Carbon Direct Microsoft

2025 EDITION

Criteria for High-Quality Carbon Dioxide Removal

Table of contents

Essential principles for high-quality carbon dioxide removal 5

Social harms, benefits, and environmental justice 6

Environmental harms and benefits 8

Additionality and baselines 9

Measurement, monitoring, reporting, and verification 10

Durability 11

Leakage 12

Afforestation, reforestation, and revegetation 14

Mangrove forestation 20

Improved forest management 26

Soil carbon 31

Enhanced rock weathering in croplands 36

Biomass carbon removal and storage 41

Abiotic marine carbon dioxide removal 48

Carbon mineralization 54

Direct air capture 59

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 100-1,000 billion metric tonnes (Gt) of carbon dioxide (CO_2) by 2100 to limit persistent 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 2022-2023, Microsoft contracted to purchase more than 6.5 million tonnes of CDR. Last fiscal year 2024, Microsoft contracted more than 22 million tonnes of high-quality CDR. After receiving approximately 115 applications in fiscal year 2023, Microsoft has received more than 200 applications each in fiscal years 2024 and 2025, representing a 90% growth in applications since the program's inaugural year.

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Over the past five years, Microsoft and Carbon Direct have observed a critical challenge in the emerging CDR industry: while there are many CDR projects on the market, many have quality gaps, ranging from establishing a baseline to ongoing monitoring, reporting, and verification. A major challenge in assessing quality is the lack of a common framework for CDR project developers and purchasers to define a best-in-class CDR project. Microsoft elaborated on the need for a common framework in our 2021 white paper, 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 white paper, 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. In another white paper, collaboratively written with Ørsted, Microsoft also explored the challenge in determining, when countries and the private sector coinvest in projects, who gets to claim the carbon removal in their inventory.

Recent policy announcements also highlighted 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 continue to provide funding for CDR project development, as well as procurement of CDR. In the European Union, the Carbon Removal Certification Framework aims to set a high regulatory bar for voluntary CDR credits. Globally, as of May 2025, 76 countries have submitted long-term strategies to the United Nations Framework Convention on Climate Change (UNFCCC), many of which include nature-based and engineered CDR in decarbonization plans. At COP29, guidance on activities involving removals under the Article 6.4 mechanism was adopted, providing initial clarity on criteria for CDR traded between countries. Together, these developments underscore the urgency for just, scientifically grounded high-quality CDR principles that ensure effective climate action across sectors and borders. These principles are applicable to sustainability procurement efforts more broadly, such as environmental attribute certificates (EACs) for heavy industry decarbonization and insetting initiatives. To translate these frameworks into commercial actions, Microsoft seeks to be at the cutting edge of the CDR industry's advancement, and actively create a market for high-quality projects.

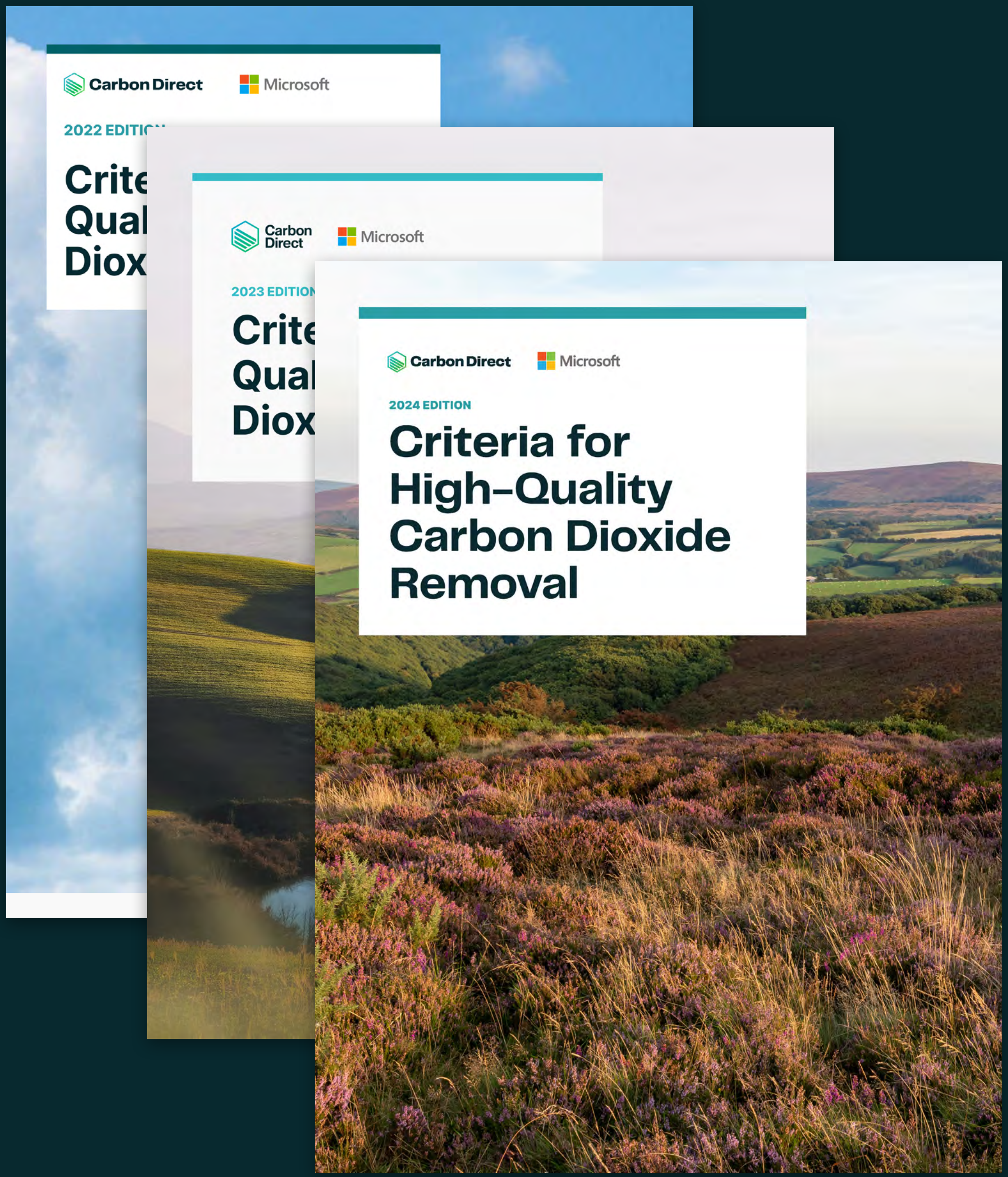
Updates in the 2025 edition

To help rapidly scale development of high-quality CDR, we developed the inaugural *Criteria for High-Quality Carbon Dioxide Removal* in 2021. This 2025 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, validation, and ongoing assurance as the project progresses. Nor are the criteria 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 2025 edition provides updates across the essential principles as well as to each of the CDR methods. This year, we have added criteria for abiotic marine CDR, an emerging CDR pathway with both potential for significant scale and significant measurement challenges. We have also added technical glossaries throughout the report to clarify the meaning of technical terms. In subsequent iterations, we expect to develop additional guidance for nascent CDR pathways, potentially including wetland restoration and carbon dioxide utilization. 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.

High-quality CDR projects must remove CO_2 from the atmosphere for a project’s contracted duration, which is the core environmental service buyers purchase. The principles of additionality, durability, limited leakage, and measurement, monitoring, reporting and verification determine whether or not that service has been delivered. High-quality projects also must safeguard the wellbeing of people and ecosystems impacted by the project. These are detailed below and for each CDR pathway in this report.

Effective project management is essential to deliver high-quality CDR projects. Project developers need to incorporate the technical, environmental, economic, commercial, operational, and political facets of a project into project management to ensure it meets relevant criteria for high-quality CDR. 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.

We engage with developers at every stage of the project life cycle, from concept development to ongoing operations to final closure and post-project monitoring. We acknowledge that early-stage projects may not yet have the resources to demonstrate full adherence, but should nonetheless commit the necessary resources to achieve criteria compliance as quickly as possible. Early-stage projects must align their planning accordingly and demonstrate clear pathways to criteria adherence prior to operations. Developers are also encouraged to engage with ongoing project monitoring and assurance activities that build confidence in implementation throughout the project life cycle.

The principles for specific CDR pathways build upon the common principles described below.

Social harms, benefits, and environmental justice

High-quality CDR projects contain strong elements of harm prevention, harm reduction, and meaningful benefits distribution. High-quality CDR projects prevent new **social harms** to people and communities and support a reduction in existing harms. Because concerns vary by CDR pathway and project, the harms that follow are not exhaustive, but are intended to describe some of the common and potentially negative impacts across all CDR pathways. Beyond preventing and reducing harm, high-quality CDR projects can provide additional **social benefits** to local communities by advancing environmental justice, building climate resilience, and supporting livelihoods.

Environmental justice focuses on improvements in the material conditions of frontline communities who experience disproportionate pollution exposure and other environmental burdens. This includes the equitable distribution of environmental benefits and harms resulting from CDR project development, implementation, and ongoing measurement, monitoring, reporting, and validation. Environmentally-just CDR projects facilitate meaningful participation and collaboration with local communities throughout the project life cycle. It is important that community involvement is equitable, inclusive, accessible, and centers perspectives from vulnerable or marginalized communities. This collaboration and shared project leadership starts by acknowledging past and present harms to frontline communities.

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.*

PROJECT DEVELOPERS MUST

- Document evidence of a low risk of community health impacts and implement 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.).
- Comply with any country, state, or local laws related to benefit-sharing agreements with local communities.
- Ensure that the project does not exacerbate or contribute new negative impacts on proximate and marginalized communities and provide monitoring and mitigation strategy.
- Guarantee that communities within and proximate to the project area will not be displaced, either through physical displacement or income-generating activity displacement (e.g., agricultural practices).
- Document ongoing direct and transparent engagement with local communities, including Indigenous peoples if present, throughout the project lifetime. This should include outlining pathways for integrating community needs/input across project phases through "involvement," as defined by the Movement Strategy Center's Spectrum of Community Engagement for evaluating procedural equity.
- Avoid developing, disturbing, or restricting access to land legally designated as culturally sensitive and provide a mitigation plan for lands that communities and local stakeholders have identified as culturally and ecologically significant and that may be impacted by project activities.
- Explicitly describe worker compensation in project proposals, detail how this compensation fits within the microeconomics of the region (e.g., whether wages are meaningfully above poverty wages), and ensure workers receive a living wage for that region.
- Explicitly describe any worker-related health and safety impacts and provide best-in-practice training and reporting channels.

PROJECT DEVELOPERS SHOULD

- Engage with local communities at the level of "collaboration" as defined by the Movement Strategy Center's Spectrum of Community Engagement.
- Promote long-term sustainable livelihoods and economic opportunities for local communities. This can include providing additional non-monetary benefits, such as training and education opportunities, improvements to local facilities, and access to the voluntary carbon market.
- Ensure that any social benefits the project claims are being tracked using appropriate indicators in the monitoring plan. Provide robust evidence to support any claims of social benefits resulting from the project.
- 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.
- Make and report progress on public carbon reduction targets and clean energy transition commitments.
- Delineate the percentage of project revenues or profits paid to community members, land owners, 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.
- Design projects with community-centered approaches that do not restrict the current use of or access to land and, where possible, that increase use or access over the course of the project lifetime.

