Document modeling procedures and validation of data sources.
- Account for both sampling error and model prediction uncertainty prior to issuing credits.

PROJECT DEVELOPERS SHOULD

- Take soil cores as deeply as possible, ideally to one meter.
- Use best laboratory analysis practices to measure carbon, such as dry combustion in a carbon and nitrogen analyzer.
    - Project developers may use novel technological approaches to measure soil carbon directly if such approaches have been validated against more established methods.
- Provide comprehensive documentation of all soil carbon quantification methods that have been reviewed by a qualified third party.

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Provide a durability term supported by a detailed monitoring and verification plan. The plan should monitor changes in management practices and subsequent reversals across the entire project area and duration of the project.
- Account for verification methods and contracting mechanisms for ensuring new practices are implemented and maintained when determining durability.
- Demonstrate robust strategies to manage reversal risks, including appropriate buffer or risk pool contributions that can address reversals due to change in land management or ownership and impacts of natural hazards.

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Conservatively quantify leakage risks, including the impacts of reduced herd numbers or crop yields following implementation of new practices.

HYBRID

Enhanced rock weathering in croplands

Enhanced rock weathering (ERW) in croplands involves spreading crushed alkaline minerals onto agricultural fields. The natural weathering process of these minerals removes atmospheric carbon to form carbonate species. Dissolved inorganic carbon moves through waterways to the ocean. Given the large volume of available alkaline materials and agricultural land, ERW as a CDR pathway could scale rapidly. However, many potential mineral feedstocks for ERW contain heavy metals and contaminants that can accumulate at high concentrations in plant matter. Further, the end oceanic bicarbonate sink cannot be tracked or verified empirically. Instead, ERW MRV typically relies on complex models to estimate CDR. The following principles for ERW build upon those described previously under the "Essential principles for high-quality carbon dioxide removal" section.

Application of agricultural lime to the soil, a process similar to the one used in enhanced rock weathering (Source: Adobe Stock)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Quantify the risk of asbestos exposure during mining, processing, transport, and feedstock application.
- Document and define safety protocols required for feedstock application.
- Quantify heavy metal concentrations in mineral amendments through elemental analysis.
- Mitigate risks associated with heavy metals by clearly documenting ongoing quality assurance and quality control processes for sampling and analyzing silicate materials, soils, and plant matter grown on fields where silicate material has been applied.
- Use elemental analysis to model the expected heavy metal dissolution and accumulation in the environment.
- Avoid contaminating drinking water supplies.
- Specify project revenues that accrue to the farmers and communities.
- Document and define safety protocols that use best practices to minimize adverse impacts to local air or water quality.
- Notify local stakeholders if adverse local environmental impacts are expected following application (e.g., air quality impacts from mineral application).

PROJECT DEVELOPERS SHOULD

- Document the impacts of silicate application on crop yield, soil chemistry (organic carbon, mineral nutrients) and farming practices (e.g., lime and fertilizer application).
- Preferentially use source materials that maximize net CDR (e.g., feedstock particle size distribution does not require additional processing prior to application and can be sourced close to application sites).

- Strive for sustainable mineral sourcing, such as using mineral waste that does not require new mining and operates with minimal environmental impact to local communities.
- Strive for renewable energy sources for mining, grinding, and transport of rocks and minerals.

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Monitor any potentially sensitive ecosystems (e.g. wetlands) downstream from project fields and mitigate, when possible, negative impacts such as: rapid pH shifts, release of heavy metals, or release of other elements through mineral weathering.
- Disclose whether mineral amendments are sourced from mining by-products, existing mines, or new mining activities. In the case of the latter, describe the environmental impact from any new mining activities.
- Mitigate risks associated with heavy metals by clearly documenting ongoing quality assurance and quality control processes for sampling and analyzing silicate materials, soils, and plant matter grown on fields where silicate material has been applied.
- Quantify heavy metal concentrations in mineral amendments through elemental analysis.
- Use elemental analysis results as inputs to model the expected heavy metal dissolution and accumulation in the environment.