Source: Tristan Goodbody, Carbon Direct

Environmental harms and benefits

Environmental harm is defined as any impact on the environment as a result of human activity that has the effect of degrading the environment, whether temporarily or permanently. Minimizing environmental harms involves preventing and mitigating negative impacts on environmental systems. Common classes of harms seen across CDR project types include release of pollutants into air, soil, and water, thermal pollution, disruption of nutrient cycling, introduction of invasive species, and habitat fragmentation. Because concerns vary by CDR pathway and context, the harms that follow are not exhaustive, but are intended to describe some of the common and potentially negative impacts across all CDR pathways. In addition to preventing and mitigating harms, high-quality projects should strive to promote **environmental benefits** by enhancing ecosystem services and underlying ecological and environmental functions, such as maintaining or increasing 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 a significant bearing on both ecosystems and communities are addressed in both sections.

PROJECT DEVELOPERS MUST

- Obtain all required 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 (e.g., soil health, biodiversity, and water resources).
- Document 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.
- Transparently report any use of toxic and/or persistent environmental pollutants, including agrochemicals, and the risk of their release into the environment.
- Implement and document a comprehensive mitigation strategy and remediation plan for identified negative impacts resulting from project activities.
- Regularly inform the local community of identified environmental risks along with plans to monitor and mitigate them.
- Implement supply chain strategies that seek to minimize or mitigate air, water, and land impacts, 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 (regardless of project geography) unless a comprehensive, public risk management plan accompanies the proposed chemical's use in the project.

PROJECT DEVELOPERS SHOULD

- Implement a strategy for promoting ecosystem services, such as clean air, water, or habitat restoration, and the ecological and environmental functions that underpin them.
- Implement a plan for monitoring and reporting against targeted benefits.
- Prioritize partnering with local organizations and industries to reduce emissions and environmental risks associated with long supply chains.
- Document robust evidence for claims of environmental benefits resulting from the project.

Additionality and baselines

Removal credits 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 laws, regulations, or other binding obligations. If current laws or regulations mandate the project's proposed activities, but are not being actively enforced, projects should provide justification for why enforcement is not expected to happen during the project's crediting period.
- Show that project activities are not common practice in the absence of financial or regulatory incentives.
- Quantify the removals the project claims relative to the most scientifically-, economically-, and legally-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, project specific, and site specific.

PROJECT DEVELOPERS SHOULD

- Provide full project financial information to demonstrate financial additionality (including any state support), particularly where multiple revenue streams are present.
- Conduct a sensitivity analysis on the key project cost variables to determine how they impact CDR credit costs.
- Document a rationale for the assumptions the project developer used for cost of debt and cost of equity when assessing project viability.
- Identify and report any potential conflicts or overlap between project activities and national or subnational policies for climate mitigation, such as Nationally Determined Contributions to the Paris Agreement.
- Ensure that all credits retired outside the host country are accompanied by a Letter of Authorization from the host government, explicitly confirming that the transfer is approved and that corresponding adjustments will be applied to the host country's national inventory.

Source: Tristan Goodbody, Carbon Direct

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 a cradle-to-grave life cycle assessment (LCA) 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, designed with the requisite lifetime to establish ongoing validation of all project performance claims.
- 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 the project claims, and disclose the specific methods used.
- Adhere to best practices (e.g., ISO standards 14040 and 14044) when preparing and submitting a project LCA, using a cradle-to-grave system boundary inclusive of the relevant MRV time window and end-of-life project activities.
- Conservatively incorporate uncertainty to avoid overstating the estimated CDR from a project, both overall and by time period (e.g., annual CDR).
- Design a regular cadence for LCA updates into the MRV plan, over the project lifetime, to ensure that carbon accounting remains tightly bound to project operations, data, and emerging science.
- Separately quantify and report emissions removal, reductions, and other avoided emissions, and delineate by GHG type.
- Use models that are calibrated and validated for the specific conditions the project will operate in, if applicable.
- Specify model assumptions that cannot be calibrated or revised due to practice constraints, if applicable. 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, including allocating GHGs at the project level.
- Ensure that the project’s MRV plan is or will be certified or endorsed by a third party (e.g., via a registry).

PROJECT DEVELOPERS SHOULD

- Use regionally appropriate sampling and data collection methods to quantify emissions and removals associated with a project, instead of using solely model-based or statistical methods.
- 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 MRV for CDR projects and accelerate CDR market development.
- Contribute data and/or project learnings to advance the development and improvement of robust global datasets and models.

Durability

Durability is the capacity for stored carbon to withstand reversal, or reemission, 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

- Document and substantiate the projected duration (in years) over which removed carbon will be stored using a combination of the best available science and relevant system performance metrics, both measured and modeled.
- Implement an MRV plan to monitor the stored carbon, reliably detect reversal events over the monitoring period, and collect enough evidence to reliably predict the likelihood of reversal events in the post-monitoring period up to the stated durability term.
- 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), including any intended transfer of liability.

PROJECT DEVELOPERS SHOULD

- Site projects in areas with a 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 operational lifetime.
- Rely on insurance-type products, such as a buffer pool, to address the risk of reversal and that satisfy the following criteria.
    - 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.
    - Draw upon like-for-like CDR for compensation, wherever possible.

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.

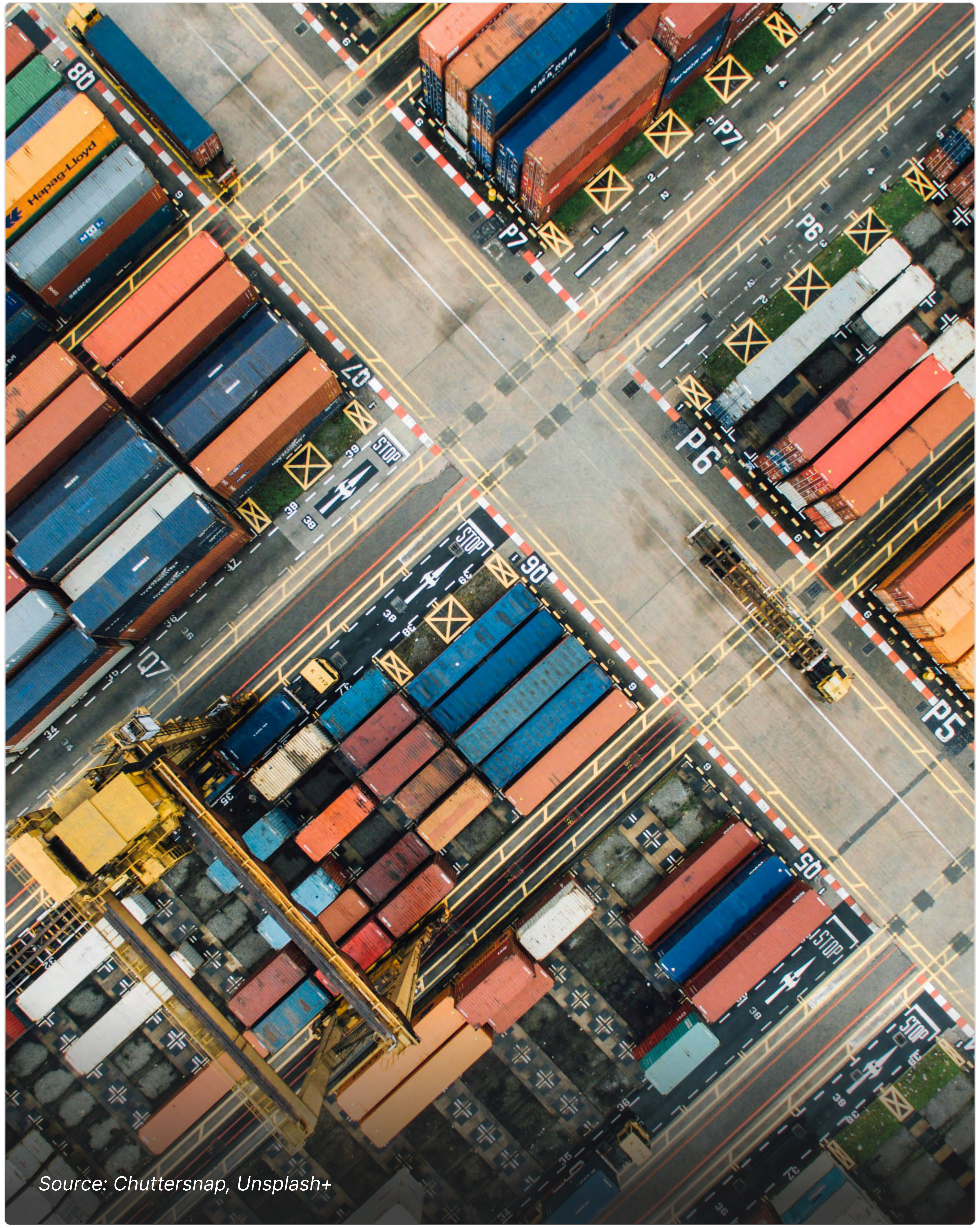
There are two forms of economic leakage: activity-shifting and market. Activity-shifting leakage occurs when agents operating within a project boundary shift production to outside the project boundary. Market leakage occurs when a project reduces the production of a good, and this local reduction induces 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 market leakage the project causes, accounting for both domestic and international leakage, or conclusively demonstrate that the project avoids any leakage.
- Design projects to avoid directly inducing activity-shifting leakage, and conservatively account for any such leakage that occurs.
- Document all potential sources of leakage and implement mitigation strategies to minimize unwanted leakage outcomes over the lifetime of the project.
- Justify the assumptions and methods used to quantify leakage.

PROJECT DEVELOPERS SHOULD

- Design project activities to reduce the probability of inducing market leakage.



Source: Chuttersnap, Unsplash+

Glossary of technical terms for the **essential principles**

Front-line communities: Communities of color, low-income communities, women and gender-diverse groups, Indigenous peoples, and other vulnerable communities affected by the intersecting crises of climate and racial injustice.

Life cycle assessment (LCA): A methodology used to evaluate the environmental impacts of a product, process, or service across its entire life cycle, from raw material extraction to end-of-life disposal or recycling.

Mitigation strategy: The planned actions and approaches designed to reduce or prevent GHG emissions and other negative environmental, social, or economic impacts of a project.

Model validation: The process of assessing how well a model's outputs match real-world data or expected behaviors to ensure its accuracy and reliability.

Model calibration: The process of adjusting model parameters to improve agreement between model outputs and observed real-world data.

Model uncertainty: The degree of confidence or potential error in a model's predictions due to limitations in data, assumptions, or parameter estimations.

Monitoring methodology: All methodologies for predicting and monitoring relevant elements and properties for carbon accounting and environmental harms, including documenting and reporting all uncertainties and assumptions made in data analysis and calculations.

Project activities: All relevant processes, facilities, and land used throughout the scope of the project, such as industrial operations, feedstock sourcing and processing, seed sourcing and planting, stakeholder engagement, chemical manufacturing, and waste disposal.

System boundary: The defined limits—physical, geographical, temporal, and conceptual—within which an LCA is conducted, identifying which elements are included or excluded.

Third party: An independent individual or organization that is not directly involved in the project's development or operation but is engaged for auditing, verification, certification, or other forms of external review.

NATURE-BASED

Afforestation, reforestation, and revegetation

Forestation is the process of planting or replanting trees to enhance carbon storage and other ecosystem services. Agroforestry integrates trees within agriculture production systems. These approaches are collectively known as **afforestation, reforestation, and revegetation (ARR).** We include criteria for Improved forest management (IFM) and Mangrove forestation in separate sections below. Given the large amount of degraded land around the globe, ARR approaches offer substantial opportunities to remove carbon from the atmosphere while simultaneously providing important co-benefits to communities and nature. ARR projects have complex social, ecological, and economic land-use dynamics, which are place-based. Given this, it is essential to site projects in socially as well as environmentally appropriate areas. The following principles for ARR projects build upon those described previously under the *Essential principles for high-quality carbon dioxide removal* section.

Social harms, benefits, and environmental justice

Environmental harms and benefits

Additionality and baselines

Measurement, monitoring, reporting, and verification

Durability

Leakage

Source: Tristan Goodbody, Carbon Direct

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

- Verify the tenure status of the target lands and develop projects only on land with clear and secure land tenure to reduce the risk of disputes and disenfranchisement of local communities.
- Avoid violence when establishing or protecting forested areas.
- Respect local or traditional approaches to land ownership and management, decision making, and benefit distribution.
- Consider the impacts (both benefits and costs) on people when selecting species for forestation.
- Ensure that, where project activities displace existing ones, alternative livelihoods substitute for displaced activities (including activities deemed destructive or illicit). When project activities displace subsistence agriculture, ensure that this does not increase food insecurity.
- Promote locally relevant gender integration, such as explicitly incorporating women into project activities, as well as incorporating low-income and other marginalized communities.
- Provide a fair and transparent mechanism for communities to opt out of or terminate lease agreements when they no longer wish to participate.
- Codevelop benefit-sharing arrangements that are appropriate for the type of local land tenure, including negotiating terms before carbon credits are sold, transparently disclosing what portion of revenue the rights holders will receive, and indicating how funds are apportioned.

PROJECT DEVELOPERS SHOULD

- Work with experienced local partners to select project locations, species, and planting approaches.
- Work with a third-party land rights specialist to develop the land tenure verification process.
- 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).
- 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

- Site projects only in places that are ecologically suitable for self-sustaining forest growth and will not cause environmental harm (e.g., water stress).
- Consider the impacts (both benefits and costs) on biodiversity when selecting species for forestation.
- Avoid the destruction of functionally intact native non-forested ecosystems—such as wetlands, grasslands, and savannas.
- Avoid damaging, destroying, or harvesting existing trees during site preparation, unless those trees are non-native or diseased.
- Avoid using species that have the potential to become invasive and follow the Precautionary Principle.

- Select a forestation strategy based on a scientifically defensible interpretation of the site's ecological and social context. For ecological restoration projects, use a scientifically defensible reference model as a guide to quantify forest recovery.
- 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 seed sources that maximize biodiversity and can flourish under future local climatic conditions.
- 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.

PROJECT DEVELOPERS SHOULD

- Expand the volume of seeds available to ensure adequate supply for pre-existing demand and to accommodate increased demand from new CDR project activity, prioritizing local job creation whenever possible.
- Use cost-effective forestation techniques that harness the site's natural recovery potential such as applied nucleation, direct seeding, or assisted natural regeneration.
- Work to abide by Kew Gardens' 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

- Identify the human and/or environmental drivers of forest loss or degradation and ensure that the proposed interventions are addressing these drivers.
- Evaluate the natural regeneration baseline using the best available science to predict natural seedling establishment and forest growth in the absence of tree planting, and to select the most adequate forestation approach.
- Explicitly incorporate pre-project natural regeneration into the baseline calculations to ensure accurate accounting.
- Ensure pre-project trees are excluded from crediting but are still monitored through the crediting period.
- If using a dynamic baseline, use remote sensing protocols that ensure adequate selection (i.e., based on relevant covariates) and matching (i.e., statistical similarity) of project plots to control plots.
- If using a dynamic baseline, select a stocking index that correlates closely with in situ forest carbon or biomass as validated by relevant field data or literature, can detect trends in above ground biomass stocks over time with sufficiently low uncertainty, and leads to conservative crediting relative to the project methodology. Prioritize stocking indices based on structural data whenever possible.

PROJECT DEVELOPERS SHOULD

- Use a dynamic baseline with statistically matched controls if project conditions allow, even if not required by the methodology, to ensure that the project is not crediting carbon removals due to natural regrowth.
- Use historical time series of remotely sensed data 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 requirements or other land-use dynamics change over time, especially where the project area is legally supposed to be forested, but it is generally not, or where future land use is uncertain.
- Provide credible evidence of barriers to adopting the project's proposed interventions when making the case for common practice additionality—particularly in landscapes where the proposed intervention is already being used.

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 science-based models and assumptions to quantify carbon accumulation in the above-ground biomass, below-ground biomass, and organic soil pools, when the pool is included. Publicly disclose these models and assumptions in the project documentation.
- Specify key assumptions that materially affect modeled carbon accumulation rates, such as the geographic and environmental variables, species-specific allometric models, and expected seedling survival rates.
- Use statistical samples and the best-available models (for example, species-specific and region-specific allometric equations) to quantify above-ground carbon. When using ad hoc models or generic allometric equations, provide a science-based justification for the methodological approach.
- Quantify changes in below-ground carbon, where this pool is included, using data from in situ sampling or conservative root:shoot ratios (i.e., use smaller ratios to mitigate uncertainty).
- Measure and monitor changes in soil carbon when claiming removals in soils, using the criteria listed in the *Soil carbon* section.
- Use ground inventories to validate remotely sensed measurements of above-ground biomass changes.
- Quantify any GHG fluxes associated with site preparation, including removal of existing vegetation or long-distance transportation of seeds and seedlings. If GHG fluxes are determined to be insignificant, provide a justification.

PROJECT DEVELOPERS SHOULD

- Use site-specific data, including but not limited to data collected by the project developer, to better parametrize models used to estimate biomass changes (such as species-specific allometries and wood density measurements).
- Ensure that projects are sited on lands where the net impact on soil carbon is expected to be positive (e.g., degraded lands), unless soil carbon is directly measured.
- Include an LCA of harvested agroforestry and plantation products if the project includes wood products or agricultural commodities in their carbon accounting.
- Quantify applicable and appreciable indirect climate impacts and include them in project carbon accounting. For example, projects sited in high altitude or high latitude areas should include estimated changes in albedo due to establishment of tree cover in the project's carbon accounting.
- Publish or share monitoring data sets whenever possible, especially when working in poorly known ecosystems or where quality information is lacking.

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).
- Select species adapted to future climate conditions and use planting patterns that foster resistance to disturbance, where appropriate.
- Implement 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.

- Implement a long-term plan to reduce avoidable reversal risks and ensure that carbon stocks are maintained for the duration of the crediting period.

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, pests and diseases, 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, sustainable harvest of non-timber forest products, 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 new methods in small areas and use monitoring results to inform scaling when interventions are first-of-a-kind locally.
- Leverage existing legal or policy instruments (e.g., conservation easements, protected area designation) to secure the durability of the carbon stocks beyond the crediting period.

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

- When claiming low leakage rates, provide evidence that project lands are degraded, that project lands have low economic value, or that project activities do not significantly displace existing land uses. The 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 the lands are predicted to have a low likelihood of future agricultural use.
  - Tree planting is integrated into ongoing agricultural practices through sustainable agroforestry systems that can support or enhance existing yields.

PROJECT DEVELOPERS SHOULD

- Use remotely sensed land-use data to determine leakage estimates, especially when coupled with land-use change models.
- Establish contractual agreements and/or implement project-specific activities that prevent leakage.
- Document positive leakage in project documents when the proposed activities are expected to result in additional carbon benefits beyond the project boundaries (e.g., project woodlots reduce fuelwood collection in existing forests), and provide supporting evidence even if the methodology does not require it.

Glossary of technical terms for **afforestation, reforestation and revegetation**

Afforestation: Planting trees or seeding in areas that have not been forested historically.

Agroforestry: A land-use management system that intentionally integrates trees or shrubs into agricultural lands.

Dynamic baseline: A baseline that compares the project area to matched control plots outside of the project area. Control plots are located in areas with similar characteristics to the project area but are not subjected to project activities. A dynamic baseline is updated regularly to reflect changes in land use and forest conditions over time.

Precautionary Principle: An approach to risk management that promotes caution and prevention when scientific certainty about cause-and-effect relationships is not fully established.

Positive leakage: A beneficial effect of project activities that are expected to lead to additional carbon benefits beyond the project boundaries (e.g., established project woodlots will result in reduced fuelwood collection in existing forests).

Recruitment: The process by which new individuals are added to a plant population, whether by germination and maturation or by dispersal.

Reforestation: The process of replanting trees in areas where forests once existed but were lost or degraded.

Reference model: A model that describes the expected condition of a site without degradation and that accounts for background and predicted changes in environmental conditions.

NATURE-BASED

Mangrove forestation

Mangrove forestation, including ARR, is the process of growing mangrove tree species to establish forest cover. Located within the intertidal zones of tropical and subtropical coastlines, mangroves are highly productive forests 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 mangroves, 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*.

Social harms, benefits, and environmental justice | Environmental harms and benefits | Additionality and baselines | Measurement, monitoring, reporting, and verification | Durability | Leakage

Source: Rod Long, Unsplash+

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.
- Implement projects on land with clear or secure land tenure to reduce the risk of tenure disputes and disenfranchisement of local communities. Mangroves commonly exist on public land with customary tenure, which raises these risks.
- Respect local or traditional approaches to land ownership and management.
- Promote locally relevant gender integration, such as explicitly incorporating women into project activities, as well as incorporating low-income and other marginalized communities.
- Use equitable approaches to addressing community-based barriers to natural regeneration or reforestation.
- Include project activities that provide alternative livelihoods to replace foregone income or nutrition if mangrove forestation reduces aquaculture production, timber harvesting, or access to other forest resources.
- Provide a fair and transparent mechanism for land owners to opt out of lease agreements when they no longer wish to participate.
- Codevelop benefit-sharing arrangements with local communities, including negotiating terms before carbon credits are sold, transparently disclosing what portion of revenues the communities will receive, and indicating how funds are apportioned.

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).
- Actively promote long-term sustainable livelihoods and economic opportunities for local communities (e.g., support local workforce development programs and initiatives).
- Use cost-effective forestation techniques to support natural regeneration and reforestation.

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 other coastal ecosystems, such as seagrass meadows and natural tidal mudflats, which are globally important and threatened ecosystems.
- Avoid damaging, destroying, or harvesting any existing mangroves during 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 benefits and costs) when selecting species for mangrove forestation.

PROJECT DEVELOPERS SHOULD

- Use cost-effective mangrove forestation techniques that harness a site's natural recovery potential such as hydrological restoration, propagule planting, or assisted natural regeneration.

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 ensure that the proposed interventions mitigate the impacts of these drivers.
- Ensure pre-project mangroves are excluded from crediting but are still 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.
- Identify constraints to natural recruitment/regeneration and either mitigate these constraints or provide evidence that site conditions are appropriate for planting.
- Separate between allochthonous and autochthonous sources of soil carbon, if crediting soil carbon gains.
- Establish control plots to directly measure natural regeneration over the course of the project.
- If using dynamic baselines, use remote sensing protocols that ensure selection of control plots that are adequately matched to project plots and accurate measurement of biomass accrual in control plots.

PROJECT DEVELOPERS SHOULD

- Use historical time series of remotely sensed data to show that natural recovery of mangrove forest is very unlikely to occur when claiming a negligible natural regeneration baseline.
- Use a dynamic baseline with statistically matched controls if project conditions allow, even if not required by the methodology, to ensure that the project is not crediting carbon removals due to natural regrowth.