PROJECT DEVELOPERS SHOULD

- Document and (where possible) measure the impacts of mineral application on adjacent ecosystems, including downstream waterways.

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Provide documentation of any revenue streams beyond carbon credits. This includes, for example, revenue from selling project materials for application on croplands as an alternative to lime.
- Explain assumptions underlying the project baseline, including naturally occurring rates of silicate mineralization, and initial carbonate mineral content.

PROJECT DEVELOPERS SHOULD

- Justify expectations of zero ambient weathering from the mineral feedstock by characterizing inorganic carbon content and by documenting mineral and waste handling practices.
- Use control plots to measure the baseline soil processes and chemistry on agricultural land, including counterfactual lime application when appropriate.

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Ensure that carbon removal claims are consistent with a net carbon-negative outcome based on a cradle-to-grave LCA that includes silicate processing, transportation, application, and impact on other non-CO_2 GHG sources.
- Document the particle size distribution, morphology, and granularity of the material applied to cropland.
- Include climate and edaphic factors such as moisture, temperature, and pH in the project region in models of weathering rates.
- Use model(s) that have previously been established in peer-reviewed literature and/or other applications with third-party evaluation.

- Document how modeling frameworks link biogeochemical and hydrological processes.
- Follow modeling best practices, including appropriate calibration and validation with appropriate independent datasets for the variable of interest (carbon drawdown).
  - These practices have not yet been well defined for ERW. We suggest that project developers use soil carbon protocols, which share many of the same proxy measurement and modeling issues, as a reference for developing appropriate sampling plans and modeling approaches.
- Document model initialization assumptions and how model uncertainty will be incorporated into conservative CDR estimates (e.g., through appropriately conservative deductions for uncertainty).
- Estimate losses of carbon back to the atmosphere during transport from the soil column via river networks to the ocean, estimate ultimate carbon storage efficiency, and discount credit volumes appropriately.
- Use direct measurements of multiple variables to ground-truth models wherever possible.

PROJECT DEVELOPERS SHOULD

- Use the best available measurement methods to evaluate changes in soil health and any other claimed co-benefits following silicate application.

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Provide a durability term that is supported by the monitoring and verification plan, and that accounts for the expected reactions and subsequent transport of aqueous ions to ocean storage.
- List carbon release risk scenarios for both precipitated and dissolved carbon (these risks should be reflected in MRV plans).

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Document the impact of applied minerals on crop yields. Quantify and deduct for leakage if yields decline as a result of project activities.

PROJECT DEVELOPERS SHOULD

- Provide an elemental analysis that quantifies the amount of rare earth elements and critical minerals in the mineral feedstock to avoid diverting resources away from other applications, like the renewable energy supply chain.
- Identify alternative uses of mineral waste and demonstrate best use in terms of GHG impact.
- Evaluate and quantify the impact of the project on land use when project infrastructure requires the use of undisturbed or high-value land.

HYBRID

Biomass-based pathways

Biomass-based pathways for CDR involve a range of processes that convert CO_2 sequestered through photosynthesis into durable forms of carbon storage. Prominent pathways include biochar, wood harvesting and storage, and geologic sequestration of biogenic CO_2 such as in bioenergy with carbon capture and storage (BECCS). These biomass carbon removal and storage (BiCRS) technologies can result in sizable and highly durable CDR. Some pathways may also generate a co-product such as electricity or hydrogen. The feedstock for biomass-based CDR can be grown directly for CDR projects or can be a byproduct of other land uses (such as forest or agricultural residues). The following principles for biomass-based CDR build upon those described previously under the "Essential principles for high-quality carbon dioxide removal" section.

Exterior of a pellet mill (Source: Adobe Stock)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Show that feedstock procurement, biomass conversion, and carbon storage operations have a low risk of major negative impacts on local communities.