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 the environmental setting of forestation areas (e.g., fringe versus deltaic settings), species-specific allometries, and survival rates of seedlings.
- Use statistical sampling for quantifying above-ground carbon, including stratifying by site hydrogeomorphology.
- Use data from in situ sampling or conservative root:shoot ratios (i.e., 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).
- Implement monitoring plans that measure changes in carbon stocks using some or all 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 ensure the accuracy of remotely sensed measurements of above-ground biomass changes.
- Implement projects on lands where the net impact of forestation or agroforestry on soil carbon is likely to be net positive, unless soil carbon is directly measured.
- Quantify any GHG fluxes associated with site preparation including removal of existing vegetation. If applicable, explain why any GHG fluxes are expected to be insignificant.
- Quantify any indirect climate impacts (e.g., methane emissions potentially resulting from hydrologic restoration or soil disturbance).

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. For example, mudflats are often considered for mangrove planting but are unsuitable, as vegetation growth is limited in these areas.
- Integrate projections and scientific models of sea level rise and other natural dynamics over multiple timescales when choosing sites for forestation and species stratification. Use these models to estimate durability horizons and communicate uncertainties.
- Ensure proper site preparation and assessment, including reestablishing hydrological connectivity where necessary and testing for appropriate soil quality (e.g., redox potential, sulfides/sulfates, etc.).
- 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 mitigate any impacts to site hydrology that might prevent successful mangrove forestation.
- Identify and mitigate human drivers of mangrove loss throughout the project life.
- Implement 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.
- Monitor and document seedling survival at multiple time points (e.g., at year one, three, and five), as well as any additional planting to replace dead seedlings in subsequent years.

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 (e.g., lumber or polewood) or emerging (e.g., biochar).
- Plant species adapted to future conditions and use planting patterns that foster resistance to disturbance, including plans to mitigate coastal squeeze (i.e., the phenomenon by which mangroves cannot migrate toward land in response to sea level rise due to impermeable surfaces such as paved urban areas).
- Incorporate appropriate flood management techniques to support early planting, such as restoring hydrological connectivity and only planting within a species' known tolerance for tidal inundation.
- Leverage existing legal or policy instruments (e.g., conservation easements, protected area designation) to secure the durability of the carbon stocks beyond the crediting period.

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

- 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 agriculture or aquaculture use over the preceding decade and minimal expected future land-use change, including a low likelihood of future agriculture or aquaculture land use.
- Use remotely sensed land-use data to determine leakage estimates, especially when coupled with models of land-use change.
- Document positive leakage when project activities are expected to lead to additional carbon benefits beyond the project boundaries, and provide supporting evidence even if the methodology does not require it.

Source: Dam, Adobe Stock

Glossary of technical terms for **mangrove forestation**

Allochthonous carbon: Organic material contributions to carbon pools from neighboring ecosystems (e.g., leaf litter in a neighboring ecosystem falling into waterways and being transported to the project area).

Autochthonous carbon: Organic material contributions to carbon pools derived from within an ecosystem; in this case, mangrove species (e.g., mangroves photosynthesizing and sequestering carbon).

Recruitment: The process by which new individuals are added to a plant population, whether by germination and maturation or by dispersal.

Hydrological restoration: The (re)establishment of appropriate site hydrology.

Hydrogeomorphology: The interaction(s) between hydrological processes (e.g., groundwater flow and precipitation) and landforms/earth minerals, as well as the interaction between geomorphic processes (e.g., soil formation and erosion) and surface/subsurface waters.

NATURE-BASED

Improved forest management

Improved forest management (IFM) changes the management of existing forested landscapes to increase carbon storage. IFM includes a broad range of practices that increase carbon stocks in forests and forest products, such as deferred timber harvest, reduced impact logging, and other silvicultural adjustments. IFM project design is rapidly evolving as registries release new dynamic baseline methodologies, but general uncertainty remains concerning additionality and market leakage. These uncertainties make accurate quantification of CDR from IFM projects challenging, resulting in a tendency for project developers to overestimate carbon benefits. Exemplary IFM projects use the most up-to-date methods and accurate data to 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*.

Social harms, benefits, and environmental justice

Environmental harms and benefits

Additionality and baselines

Measurement, monitoring, reporting, and verification

Durability

Leakage

Source: Aquasolid, iStock

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 any project benefits resulting from a third-party transfer of carbon rights are equitably shared among members of the community. Actively include land stakeholders in project planning, execution, and operation when projects occur on public lands, communally owned lands, or lands with customary tenure.
- Codevelop benefit-sharing arrangements with participating land owners, including negotiating terms before carbon credits are sold, transparently disclosing what portion of revenues the communities will receive, and indicating how funds are apportioned.
- Avoid increasing the risk of natural disturbances that may directly or indirectly impact local communities.

PROJECT DEVELOPERS SHOULD

- Design the project so that it supports local and regional industry, livelihoods, culture, and sustainable forestry practices over the long term.
- Provide a fair and transparent mechanism for land owners to opt out of or terminate lease agreements when they no longer wish to participate.

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 document any use of toxic and/or persistent environmental pollutants, including agrochemicals used for suppression of unwanted vegetation, and the risk of releasing these pollutants into the environment.
- Implement forest management practices that are appropriate to the local forest ecosystem and maintain or increase biodiversity.
- Enroll properties with third-party certification bodies such as the Forest Stewardship Council, Sustainable Forestry Initiative, or the American Tree Farm System.

PROJECT DEVELOPERS SHOULD

- Implement forest management practices that enhance habitat for regionally threatened or endangered species or species that are in decline and improve ecosystem connectivity, where possible.
- Avoid increasing the risk of natural disturbances that may directly or indirectly harm 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 two criteria.
  - Baselines must reflect initial standing carbon stocks and historical forest management practices unless a regional assessment is more appropriate, in which case the baseline must reflect typical forest management practices on similar land ownerships in the region.
  - Baselines must account for recent or projected changes in forest product demand. For example, projects located in regions with decreasing harvesting trends, such as those due to closed mills, can be expected to have increasing baseline stocks.
- Use a methodology that generates credits using a dynamic baseline when (a) regional forest inventory or remote sensing data have low biomass uncertainty, (b) reference areas with similar management history are available and identifiable, and (c) a suitable dynamic baseline methodology exists for the project jurisdiction.
- Restrict credit generation using a common practice baseline constraint such that credits are only issued for carbon above the average stocking level found on comparable properties.
- 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 forest measurement tools to measure and verify changes in carbon storage.
- Use statistically representative field inventories and/or remote sensing. If remote sensing models are used, calibrate and validate remote sensing models with ground-truth measurements. Continuously improve model performance over time as better data sources and modeling techniques become available.
- Utilize allometry based on published regional- and species-specific data.
- Include reporting only on carbon pools with increased storage, where data and measurements can be well substantiated (e.g., excluding increases in soil carbon when uncertainty is high).
- Include reporting on all carbon pools where project activities result in decreased carbon storage (e.g., harvesting or site preparation for planting).

PROJECT DEVELOPERS SHOULD

- Include potential effects of climate change on tree growth and stand development when modeling ex ante credit estimates.

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).

PROJECT DEVELOPERS SHOULD

- Improve forest health and reduce disturbance hazards (e.g., wildfire, insects, etc.) on project lands, including those 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 potential effects of climate change on stand development and forest health when accounting for reversal risks.
- Leverage existing legal or policy instruments (e.g., conservation easements, protected area designation) to secure the durability of the carbon stocks beyond the crediting period.

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

- Use conservative leakage deductions that are in line with regional scientific studies on leakage from IFM projects.
- Establish contractual agreements or use certification schemes that prevent activity leakage.

PROJECT DEVELOPERS SHOULD

- Deduct market leakage at the same time that increased carbon stocks are credited, even if existing offset protocols do not require this standard.
- Consider whether regional mills are running at capacity (e.g., due to high demand in wood product markets).
- Determine the impact of non-participating lands in the region with the capacity to produce similar timber products.
- Consider whether the wood products that would otherwise be produced on the project lands are highly substitutable.

Glossary of technical terms for **improved forest management**

Forest management: Any planned human intervention in a forest ecosystem to achieve specific goals and objectives, which can typically be grouped as environmental, economic, and social.

Natural disturbance: Any non-human-induced event that changes forest canopy structure, species composition, or age-class distribution, such as storm events, natural fire, insect pest outbreaks, and disease outbreaks.

Dynamic baseline: A baseline that compares the project area to matched control plots outside of the project area. Control plots are located in areas with similar characteristics to the project area but are not subjected to project activities. A dynamic baseline is updated regularly to reflect changes in land use and forest conditions over time.

Long-lived wood products: Wood products generated from timber harvests that persist for decades or centuries.

Allometry: A method for establishing quantitative relationships between measurable dimensions of trees and other tree properties (e.g., diameter and height measurements can be used to estimate a tree’s biomass).

NATURE-BASED

Soil carbon

Soil carbon CDR involves adoption of new conservation practices, regenerative agricultural management, or soil microbiology management to 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 the long-term sustainability of agricultural operations and increasing their resilience to climate change. While scientists have a good understanding of how on-farm management practices that sequester carbon in soils are implemented, the precise impact of these practices on soil carbon stocks is dependent on site-specific considerations, such as soil type, crop, and climate. Soil carbon scalability 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*.

Social harms, benefits, and environmental justice

Environmental harms and benefits

Additionality and baselines

Measurement, monitoring, reporting, and verification

Durability

Leakage

Source: Юрий Дровнин, 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 (e.g., fertilizer, herbicides, etc.), including the health and welfare of agricultural producers (e.g., farmers and ranchers).
- Articulate and, if necessary, implement a strategy for mitigating negative economic impacts on producers resulting from changes in crop yields or management costs.

PROJECT DEVELOPERS SHOULD

- Allow flexibility in producer practices given variable climate, environmental, and market conditions.
- Ensure contracts allow flexibility so producers are not locked into inadvisable 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 as a result of improving soil health through regenerative practices (i.e., being charged 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 producers.
- Identify how project labor will be distributed and compensated, considering that agricultural 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 negative ecosystem impacts from changing agricultural practices, including from changes in inputs (e.g., fertilizer, herbicides, etc.). Negative ecosystem impacts can include, but are not limited to, lower air quality, reduced water quality, land degradation, downstream waterway pollution, and sound pollution.

PROJECT DEVELOPERS SHOULD

- Monitor and quantify ecosystem co-benefits, where possible. Ecosystem co-benefits can include, but are not limited to, improved soil health, erosion control, increased biodiversity, improved water quality, and higher air quality.

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.

- Gather management history to demonstrate that any new practice is not already a common management practice across the farm or ranch.
- Use baselines that are specific to the project region and agricultural system to quantify the change in soil carbon resulting from new management practices.
- Assess the barriers that prevent farmers from implementing planned project practices. These may include financial barriers, lack of available equipment, knowledge gaps, or other barriers.

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

- Quantify net project carbon removals including any material emissions increases (e.g., from increased fertilizer applications).
- Document sampling design, including any stratification by practice, soil type, crop, and other relevant environmental factors.
- Document the analytical and calculation methods used to quantify changes in soil carbon stocks, including the mass/depth basis and any correction applied.
- When using modeling to estimate soil carbon changes, implement project-specific direct soil sampling at project outset, and at least once every five years, 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, a minimum of one meter of soil depth for some types of tillage change).
- Use the best available 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 in the specific setting where they will be applied.
- 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, or management context.
- Use modeling best practices, including appropriate calibration and validation with region- and practice-appropriate independent datasets, and comprehensively assess model prediction uncertainty.
- Document model procedures and sources of validation data.
- Quantify and account for sampling error and error associated with lab processing, instrumentation, carbon quantification method, and model prediction uncertainty. Make appropriate adjustments to credit volumes prior to issuing credits to account for error.

PROJECT DEVELOPERS SHOULD

- Take soil cores as deeply as possible, ideally to one meter.
- Provide comprehensive documentation of all soil carbon quantification methods that have been reviewed by a qualified third party.
- Identify a plan to share soil carbon data in a public repository, which could be used to improve model-based quantification approaches. This is particularly relevant for projects in areas with limited soil carbon data availability.

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 for the full duration of the project.
- Use verification methods and contracting mechanisms that maximize the likelihood that new practices will be implemented and maintained for the full durability term.
- Document robust strategies to monitor and mitigate reversal risks, both during and beyond the project crediting period. This must include appropriate buffer or risk pool contributions that can mitigate reversals due to changes in land management or ownership, changes in management practices, and impacts of natural hazards.

PROJECT DEVELOPERS SHOULD

- Identify mechanisms (e.g., incentives, agronomic support) to minimize producer attrition prior to the fulfillment of the durability term.
- Estimate the economic burden that participating producers will take on when adopting new agricultural practices (e.g., purchasing new machinery) to inform the risk that producers will leave programs for economic reasons.
- Support the generation of commercial-scale, long-term data to better understand biophysical reversal rates that occur when project practice changes revert.
- Seek and support implementation of policy incentives that promote durability, where 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

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

Source: Getty images for Unsplash+

Glossary of technical terms for **soil carbon**

Soil organic carbon: Carbon stored in soil in the form of organic matter or organic compounds, generally derived from the breakdown of plant matter by microorganisms.

Soil inorganic carbon: Carbon stored in soil in the form of carbonate species, including aqueous bicarbonate (HCO_3-) or carbonic acid (H_2CO_3) in soil pore water and solid carbonate minerals like calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$).

Regenerative agriculture: A broad term encompassing a set of agricultural practices, like cover cropping or reduced tillage, that are aimed at enhancing soil health and increasing stores of soil carbon. Regenerative agriculture is also called conservation agriculture or climate-smart agriculture.

Microbial inoculum: Soil amendment containing a collection of live microorganisms selected for specific functional traits and applied to soil with the intent of altering nutrient cycling or other soil functions.

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 could scale rapidly as a carbon removal method. However, ERW presents an ecotoxicity risk as many potential mineral feedstocks for ERW contain heavy metals and contaminants that can accumulate at high concentrations in soil and plant matter. Further, the end oceanic bicarbonate sink is geographically remote from fields where minerals are applied, making it difficult for ERW project developers to track stored carbon. Instead, developers typically rely on complex models to estimate CDR for project MRV. The following principles for ERW build upon those described previously under the *Essential principles for high-quality carbon dioxide removal* section.

Social harms, benefits, and environmental justice

Environmental harms and benefits

Additionality and baselines

Measurement, monitoring, reporting, and verification

Durability

Leakage

Source: Julio Ricco, 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

- Characterize risk of contaminant mobility to soils and groundwater and uptake in crops by quantifying: (1) mineral amendment dissolution rates, and (2) heavy metals concentrations and speciation, where appropriate (e.g., hexavalent chromium).
- Quantify the risk of asbestos exposure during mining, processing, transport, and feedstock application.
- Document and define safety protocols required for feedstock handling and application, including measures for the individual worker (e.g., personal protective equipment and material working procedures) and project-level measures (e.g., limiting spreading during high-wind conditions).
- Mitigate risks associated with heavy metals by clearly documenting ongoing quality assurance and quality control processes for sampling and analyzing mineral feedstocks, soils, and plant matter grown on fields where feedstocks have been applied.
- Avoid contaminating drinking water supplies.
- Document and define safety protocols that use best practices to minimize adverse impacts to local air or water quality.
- Notify local stakeholders and communities if adverse local environmental impacts are expected following application (e.g., air quality impacts from mineral application).

PROJECT DEVELOPERS SHOULD

- Document the impacts of mineral application on crop yield, soil chemistry (e.g., organic carbon, mineral nutrients), and farming practices (e.g., lime and fertilizer application).
- Preferentially use source materials that maximize net carbon removal (e.g., existing particle size distribution does not require additional processing and is close to application sites).
- Strive to source minerals sustainably, such as using mineral waste that does not require new mining and results in minimal environmental impact to local communities.
- Strive to source renewable energy to power operations for mining, grinding, and transporting 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

- Quantify heavy metal concentrations in mineral amendments through elemental analysis.
- Use the results of elemental analysis as inputs to model the expected heavy metal dissolution and accumulation in the environment.
- Monitor any potentially sensitive ecosystems (e.g., wetlands) located downstream from project fields and, when possible, mitigate negative impacts such as rapid pH shifts, heavy metal contamination, or release of other elements through mineral weathering.
- Mitigate environmental risks associated with heavy metals by clearly documenting ongoing quality assurance and quality control processes for sampling and analyzing mineral feedstocks, soils, and plant matter grown on fields where feedstocks have been applied.

- Disclose whether mineral amendments are sourced from mining by-products, existing mines, or new mining activities. In the case of new mining activity, forecast the environmental impact from the new mining activities and include those predictions in an analysis of the project's net impacts.

PROJECT DEVELOPERS SHOULD

- Document and, where possible, measure the potential co-benefits of mineral application for 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 assumptions about naturally occurring rates of mineral weathering and initial carbonate mineral content.
- Use control plots to measure the baseline soil processes and chemistry on agricultural land, including counterfactual lime application when appropriate.

PROJECT DEVELOPERS SHOULD

- Characterize inorganic carbon content in mineral feedstocks and document mineral and waste handling practices to justify expectations of zero ambient weathering.

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 mineral feedstock 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 are established in peer-reviewed literature and/or other applications with third-party evaluation.
- Document how modeling frameworks link biogeochemical and hydrological processes.
- Implement 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. Soil carbon protocols share many of the same proxy measurement and modeling issues and could serve as a reference for developing appropriate sampling plans and modeling approaches.
- Document model initialization assumptions and how model uncertainty will be incorporated into conservative carbon removal 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 quantify changes in soil health and any other claimed co-benefits following mineral feedstock application.
- Collect data and contribute to key research questions within the field, including far-field zone losses, feedstock impacts on soil organic carbon change, impacts of baseline agricultural lime use, agricultural management impacts on feedstock weathering rates, and agronomic impacts of feedstock application, where possible.

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 MRV 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 because of project activities.

PROJECT DEVELOPERS SHOULD

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

Glossary of technical terms for **enhanced rock weathering in croplands**

Alkaline mineral: Material which contains alkali or alkaline-earth metals such as calcium, magnesium, sodium, and potassium and is used as a mineral feedstock for ERW.

Natural mineral weathering: Slow breakdown of minerals due to dissolution in water (e.g., rainwater, pore water, or groundwater) containing dissolved carbonate species derived from atmospheric CO_2.

Carbon mineralization: A broad term encompassing all pathways (and associated timescales) through which CO_2 reacts with ions derived from alkaline minerals to form carbonate minerals Also called “mineral carbonation.”

Carbonate species: Chemicals and materials containing the carbonate ion (CO_{32}-); in aqueous systems, often in the form of bicarbonate (HCO_3-), carbonic acid (H_2CO_3), or dissolved CO_2 gas depending on the pH; in solid systems, often in the form of carbonate minerals, such as calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and magnesite ($MgCO_3$).

Heavy metals: Naturally occurring metallic elements of high atomic weight that can be toxic to humans, even at low concentrations, and pose a risk of uptake by plants (e.g., lead, cadmium, arsenic, chromium, and nickel).

Oceanic bicarbonate sink: The channel by which the ocean absorbs and stores atmospheric CO_2 in the form bicarbonate ions (HCO_3-), helping to buffer changes in atmospheric CO_2 changes over time.

HYBRID

Biomass carbon removal and storage

Biomass carbon removal and storage (BiCRS) refers to strategies that leverage photosynthesis, combined with a few processing steps, to remove CO_2 from the atmosphere and store biogenic carbon in long-lived reservoirs, either underground or in durable products. Some BiCRS pathways may also generate coproducts such as electricity, heat, or hydrogen. Prominent pathways include biochar production and storage, wood harvesting and storage, and geologic sequestration of biogenic CO_2 through pathways like bioenergy with carbon capture and storage (BECCS). The biomass feedstock for BiCRS can be specifically cultivated for CDR projects or derived as a byproduct of other activities, such as residues from forestry and agriculture. The following principles for BiCRS CDR build upon those described previously under the *Essential principles for high-quality carbon dioxide removal* section.

- Social harms, benefits, and environmental justice
- Environmental harms and benefits
- Additionality and baselines
- Measurement, monitoring, reporting, and verification
- Durability
- Leakage
- Other considerations
- Pathway-specific considerations

Source: Rene Notenbomber, iStock

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 biomass feedstock sourcing does not compromise essential resources, including fuel sources, for local communities.

PROJECT DEVELOPERS SHOULD

- Articulate how project activities, like feedstock production and product or coproduct sales, will benefit under-resourced and marginalized populations, including benefits like wealth generation and economic empowerment.
- Educate end users about the potential benefits and risks associated with project coproducts, such as biochar.

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 any major negative impacts on the surrounding ecosystems (including soil health, biodiversity, water quality, and air quality).
- Monitor any use of toxic and/or persistent environmental pollutants, including agrochemicals used in the production of purpose-grown feedstock.
- Provide a detailed strategy for ensuring—through tracking, mitigating, monitoring, and other methods—that the physical coproducts and wastes of the project (e.g., biochar, wood, liquids, gases, emissions, etc.) have a low risk of negative impacts on ecosystems.

PROJECT DEVELOPERS SHOULD

- Explore opportunities to maximize and quantify environmental co-benefits (e.g., fire suppression from feedstock procurement).
- Substantiate any environmental benefits associated with procuring feedstock for the project.

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, monitor, and quantify any carbon accounting impacts of the most likely counterfactual scenario for the biomass resources in question, throughout the duration of the project. Include their current use, assumed counterfactual carbon storage, and any potential future uses in the absence of the project.
- Document landscape carbon stock changes if biomass feedstocks are sourced directly from land management activities (e.g., ecological restoration, vegetation management, etc.). Carbon stocks must be documented at the landscape level, within the land area from which biomass is sourced, and must credibly estimate carbon stocking within the sourcing area under the project and baseline scenarios.

- Document the financial viability of the project, with and without revenue from carbon credits, using a financial or techno-economic model. The model must include the impact of coproducts, tax deductions and credits, regulations, policy incentives, and other financial factors. Examples of policy incentives in the United States include the 45Q tax credit, Clean Fuel Standards, and the Inflation Reduction Act.
- Include and justify the cost of the biomass feedstock, delineating transportation and procurement costs, and the per-unit pricing of all project products such as biochar, bio-oil, electricity, ethanol, or steam.

PROJECT DEVELOPERS SHOULD

- Justify the current project cost estimate, and quantify and support its potential for change based on cost curve projections

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 against a credible baseline, based on cradle-to-grave LCAs that include biomass feedstock procurement (including land-use change for purpose-grown feedstocks), land management activities (e.g., ecological restoration, vegetation management, land clearing, etc.), process emissions, carbon storage operations, environmental disturbances, and embodied emissions.
- Conduct an attributional LCA based on primary data where available. Justify values used in the LCA that are derived from literature or databases and conduct sensitivity analyses for values with high uncertainty.
- Quantify the consequential GHG impacts of project implementation, including the impacts of feedstock sourcing, energy procurement, and leakage. Justify values used in the LCA that are derived from literature or databases and conduct sensitivity analyses for values with high uncertainty.
- Clearly outline emission allocation methods for coproducts, including a sensitivity analysis on allocation assumptions and different product scenarios.
- Provide detailed accounting and justification of counterfactuals for waste or residue feedstocks.
- Provide the implementation and operational details of any third-party MRV platforms the project will use, including access permissions, personnel responsible for making updates, approach to integration of automated inputs, and the process for platform quality checks.
- Select energy and material sources with the lowest fossil GHG emissions per gross tonne of CO_2 removed, where multiple viable configurations are available.