PROJECT DEVELOPERS SHOULD

- Actively promote long-term sustainable livelihoods and economic opportunities for local communities (e.g., developing local and regional biomass-based CDR expertise).
- Articulate how project activities, like feedstock production and product or co-product sales, will benefit under-resourced and marginalized populations, including through wealth generation and economic empowerment.

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Show that feedstock procurement, biomass conversion, and carbon storage operations have a low risk of major negative impacts on the surrounding ecosystems, including soil health, biodiversity, water quality, and air quality.
- Develop and share a strategy for mitigating, monitoring, and remediating adverse impacts to air, water, and land quality, including those impacts from biomass processing and storage.
- Transparently report any use of toxic and/or persistent environmental pollutants, including agrochemicals used in the production of purpose-grown feedstock.

PROJECT DEVELOPERS SHOULD

- Identify and implement the best available techniques to mitigate harmful environmental impacts (e.g., air emissions, water discharge).
- Explore opportunities to maximize and quantify environmental co-benefits (e.g., fire suppression from feedstock procurement).

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Identify the current use, if any, or other fate of biomass resources intended for the project.
- Identify the most likely counterfactual for biomass resources in question over the length of the project (see Biomass sustainability section below).
- Explain the financial viability of the project with and without revenue from carbon credits, including the role of tax, regulation, or policy incentives (e.g., in the United States, 45Q, Clean Fuel Standards, and the Inflation Reduction Act).

PROJECT DEVELOPERS SHOULD

- Identify cost curve projections, and basis for projections, for future projects.

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Ensure that CDR claims are consistent with a net carbon negative outcome based on a cradle-to-grave LCA, including biomass feedstock procurement, process emissions, carbon storage operations, and environmental disturbances.
- For waste or residue feedstocks, provide detailed accounting and justification of counterfactuals.

- Implement guidance for MRV listed in the "Process-specific considerations" (**box 1**).

PROJECT DEVELOPERS SHOULD

- Conduct both attributional and consequential LCAs.
- Clearly outline allocation methods for co-products, including a sensitivity analysis on allocation assumptions and different product scenarios.

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Create geologic storage sites, where applicable, using established permitting processes (e.g., EPA Class VI permitting for deep injection wells in the United States or ISO 27914:2017 standard for CO_2 storage).
- Quantify and report expected changes in the amount of carbon sequestered over time (e.g., through decay or physical leakage).
- Follow guidance set forth for durability of direct air capture in this document when storing gaseous CO_2 (e.g., BECCS).

PROJECT DEVELOPERS SHOULD

- Rely on empirical measurements for durability claims, rather than models, whenever possible.

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Quantify, and include in carbon measurement, the carbon emissions that may result from project consumption or displacement of local and regional material and energy supplies (e.g., energy diverted for capture and compression of CO_2 at retrofitted facilities).

- Quantify, and include in carbon measurement, any carbon emissions from potential land-use change or bioeconomy product supply impacts incurred by feedstock sourcing.

PROJECT DEVELOPERS SHOULD

- Avoid relying on feedstocks with potential land-use change impacts or bioeconomy product supply impacts (i.e., by following the guidance on sustainable biomass sourcing, below).

Other considerations

Biomass sustainability

PROJECT DEVELOPERS MUST

- Where applicable, source biomass feedstock following the guidelines outlined in *A Buyer's Guide to Sustainable Biomass Sourcing for Carbon Dioxide Removal*, including biomass that:
    - Comes from sources with operational integrity and oversight through strong governance, standards, and supply chain transparency
    - Comes from sources for which operations minimize negative impacts on Indigenous Peoples, workers, and local communities
    - Comes from sources where it can be produced without threatening protected areas or reducing regional carbon stocks
    - Comes from sources that do not distort markets for agricultural or forestry products

PROJECT DEVELOPERS SHOULD

- Analyze future biomass sustainability considering all existing and planned sources of biomass demand in the project's biomass sourcing region.