PROJECT DEVELOPERS SHOULD

- Document the rationale for selecting the project registry and affiliated protocol, and highlight where the project exceeds protocol requirements.

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

- Use geologic storage sites, where applicable, created under established permitting processes (e.g., Environmental Protection Agency (EPA) Class permitting for deep injection wells in the United States or meet ISO 27914:2017 standard for CO_2 storage).

- Quantify and document expected changes in the amount of carbon sequestered over time (e.g., through decay or physical leakage).
- Use guidance set forth for durability in the *Direct air capture* section of this document when storing gaseous CO_2 (e.g., BECCS).
- 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 accounting and MRV, the carbon emissions that may result from the project's consumption or displacement of regional materials and energy supplies (e.g., energy diverted for capture and compression of CO_2 at retrofitted facilities).
- Quantify the market impacts and carbon emissions resulting from biomass procured at a price that exceeds the cost incurred by the supplier, including potential biomass market distortions and associated resource diversion.
- Quantify and include, in carbon accounting and MRV, any carbon emissions from potential land-use change or impacts to bioeconomy product supply (e.g. biofuels or biochemicals displacement) 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

- Source biomass feedstock following the guidelines outlined in *A Buyer's Guide to Sustainable Biomass Sourcing for Carbon Dioxide Removal*, where applicable. Biomass must come from sources that adhere to the following guidelines:
  - Operate with integrity and oversight through strong governance, standards, and supply-chain transparency.
  - Minimize negative impacts on Indigenous Peoples, workers, and local communities.
  - Produce biomass without threatening protected areas or reducing regional carbon stocks.
  - Do not distort markets for agriculture or forestry products.

PROJECT DEVELOPERS SHOULD

- Forecast future biomass sustainability (using the "must" criteria above, as appropriate) given the existing and planned projects in the developer's intended biomass sourcing area.

Pathway-specific considerations

Biochar

PROJECT DEVELOPERS MUST

- Verify, using end-to-end tracking, that all biochar generating CDR credits is durably stored in a long-term sink. Biochar storage must minimize reversal risk and prevent biochar use in combustion applications or other applications that would rapidly release CO_2 to the atmosphere.
- Provide biochar elemental analysis (e.g., carbon, hydrogen, oxygen), based on the best available models, to substantiate storage durability and quantify biochar recalcitrance and carbon loss over a 100-year time frame.
- Ensure that biochar is regularly tested for heavy metals, toxins (e.g., tar), and polycyclic aromatic hydrocarbons (PAHs) to minimize environmental harms (e.g., adhere to the European Biochar Certificate and World Biochar Certificate guidelines, as well as local regulations).
- Prove that the project results in the production of additional biochar, above a verifiable and established baseline production scenario.
- Measure, and include in an LCA or carbon accounting model, any methane emissions from the biochar production process.
- Account for end-of-life scenarios, for materials that utilize biochar as an additive or component, to prevent potential carbon reversals once those materials reach the end of their useful life.
- Conduct testing (e.g., carbon-14 isotope) on biochar produced from partially fossil-based waste, in order to ascertain the biogenic content for credit issuance.

PROJECT DEVELOPERS SHOULD

- Measure biochar decomposition rates after application, differentiating between labile and recalcitrant fractions, to refine existing decay models.
- Consider energy efficiency in project design, such as by exploring the utilization of waste heat from the pyrolysis process, where feasible and supportive of the primary CDR objectives.

BECCS

PROJECT DEVELOPERS MUST

- Ensure that environmental releases, such as sorbent or solvent slip, are adequately measured and monitored to identify hazards and that emissions remain below regulatory thresholds.
- Implement rigorous safety and community outreach plans to mitigate risks associated with uncontrolled CO_2 release during transportation and storage.
- Use established standards to conduct testing (e.g., carbon-14 isotope) to distinguish between biogenic CO_2 and fossil CO_2 produced from partially fossil-based waste, where applicable.
- Describe in detail the energy requirements (including sources) for retrofitting and operating a carbon capture system, and quantify the associated emissions within the project’s carbon accounting (such as in the leakage assessment or the overall LCA).

PROJECT DEVELOPERS SHOULD

- Quantify positive leakage effects from coproduct outputs such as electricity and steam.

Biomass storage

PROJECT DEVELOPERS MUST

- Design storage methods to minimize decomposition, inhibit biological degradation, and mitigate the risk of external disturbances, such as intrusion by biotic agents, geological events, and weather events.
- Provide a cradle-to-grave LCA that includes all relevant portions of the project, including topsoil disturbance and transport of biomass feedstock.
- Use in situ sensors and gas sampling in the biomass storage environment to monitor for sealing integrity and indicators of degradation.
- Use in situ sensors and gas sampling of methane for MRV.

PROJECT DEVELOPERS SHOULD

- Maintain a buffer pool of credits to mitigate uncertainty in factors like durability and methanogenesis, until MRV substantiates modeled outcomes.
- Ensure the storage site is securely established, both physically and legally, to prevent disturbances from human interference and activities over timeframes relevant for durability, to the extent possible.
- Use sample excavations, from either the actual project storage site or a representative test storage site, to enhance MRV. In cases where direct sampling could compromise sealed areas, establish a dedicated MRV subplot for systematic testing.

Waste-to-energy with carbon capture and storage

While waste-to-energy (WtE) with carbon capture and storage (CCS) falls under the broader category of BECCS, the specific characteristics and nuances of this project type warrant its classification as a distinct subcategory.

PROJECT DEVELOPERS MUST

- Verify the split of fossil and biogenic CO_2 through direct testing and sampling (e.g., carbon-14 testing), ensuring sufficiently frequent monitoring from multiple metering locations.
- Ensure that the WtE facility charges a gate-fee, or uses a similar mechanism, to track all waste it receives.
- Ensure that the WtE facility incinerates waste that has been sorted for recycling or reuse (or other activities higher on the waste hierarchy), or demonstrate the unfavorability of waste sortation.
- Ensure that any additional waste a facility sources to facilitate the operation of the capture unit is reflected in the project's LCA, including transportation emissions.
- Demonstrate that the facility meets all additionality criteria, especially in terms of regulatory additionality, when emissions from such a facility may be taxed.
- Ensure biogenic-only feedstock is used, only if it is a true waste product and has been rejected from recycling, reuse (or other activities higher on the waste hierarchy) or has been permitted for use under local law.
    - If biogenic feedstock is used to increase the heating value of the feedstock, the feedstock must adhere to *A Buyer's Guide to Sustainable Biomass Sourcing for Carbon Dioxide Removal*.

PROJECT DEVELOPERS SHOULD

- Ensure waste is sorted to remove recyclable or reusable material and that sorting is conducted by an entity other than the WtE facility owner, where possible. If the operator is responsible for sorting waste, ensure this is done in an objective manner.
- Use waste primarily sourced from the surrounding area, and limit use of imported waste to waste from countries meeting relevant waste targets.

Glossary of technical terms for **biomass carbon removal and storage**

Biochar: Stable solid, rich in carbon, that is produced by heating biomass in the absence of oxygen (pyrolysis), or in limited oxygen that does not permit full combustion (gasification and partial combustion). Biochar must be stored in a reservoir or application that prevents storage reversal (i.e., it must not be combusted). Applications include using biochar as a soil amendment or incorporating it into long-lived materials, such as cement.

Bioenergy with carbon capture and storage (BECCS): A CDR method that involves using biomass to generate energy or fuels while capturing and storing the biogenic CO_2 emissions produced from combustion, gasification, fermentation, or other biomass conversion pathways. This can include processes like biopower or WtE with CCS, ethanol CCS, and pulp and paper CCS.

Biomass burial: A CDR method that involves storing biomass in engineered or naturally suitable environments, such as underground vaults or in sediment, to slow decomposition and sequester carbon for long periods of time.

Coproduct emission allocation: Method used in an LCA to distribute GHG emissions among multiple products derived from the same process, such as on the basis of coproduct mass or energy contents.

Cradle-to-grave LCA: LCA with a broad system boundary, which includes all emissions from energy and material sourcing and consumption, waste treatment, constructionand decommissioning, compression, transportation, and storage or reuse of captured carbon.

Recalcitrant: Organic carbon in biochar and biomass that resists decomposition, preventing the loss of stored carbon to the atmosphere.

Labile: Organic carbon in biomass and biochar that is readily decomposed, such that stored carbon is cycled back into the atmosphere.

Elemental analysis: A scientific testing method used to determine the composition of a material in terms of its chemical elements (e.g., carbon, hydrogen, oxygen).

Waste-to-energy with carbon capture and storage (WtE with CCS): A subset of the BECCS CDR method that often involves combusting mixed biogenic and fossil waste (e.g., municipal solid waste) to generate energy (heat or electricity), capturing the resulting CO_2 emissions, and providing long-term geologic storage for the captured CO_2.

HYBRID

Abiotic marine carbon dioxide removal

Marine carbon dioxide removal (mCDR) pathways utilize the ocean's physical circulation, biogeochemical processes, and marine ecosystems to remove atmospheric CO_2 and durably store it in various forms. To safely deploy mCDR technologies and ensure precise carbon accounting, advanced forecasting and monitoring methodologies are essential, as these pathways both affect and rely on the dynamic ocean regime and marine life, including its intrinsic uncertainties. High-quality mCDR projects prioritize rigorous carbon measurement, monitoring, reporting, and verification (MRV) in addition to equally rigorous MRV of the ocean ecosystem and marine life (eMRV) to mitigate harm. The methodologies and protocols required for mCDR projects are under active development and are being continuously refined as new data emerges. Due to the emergent, high-stakes nature of this field, enhanced rigor is imperative, and the following criteria have been developed to reflect that standard.

Among the suite of mCDR pathways under development, this set of criteria focuses on the abiotic pathways of Ocean Alkalinity Enhancement (OAE), which captures and stores atmospheric CO_2 as bicarbonate dissolved in the ocean, and Direct Ocean Removal (DOR), which removes CO_2 from ocean waters and stores it externally. These methods offer the potential for durable, large-scale CO_2 removal in the coming decades.

- Social harms, benefits, and environmental justice
- Environmental harms and benefits
- Additionality and baselines
- Measurement, monitoring, reporting, and verification
- Durability
- Leakage
- Other considerations

Source: Ivan Bandura, Unsplash+

Social harms, benefits, and environmental justice

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

PROJECT DEVELOPERS MUST

- Develop a social harms and benefits plan with consideration of potential impacts on fisheries, aquaculture, and existing coastal industries.
- Implement strategies for community engagement with consideration of preventing and addressing any misperceptions regarding potential risks associated with project activities.
- Minimize disruption of coastal businesses or those relying on the ocean.
- Ensure local traditional and Indigenous practices are not disrupted by project activities.

PROJECT DEVELOPERS SHOULD

- Actively engage with local communities and provide education on the regional ocean, ocean stewardship, and how project activities interact with the coastal and oceanic ecosystem.
- Address significant concerns from local communities, stakeholders, and fisheries through community education and, when appropriate, research and development with a third party or modifying the project plans prior to large-scale project implementation.
- Evaluate how project activities can improve existing climate and social inequities, including near major feedstock sources and processing facilities.
- Support local fisheries and aquaculture through partnerships involving co-benefits and profit sharing.
- Provide employment opportunities to local communities including those historically marginalized.

Environmental harms and benefits

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

PROJECT DEVELOPERS MUST

- Develop eMRV protocols with consideration of the regional and relevant global oceanic regime, ecosystem health, all effluents discharged from project activities, and ecosystem responses.
- Implement strategies to mitigate potential harm caused by project activities.
- Monitor all effluents, site-specific reactions, and ecosystem responses from project activities, at clearly defined intervals on an ongoing basis.
- Develop and integrate specific eMRV plans for all keystone, vulnerable, sensitive, and endangered species that could be affected by project activities.
- Identify and define thresholds of harm for any changes to the oceanic regime and ecosystem caused by project activities.
- Implement plans for suspending project activities if the project causes harm or exceeds established thresholds. Include timely reporting and communication with local authorities and communities.
- Implement eMRV protocols for appropriate geospatial locations (e.g., depth) that span the project's duration and a defined period after project completion.
- Establish a baseline of the health of the marine ecosystem and relevant global and regional oceanic regime. Report all assumptions and uncertainties.
- Establish the baseline impacts on the marine ecosystem from all relevant pre-existing base facilities (e.g., desalination facility) processes, emissions, and disturbances, prior to project initiation.

- Use scientific studies, protocols, and monitoring methodologies to ensure sufficiently high accuracy (e.g., high-resolution ocean models, remote sensing, and autonomous platforms).
- Quantify and integrate inherent uncertainties into the eMRV plan.
- Assess potential impacts from project activities using available data and by conducting studies through an approved third party. Transparently share essential data relating to environmental impacts with the local community and broader scientific community.

PROJECT DEVELOPERS SHOULD

- Transparently share all data relating to the project with local communities and the broader scientific community.
- Use data from field trials and mesocosm studies to gather insights into potential large-scale impacts on and responses resulting from the project's activities.
- Evaluate and incorporate climate change impacts on the oceanic regime and ecosystem into assessments for establishing potential acceptable risk levels for project activities.
- Collaborate with local research institutions to advance studies on sustainable ocean management, eMRV methodologies, and the protection of marine food systems.
- Monitor all pre-existing base facility effluents, emissions, relevant site-specific reactions and disturbances at clearly defined intervals on an ongoing basis.
- Consult with pre-existing facilities and other relevant local industries to identify potential opportunities to increase the environmental safety of external processes.

Additionality and baselines

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

PROJECT DEVELOPERS MUST

- Establish a baseline of the relevant oceanic regime through historical data and monitoring methodologies that includes variability ranges, significant outlier events, and inherent uncertainties. Document and transparently share assumptions and uncertainties.
- Establish relevant baseline data for all pre-existing base facilities and processes, prior to initiating the project.

Measurement, monitoring, reporting, and verification

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

PROJECT DEVELOPERS MUST

- Conduct a life-cycle assessment (LCA) with consideration of processes such as mineral dissolution and gas exchange.
- Use high-quality monitoring methodologies to quantify CDR and report assumptions and uncertainties.
- Identify conservative upper and lower bounds of the project's anticipated CDR volumes within a specific time frame for quantification of an uncertainty budget.

- Assess and incorporate data variability and inherent uncertainties into the baseline.
- Implement an MRV plan that includes region-specific and relevant global processes, accounting for ocean circulation and biogeochemical cycles.
- Regularly update the project's MRV plan to incorporate the best available science and monitoring tools and techniques.
- Directly monitor the relevant properties and chemical composition of project feedstocks, products, intermediates, and by-products. Predict and assess any potential responses upon discharge into seawater that could impact the project's CDR efficacy.
- Ensure proper carbon accounting for all end uses and fates of captured CO_2 to avoid double counting.

PROJECT DEVELOPERS SHOULD

- Use energy with low associated emissions and provide the electricity emissions factor and the latest emissions factor for the local electrical grid if purchasing electricity from the grid. The use of marginal emissions factors may be appropriate, depending on grid conditions.

Durability

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

PROJECT DEVELOPERS MUST

- Predict and monitor relevant global and regional changes to the oceanic regime that pose a risk of releasing carbon stored within the ocean.
- Regularly update durability calculations with project data and the latest scientific research.
- Implement long-term plans for specifically monitoring the durability of captured CO_2 well after project completion. Transparently share relevant data with the scientific community.
- Monitor for conditions and processes, at all relevant points in the project's facility, that could result in CO_2 outgassing and/or secondary carbonate precipitation.
- Disclose the biogeochemical model used to predict the fate of the captured CO_2.
- Disclose the use of CO_2 as a feedstock, and the risk of CO_2 reversal from any non-durable product or commodity.
- Follow guidance set forth for durability of direct air capture in the High-Quality Criteria for Carbon Dioxide Removal when storing pure CO_2 (e.g., as in DOR projects).

PROJECT DEVELOPERS SHOULD

- Seek long-term monitoring solutions for storage, such as through regulatory takeover as envisioned by the European Union Carbon Capture and Storage Directive.

Leakage

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

PROJECT DEVELOPERS MUST

- Predict, monitor, and report changes in the oceanic regime, regionally and globally, that could result in the release of CO_2 or unfavorably impact the carbon cycle elsewhere.
- Monitor and mitigate disruptions to local coastal businesses or those relying on the ocean in a way that could lead to increased emissions outside the project boundary, including land-based and maritime activities.
- Account for energy use induced by project activities and evaluate potential leakage from (1) upstream and downstream use of fossil-fuel energy sources and (2) electricity powering operations, including grid-related emissions from power purchase and use.
- Account for the counterfactual use of feedstocks and any increased production demand induced by consuming those feedstocks for project activities.

Other considerations

Permits and Law

PROJECT DEVELOPERS MUST

- Conduct the project in accordance with all applicable regional, national, and international laws, regulations, and best practices for ocean-based activities that are not necessarily legally binding.
- Adhere to any applicable regulations from the London Convention and London Protocol regarding marine geoengineering activities and any non-coastal discharge into the ocean, the principles laid out in the United Nations Convention on the Law of the Sea (even if the host country has not ratified it), maritime zone regulations, regulations on exploitation of ocean resources, exclusive economic zones, and high seas boundaries and use rights.
- Mitigate negative impacts on international maritime activities.
- Consult with relevant agencies regarding all applicable coastal zone management plans, new or existing permits, and certifications.
- Engage in public comment periods and stakeholder consultations as part of the permitting process.

PROJECT DEVELOPERS SHOULD

- Work with national and international governmental bodies to cooperatively share relevant information and establish clear, sustainable, and equitable governance for the deployment of mCDR.
- Demonstrate consistency with coastal zone management plans of adjacent coastal states, where applicable.
- Assess project compliance with evolving governance frameworks, including the potential impact of the new Agreement on Marine Biodiversity of Areas beyond National Jurisdiction (BBNJ Agreement) for activities in international waters.
- Consult with local permitting agencies and identify any areas where the project should go above and beyond requirements to mitigate environmental harm and ensure the durability of mCDR.

Scalability

PROJECT DEVELOPERS MUST

- Evaluate and incorporate any necessary adjustments to the eMRV and MRV plan that may result from increasing the scale of the mCDR project, such as a decrease in the signal-to-noise ratio and increased uncertainty.
- Predict and mitigate potential social and environmental harms and benefits associated with increasing the scale of the project, including those linked to increased feedstock consumption.
- Predict and evaluate the potential impacts of halting project operations (at scale) to the environment and durability of stored carbon.
- Develop plans to stop project operations if ecosystem harm is detected or harmful thresholds are exceeded. Incorporate a risk assessment of termination shock and a remediation strategy for the project at anticipated scales.
- Follow the guidance set forth in this document for scalability of direct air capture when applicable.

Glossary of technical terms for **abiotic marine carbon dioxide removal**

Environmental monitoring, reporting and verification (eMRV): refers to rigorously predicting and monitoring all potential acute, chronic, and cumulative impacts of project activities on the oceanic regime and the health of the ecosystem.

Ocean modeling: refers to numerical modeling relevant to mCDR, including ocean biogeochemistry and physical processes.

Oceanic ecosystem: refers to the interaction between living and non-living components within marine environments. This includes all marine life and their interconnected relationships such as community responses and biodiversity:

Marine life: refers to all living organisms in the ocean, through the food chain, and species directly dependent on the ocean (e.g., migration patterns of birds).

Oceanic regime: refers to all conditions and processes of the oceans. This includes ocean biogeochemistry and circulation:

Ocean biogeochemistry: refers to the processes and interactions that regulate the cycling of elements in the ocean. This includes all parameters and processes that pertain to marine life (e.g., photosynthetic processes and biogenic calcification), all mechanisms that relate to sedimentation at the sea floor, and all physical and chemical properties and processes within the ocean (e.g., nutrient cycling and air-sea-gas exchange).

Ocean circulation: refers to all movement of ocean water.

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Carbon mineralization

Carbon mineralization is a broad term encompassing all pathways (and associated timescales) through which CO_2 reacts with ions derived from alkaline minerals to form stable carbonates. Also referred to as "mineral carbonation," it is related to ERW and abiotic mCDR where carbon is stored in bicarbonate ions. In contrast, the products of carbon mineralization are carbonate minerals, a highly durable method of storing carbon. Carbon mineralization binds carbon in rock in both underground (in situ) and aboveground (ex situ) sites. Carbonate minerals can be incorporated into products as low-carbon feedstocks, such as concrete aggregate. Further, some industrial feedstocks can adversely impact ecosystems and communities unless 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 criteria for *Enhanced rock weathering in croplands*.