Box 1. Process-specific considerations

Biochar

PROJECT DEVELOPERS MUST

- Verify that biochar is not used for combustion applications or other applications that would rapidly release CO_2 to the atmosphere.
- Provide biochar elemental analysis (carbon, hydrogen, oxygen) to substantiate storage durability and account for biochar recalcitrance and carbon loss over a 100-year time frame based on best available models.
- Ensure that biochar is tested to minimize environmental harms (e.g., adhere to guidelines from the International Biochar Initiative or European Biochar Certificate).
- Prove that the project results in the production of additional biochar, above a verifiable and established baseline production scenario.
- Measure, and include in carbon measurement, any methane emissions from the biochar production process.

PROJECT DEVELOPERS SHOULD

- Measure biochar decay rates after application and share this data to improve decay models, including decay rates for recalcitrant and labile fractions.
- Quantify the utilization of heat from the pyrolysis process.

Biomass burial

PROJECT DEVELOPERS MUST

- Bury wood in a burial chamber designed to minimize decomposition and maximize durability.
- Provide a cradle-to-grave LCA that includes all relevant portions of the supply chain, including disturbed topsoil and transport of biomass feedstock.
- Use in situ sensors and gas sampling of methane for MRV, along with sample excavations and/or site maintenance.

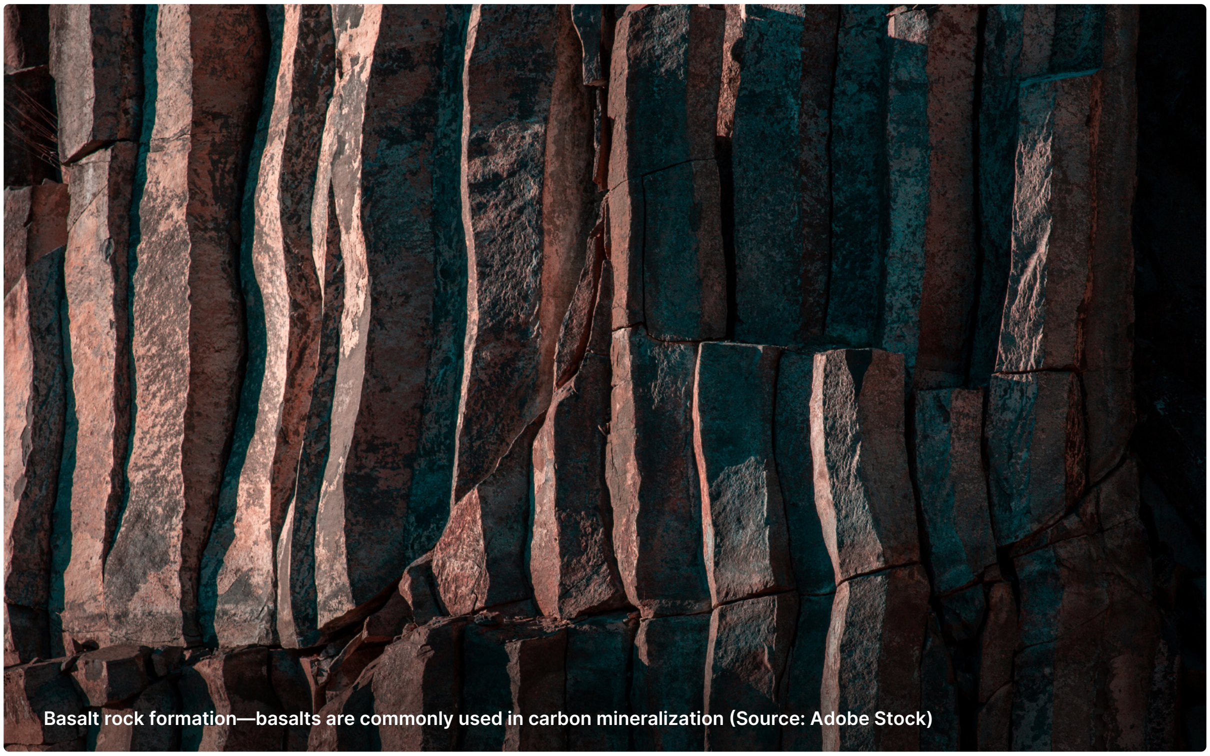
PROJECT DEVELOPERS SHOULD

- Create conditions that achieve an anoxic environment, inhibiting biological degradation.
- Minimize the risk of disturbance by biotic agents like termites and deep-rooted plants.
- Maintain a buffer pool of credits to mitigate uncertainty in factors like durability and methanogenesis, until MRV substantiates modeled outcomes.

ENGINEERED

Carbon mineralization

Carbon mineralization transforms atmospheric CO_2 into minerals during a naturally occurring reaction. The products of mineralization are carbonate minerals, the most durable form of stored carbon. Carbon mineralization binds carbon in rock in both underground (in situ) and aboveground (ex situ) sites. In situ mineralization injects CO_2 underground into rock formations capable of forming durable carbonate minerals. Ex situ mineralization uses aboveground reactors or industrial processes to produce carbonate minerals. Carbonate minerals can be incorporated into products as low-carbon feedstocks, such as concrete aggregate. Further, some industrial feedstocks that would otherwise adversely impact ecosystems and communities may be repurposed for mineralization. The following principles for carbon mineralization build upon those described previously under the "Essential principles for high-quality carbon dioxide removal" section. For agricultural applications, please refer to the section on criteria for "Enhanced rock weathering in croplands."



Basalt rock formation—basalts are commonly used in carbon mineralization (Source: Adobe Stock)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Minimize risk of adverse impacts on ecosystems and communities (e.g., changes in water quality, land use, and pollutant use).
- Transparently engage with local communities throughout the project lifetime. If the project site is an existing industrial operation, clearly describe how engagement processes are expanded to include the CDR project.
- Document practices used to ensure safe working conditions (e.g., handling hazardous minerals).

PROJECT DEVELOPERS SHOULD

- Actively promote long-term sustainable livelihoods and economic opportunities for local communities, including identifying and addressing where possible, historical negative economic and environmental impacts to local communities.
- Document efforts to remediate past negative environmental impacts on the community. Where possible, remediate past negative environmental impacts on the community such as from historical mining operations.

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Measure and disclose the volume and composition of all waste streams (solid, liquid, and gas) associated with the project, and their disposal methods.
- Disclose whether ex situ mineralization projects source raw materials and inputs from existing mines, industrial byproducts, or require new mining activities. In the case of new mining activity, describe the environmental impact from such a mine or quarry.

PROJECT DEVELOPERS SHOULD

- Develop mitigation plans for unintended release of a waste stream into the environment.
- Quantify the net amount of water, potable and non-potable, used during mineralization.
- For in situ mineralization projects, quantify the risk to local seismicity and the mitigation actions used to prevent those risks.

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Include a mass balance accounting for all states of carbon (solid, liquid, and gas), metals that contribute to mineral carbonate formation, and alkalinity imported or exported from the project boundaries when quantifying project baselines and changes in mineralization rates.
- Account for the rate of natural mineralization when calculating the project baseline.
- Quantify the carbonate mineral content in feedstocks.
- Document all revenue streams for the project including the sale of refined metals, material products, and any cost savings resulting from mineralization technology adoption at existing facilities.

PROJECT DEVELOPERS SHOULD

- Select feedstocks with low carbonate mineral concentrations to reduce uncertainty in carbon measurement.
- Monitor feedstock carbonate mineral content throughout the project duration.
- Develop control plots to measure natural rates of mineralization before, during, and after project deployment when relevant.
- Account for changes in mineralization reaction rates over time due to consumption of highly reactive material and passivation of feedstock.

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Use best available measurement methods with built-in redundancy to directly measure carbon stocks and fluxes in materials.
- Conduct a cradle-to-grave LCA and specify the use of attributional or consequential LCA. The LCA must conservatively quantify all GHG emissions associated with the full suite of inputs and products from the project.
- Evaluate and monitor, where appropriate, the impact of the project on other GHG pathways (e.g., methanogenesis, nitrogen cycle).
- Supplement and calibrate modeling with direct physical and/or chemical evidence of mineralization.
- Identify the source of metals (such as calcium and magnesium) contributing to mineral formation and include the carbon impact of the metal source in project MRV.

PROJECT DEVELOPERS SHOULD

- Identify all carbon reservoirs and monitor carbon movement between reservoirs with appropriate tools (e.g., tracer, isotopic studies).
- Use cost assessments and LCAs that clearly identify and differentiate continuously produced and stockpiled industrial feedstocks.
- Include cross verification with redundancy (e.g., cross referencing gas, liquid, and solid phase fluxes and mass balances).

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS SHOULD

- Consider reversal risks for both solid and aqueous carbon and include these risks in MRV plans.
- Develop release scenarios and mitigation plans that reflect the anticipated impacts of climate change and changes in land use or water reservoir development when relevant.
- Consider feedstock supply and/or subsurface reservoir capacity and injectivity when planning large-scale mineralization projects.

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Evaluate and quantify the impact of the project on land use, especially when project infrastructure encroaches on high-value land use.

PROJECT DEVELOPERS SHOULD

- Quantify the production of valuable co-products and, for retrofits to pre-existing industrial facilities, provide evidence of the historic volume of production.
- Consider the size and distance to market or area of application for projects in the built environment.

ENGINEERED

Direct air capture

Direct air capture (DAC) projects involve mechanical and chemical systems that remove and concentrate CO_2 from ambient air. This CO_2 is then disposed of in a long-term carbon sink or used as a feedstock. DAC projects typically do not require rare or critical materials and could be sited in many geographies, including near CO_2 storage resources and low-cost or stranded low-carbon energy assets. Net-negative DAC projects rely on large amounts of low-carbon energy, both heat and electricity, which may limit deployment speed and scale. The following principles for DAC build upon those detailed previously under the “Essential principles for high-quality carbon dioxide removal” section.

Climeworks' Orca direct air capture facility near Reykjavík, Iceland (Source: Climeworks)

Social harms, benefits, and environmental justice

These criteria build on and extend the social harms, benefits, and environmental justice considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Assess potential impacts from sorbent or solvent slip downwind of the facility, even if compliant with general health and safety guidelines and all applicable local and regional regulations.
- Articulate a strategy to measure and mitigate any material impacts to air, water, and land quality, including emissions from solvent or sorbent slip and discharge into local air, water, and land.
- Avoid developing or disturbing land that has been identified as culturally sensitive or ecologically important by community stakeholders. This includes land used directly for DAC facilities, land used for renewable energy installations to power DAC facilities, and land used for CO_2 transport or geological storage.
- Prevent community displacement by ensuring that any new or expanded pipelines, roads, wells, or other infrastructure do not inequitably impact historically disadvantaged or marginalized communities.
- Evaluate and mitigate any adverse impacts from increased water consumption. These may include increased water prices and/or decreased local water quality, including discharges from capture facilities and sorbent and solvent manufacturing facilities.

PROJECT DEVELOPERS SHOULD

- Minimize the need for new inputs (e.g., energy, construction materials, sorbents, and solvents) by applying best practices in reuse and circularity.
- Monitor and improve material and process efficiency.
- Pay a living wage and actively promote long-term economic opportunities for local communities by providing training programs that develop a pipeline of local workers skilled at DAC management and operation.
- Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

Environmental harms and benefits

These criteria build on and extend the environmental harms and benefits considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Measure the amount and type of material released to the air, water, and soil, both during the startup and commissioning phase, as well as during steady state operations.
- Evaluate and mitigate any adverse impacts from increased water consumption, including decreased local water quality due to discharges from capture facilities and sorbent or solvent manufacturing facilities.
- Articulate a strategy to measure and mitigate any material impacts to air, water, and land quality, including emissions from solvent or sorbent slip and discharge into local air, water, and land.

PROJECT DEVELOPERS SHOULD

- Apply a global perspective on permitting, to identify the most stringent requirements on environmental impacts (e.g., air emissions, water discharge) as guidance on best practices.
- Develop a remediation plan for unintended releases of chemicals to the environment.

Additionality and baselines

These criteria build on and extend the additionality and baselines considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Explain the economic viability of the project with or without the requested investment and/or CDR procurement, and the role of tax or policy incentives (e.g., 45Q in the United States, or state auctions for carbon removals in some European Union countries).
- Quantify baseline GHG fluxes and expected GHG fluxes from material and energy consumption, site preparation, carbon storage and utilization, decommissioning, and end-of-life.

Measurement, monitoring, reporting, and verification

These criteria build on and extend the measurement and MRV considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Account for all sources of emissions throughout the entire project lifecycle, such as direct and indirect land-use change, concrete and steel production and construction, procurement of capture media and chemicals, disposal of waste products, and energy use during DAC operations.
- Include full lifecycle impacts encompassing both upstream leakage and downstream usage in carbon measurement when using fossil-fuel energy sources (regardless of whether co-capture is involved in the process).
- Include full lifecycle impacts of the electricity powering operations, including grid-related emissions from grid-connected power purchase and use.
- Present a viable MRV plan that adheres to key regulatory requirements (e.g., EPA Class VI well permits) for subsurface storage.
- Demonstrate displacement of high carbon-intensity products or processes for DAC projects coupled to CO_2 utilization.
- Ensure that CDR credits are not double-counted against the environmental attributes of carbon-containing products where DAC-sourced CO_2 is used as a feedstock.
- Disclose if CO_2 storage is physically connected to a reservoir where CO_2-based enhanced oil recovery is practiced. If so, the project developer must ensure that DAC-based removals are not double counted against lower-carbon-intensity oil production.
- Include documentation or status of permit applications for storage sites.

PROJECT DEVELOPERS SHOULD

- Design a project that emits less than 0.3 tonnes of CO_2 per tonne CO_2 removed.
- Use energy with low associated emissions.
- If applicable, clearly demonstrate new, low-carbon electricity generation was added to the grid (or grid balancing area) that serves the project. If purchasing electricity from the grid, provide a copy of the power purchase agreement, including the electricity emissions factor, and the latest emissions factor for the local electrical grid.
- Provide an LCA sensitivity analysis by varying key parameters such as energy and chemicals use.

Durability

These criteria build on and extend the durability considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Demonstrate sufficient CO_2 storage capacity for the entire project's lifetime or sufficient physical CO_2 offtake with credible third-party providers.
- Demonstrate sufficient injectivity at the storage site, including a well count.
- Demonstrate low CO_2 release risk as estimated by the methodologies outlined in the World Resource Institute's *Guidelines for Carbon Dioxide Capture, Transport, and Storage*, Section 4.3.1.2.
- Develop an MRV plan, consistent with best practices for the chosen storage location, to detect unplanned physical leakage or reversals.
- Select and finalize geologic storage sites, where applicable, using established permitting processes (e.g., EPA Class permitting for deep injection wells in the United States or meet ISO 27914:2017 standard for CO_2 storage).

PROJECT DEVELOPERS SHOULD

- Disclose the use of CO_2 as a feedstock for the production of any non-durable product or commodity.
- Seek long-term monitoring solutions for storage (e.g., via regulatory take-over as envisioned by the EU CCS Directive).

Leakage

These criteria build on and extend the leakage considerations included under the "Essential principles for high-quality carbon dioxide removal" section.

PROJECT DEVELOPERS MUST

- Demonstrate that any new energy needed for DAC operation does not extend or create new demand for emissions-intensive energy.

Other considerations

Materials

PROJECT DEVELOPERS MUST

- Demonstrate that process inputs, including capture media, have low operational safety risk.

PROJECT DEVELOPERS SHOULD

- Use earth-abundant inputs, such as magnesium, calcium, silicates, sodium hydroxide, or other such inputs appropriate for a given process.
- For solvent-based systems, produce, transport, store, and manage solvent and solvent degradation products with low risk to operators, neighboring communities, and the environment.
- For sorbent-based systems, demonstrate the ability to synthesize sorbent at a scale of one metric tonne per year or at a scale consistent with the project timeline, and present a viable strategy for sorbent recycling or disposal.
- Provide a copy of permit applications or permits received for air emissions, wastewater disposal, and solid waste disposal, if applicable.

Infrastructure

PROJECT DEVELOPERS SHOULD

- Describe relevant transmission infrastructure, including new power and utility lines and CO_2 pipelines.

Scalability

PROJECT DEVELOPERS MUST

- Present reasonable cost estimates, ideally verified by third parties, peer review, or demonstrated in prior projects.
- Test and validate that thermal and electrical energy supply matches theoretical thermodynamic energy requirements.
- Demonstrate the capacity to manufacture or procure proposed design components and systems.
- Ensure viable low-carbon energy supply at scale, ideally via evidence of contracted or captive energy supply.

PROJECT DEVELOPERS SHOULD

- Provide a document, with a block flow diagram, describing the process concept and location, including the role of any organizations involved in project development.
- For first-of-a-kind DAC technology, successfully construct and operate prototypes that build confidence in DAC feasibility and efficacy at scale.
- Ensure vendors and subcontractors provide performance, schedule, and cost data for key DAC technologies.
- Disclose key technology scale up and deployment risks (e.g., technical and commercial readiness, project management structure, and supply chains bottlenecks) and develop strategies to manage these risks.

Conclusion

Thank you for engaging with Microsoft and Carbon Direct to advance development of high-quality CDR. Our collaboration builds upon the previous years' work by incorporating the latest research findings and industry insights. We are committed to regularly updating and refining these criteria to ensure we provide relevant and actionable information for a rapidly evolving industry.

We recognize that this work is part of a collective effort, and we encourage open dialogue within the CDR community. We welcome feedback, comments, and questions about the guidance presented in this document. Please feel free to reach out to Microsoft's Carbon Removal team at mscdr@microsoft.com and Carbon Direct at info@carbon-direct.com. Engaging in active discourse is vital to driving innovation and refining our understanding of high-quality CDR.

To foster the growth of the CDR market and facilitate the development of high-quality projects, we call upon the support of financial institutions, project developers, and the wider CDR community. It is through increased investment, collaboration, and community engagement that we can collectively build a strong foundation for the future of CDR. We invite interested parties to explore Microsoft's procurement cycle and consider how they can contribute to the pipeline of high-quality CDR projects. For more information on the Microsoft procurement process or to inquire about potential partnership opportunities, please visit the Microsoft Carbon Removal Program page.

Ultimately, our goal is to contribute to a rapid and just climate transition. By collaborating, sharing insights, and promoting transparency, we can create a robust CDR market that will play an essential role in combating climate change. Thank you for your engagement—we look forward to working with you as we continue on this vital journey.

Acknowledgement

This fourth edition of the *Criteria for High-Quality Carbon Dioxide Removal* stands as a testament to the collaborative spirit and deep expertise of over 50 science contributors from Carbon Direct, Microsoft, and independent reviewers across industry and academia. The specialized knowledge and commitment of our contributors is the cornerstone of this edition, providing wide-ranging expertise in a range of fields from engineering and project implementation to ecology and climate justice. We also acknowledge the valuable support provided by our management, marketing, legal, editorial, and design teams. These contributions significantly enhanced the clarity, accessibility, and impact of our work. We extend our deepest gratitude to all who have played a part in bringing this edition to fruition.