Social harms, benefits, and environmental justice

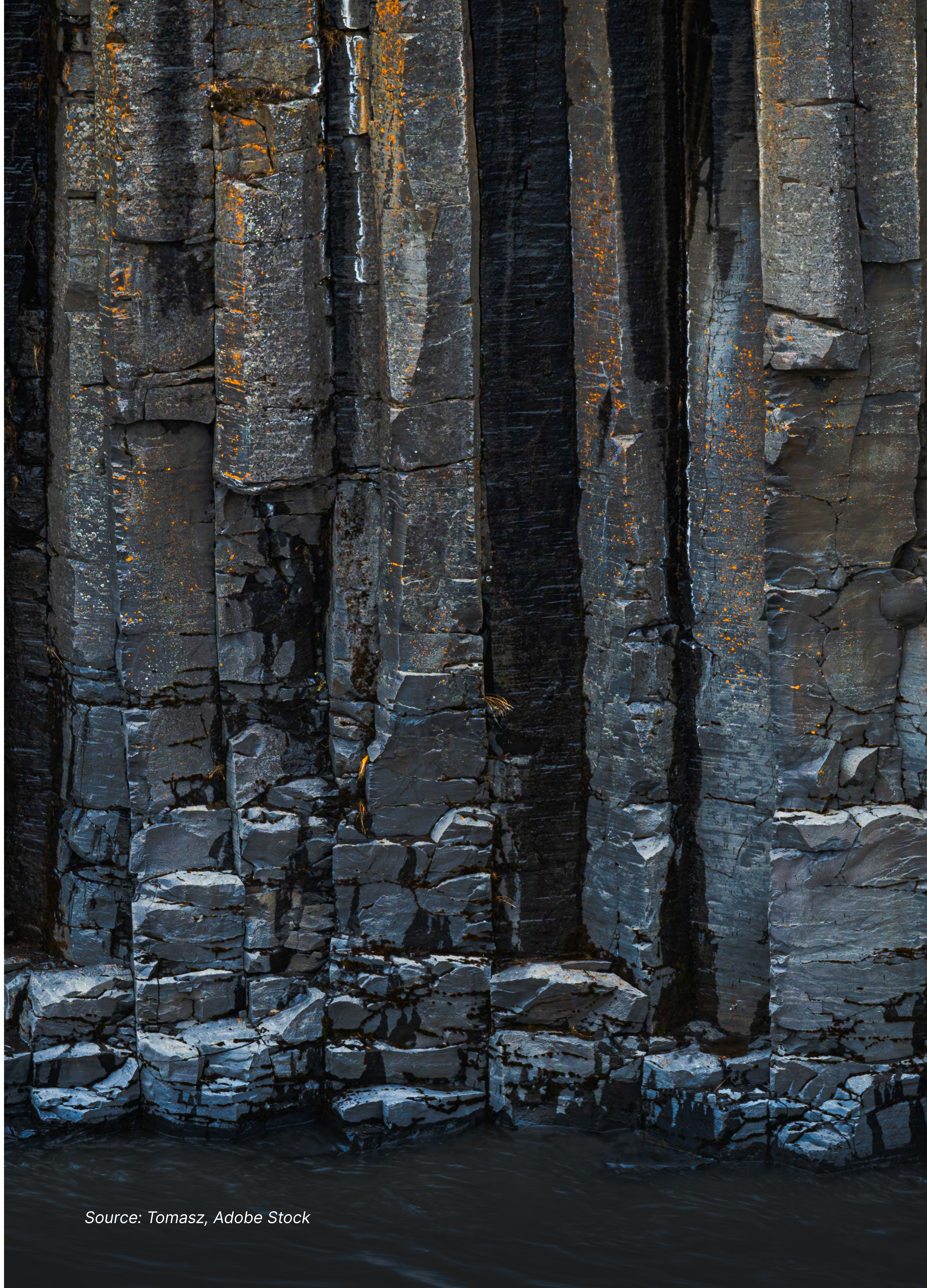
Environmental harms and benefits

Additionality and baselines

Measurement, monitoring, reporting, and verification

Durability

Leakage



Source: Tomasz, 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, communities, and workers (e.g., changes in water quality, land use, pollutant use, and exposure to harmful materials).
- Document how a facility's established community engagement processes are expanded when CDR activities are added onto existing industrial processes (e.g., concrete production or active mine site).

PROJECT DEVELOPERS SHOULD

- Remediate past negative environmental impacts on the community, where possible (e.g., from historical mining operations) and document these efforts.

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, composition, and disposal methods of all waste streams (i.e., solid, liquid, and gas) associated with the project.
- Disclose whether ex situ mineralization projects source raw materials and inputs from existing mines and industrial by-products, or if they require new mining activities. In the case of new mining activity, measure and mitigate any environmental impacts from the new mine or quarry.
- Quantify the net amount of water, potable and non-potable, that the project consumes during mineralization.

PROJECT DEVELOPERS SHOULD

- Implement mitigation plans for unintended release of a waste stream into the environment.
- For in situ mineralization projects, quantify the risk to local seismicity and implement 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 (e.g., solid, liquid, and gas), any metals that contribute to mineral carbonate formation, and all alkalinity imported or exported from the project boundaries when quantifying project baselines and changes in mineralization rates.
- Measure the rate of natural mineral weathering 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 from adopting mineralization technology 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.
- Implement control plots to measure natural mineral weathering rates before, during, and after project deployment, when relevant.
- Measure changes in mineralization reaction rates over time due to consumption of highly reactive material and feedstock passivation.

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 measurement methods and tools to directly measure carbon stocks and fluxes in materials.
- Disclose any modeling tools used to supplement and inform measurements, along with information on model validation, calibration, and uncertainty.
- Ensure that carbon removal claims are consistent with a net carbon-negative outcome based on a cradle-to-grave LCA. The LCA must conservatively quantify all GHG emissions associated with the full suite of inputs and products from the project.
- Measure and monitor, where appropriate, the impact of the project on other GHG pathways (e.g., methanogenesis, nitrogen cycle).
- Identify the source of metals, such as calcium and magnesium, that are contributing to mineral formation. Include the carbon impact of the metal source in the project's MRV.
- Document the degree of heterogeneity or homogeneity in industrial waste or mineral feedstocks and quantify its effect on measurement certainty and life cycle impacts.

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 with mass balances).
- Supplement and calibrate modeling with direct physical and/or chemical evidence of mineralization.

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

- Implement downstream use and/or storage pathways for the carbonated materials that minimize the likelihood of reversal.

PROJECT DEVELOPERS SHOULD

- Include reversal risks for both solid and aqueous carbon in MRV plans.
- Implement release scenarios and mitigation plans that reflect the anticipated impacts of climate change and changes in land use or water reservoir development, when relevant.
- Include 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

- Quantify the impact of the project on land use, especially when project infrastructure encroaches on high-value land use.
- Ensure that any new energy needed for mineralization operations does not extend demand, or create new demand, for emissions-intensive energy.
- Integrate project activities into active mining processes in a way that causes minimal disruption to or influence on current or future mining outputs, where applicable.

PROJECT DEVELOPERS SHOULD

- Quantify the project's production of valuable coproducts and, for retrofits to pre-existing industrial facilities, provide evidence of the historic volume of production.
- Include the size and distance to market or area of application for projects in the built environment.

Glossary of technical terms for **carbon mineralization**

Alkaline mineral: Mineral which contains alkali or alkaline-earth metals such as calcium, magnesium, sodium, and potassium and is used as a mineral feedstock.

Natural mineral weathering: Slow breakdown of minerals due to atmospheric conditions where CO_2 reacts with the minerals in rocks to form carbonate species.

Carbonate species: Chemicals and materials containing the carbonate ion (CO_{32}-); in aqueous systems, often in the form of bicarbonate (HCO_3-) or carbonic acid (H2CO_3), or dissolved CO_2 gas depending on the pH; in solid systems, often in the form of carbonate minerals, such as calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and magnesite ($MgCO_3$).

In situ mineralization: Mineralization as a result of the chemical reaction between CO_2 and minerals in naturally occurring geologic formations, deep underground; typically, aqueous or supercritical CO_2 is injected into a deep geologic formation, where it mineralizes to form solid carbonate minerals over time.

Ex situ mineralization: Mineralization as a result of the chemical reaction between CO_2 and industrial waste resources or excavated alkaline minerals, typically in a dedicated reactor or industrial process.

Mass balance: Systematic way to track and quantify all mass flows entering or exiting a system to follow the Law of Conservation of Matter.

Built environment: The constructed physical world, including buildings, infrastructures, and urban spaces.

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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 the speed and scale of deployment. The following principles for DAC build upon those detailed previously under the *Essential principles for high-quality carbon dioxide removal* section.

Social harms, benefits, and environmental justice

Environmental harms and benefits

Additionality and baselines

Measurement, monitoring, reporting, and verification

Durability

Leakage

Other considerations

Source: Julia Dunlop, 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

- Quantify potential impacts from sorbent or solvent slip downwind of the facility, even if the project is compliant with general health and safety guidelines and all applicable local/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, disturbing, or restricting access to land legally designated as culturally sensitive or ecologically important by community members or local stakeholders. This includes land the project directly uses for DAC facilities, renewable energy installations to power DAC facilities, or other utilities required for operations (e.g., local water resources, land for CO_2 transport, land for 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.
- Measure and mitigate any adverse impacts on local communities from increased water consumption. These impacts may include increased water and wastewater treatment prices and/or decreased local water quality, including discharges from capture facilities and sorbent/solvent manufacturing facilities.
- Document all land-use changes required for project deployment, including any new infrastructure.

PROJECT DEVELOPERS SHOULD

- Minimize the need for new inputs (e.g., energy, construction materials, sorbents/solvents) by monitoring and improving material and process efficiency, including application of best practices in reuse and circularity.
- Prioritize material sourcing that minimizes disproportionate impacts on frontline communities.
- Actively promote long-term economic opportunities for local communities by providing training programs that implement a pipeline of local workers skilled at DAC management and operation.
- Minimize land-use changes that could have negative community consequences, including any new infrastructure required for project deployment.

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 during the project's construction and startup/commissioning phase, as well as during its steady state operations.
- Measure and mitigate any adverse impacts from increased water consumption, including decreased local water quality due to discharges from capture facilities and sorbent/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.
- Implement a remediation plan for unintended releases of chemicals to the environment.

PROJECT DEVELOPERS SHOULD

- Use 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.

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., the 45Q tax credit the United States or, in some European Union countries, state auctions for carbon removals).
- Quantify baseline GHG fluxes and expected GHG fluxes from material and energy consumption, site preparation, carbon storage/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

- Ensure that carbon removal claims are consistent with a net carbon-negative outcome based on a cradle-to-grave LCA.
- Conservatively quantify all life cycle GHG emissions, 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 natural gas leakage and downstream usage, in carbon measurement considerations, when a project uses fossil-fuel energy sources.
- Measure the relative fraction of atmospheric and fossil CO_2 sent to storage and validate any discrete measurements (e.g., C-14 sampling) with continuous measurements of all carbon flows within the system, including fossil fuel consumption, when projects co-capture fossil and atmospheric CO_2.
- Include full lifecycle impacts of the electricity powering operations, including grid-related emissions from grid-connected power purchase and use.
- Provide substantive details of the power purchase agreement when purchasing electricity from a grid, including the electricity emissions factor, the latest emissions factor for the local electrical grid, and related RECs.
- Present a viable MRV plan that adheres to key regulatory requirements (e.g., Class VI well permits) for any subsurface storage and CO_2 transportation activities that are part of the project.
- Model displacement of high carbon-intensity products or processes for DAC projects coupled to CO_2 utilization.
- Ensure that removal credits are not double counted against 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 oil production with a lower carbon intensity.
- Include documentation or the status of permit applications for storage sites.
- Design a project that emits less than 0.3 tonnes of fossil GHG emissions per gross tonne CO_2 removed.

PROJECT DEVELOPERS SHOULD

- Use energy with low associated emissions, ensure the additionality of any low-carbon energy procured, and use advanced carbon accounting methodologies (e.g., temporally aligned power or carbon matching) to estimate the broader emission impacts of a project's energy procurement.
- Ensure new, low-carbon electricity generation is added to the corresponding regional grid (or grid balancing-area) if the project is connected to a 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

- Use safe and durable geologic storage sites, where applicable, following established permitting processes (e.g., EPA Class VI permitting for deep injection wells in the United States or meet ISO 27914:2017 standard for CO_2 storage).
- Demonstrate sufficient CO_2 storage capacity for the entire project lifetime, or sufficient physical CO_2 offtake with credible third-party providers.
- Demonstrate sufficient injectivity at the storage site, including well count.
- Demonstrate low CO_2 release risk, as estimated by the methodologies outlined in the IPCC AR6 WGIII report, Section 12.3.1.
- Implement an MRV plan, consistent with best practices for the chosen storage location, to detect unplanned physical leakage or reversals.
- Disclose the use of CO_2 as a feedstock to produce any non-durable product or commodity.
- Seek long-term monitoring solutions for storage (e.g. via regulatory take-over as envisioned by the European Union's 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.
- Produce, transport, store, and manage solvent and solvent degradation products with low risk to operators, neighboring communities, and the environment, when a project uses a solvent-based system.
- 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, when a project uses a sorbent-based system.
- Provide a copy of permit applications or permits a project has received for air emissions, wastewater disposal, and solid waste disposal, if applicable.

Infrastructure

PROJECT DEVELOPERS SHOULD

- Describe relevant transmission infrastructure, including new power lines, new utility lines, and CO_2 transportation infrastructure such as pipelines, truck, barge, or rail.

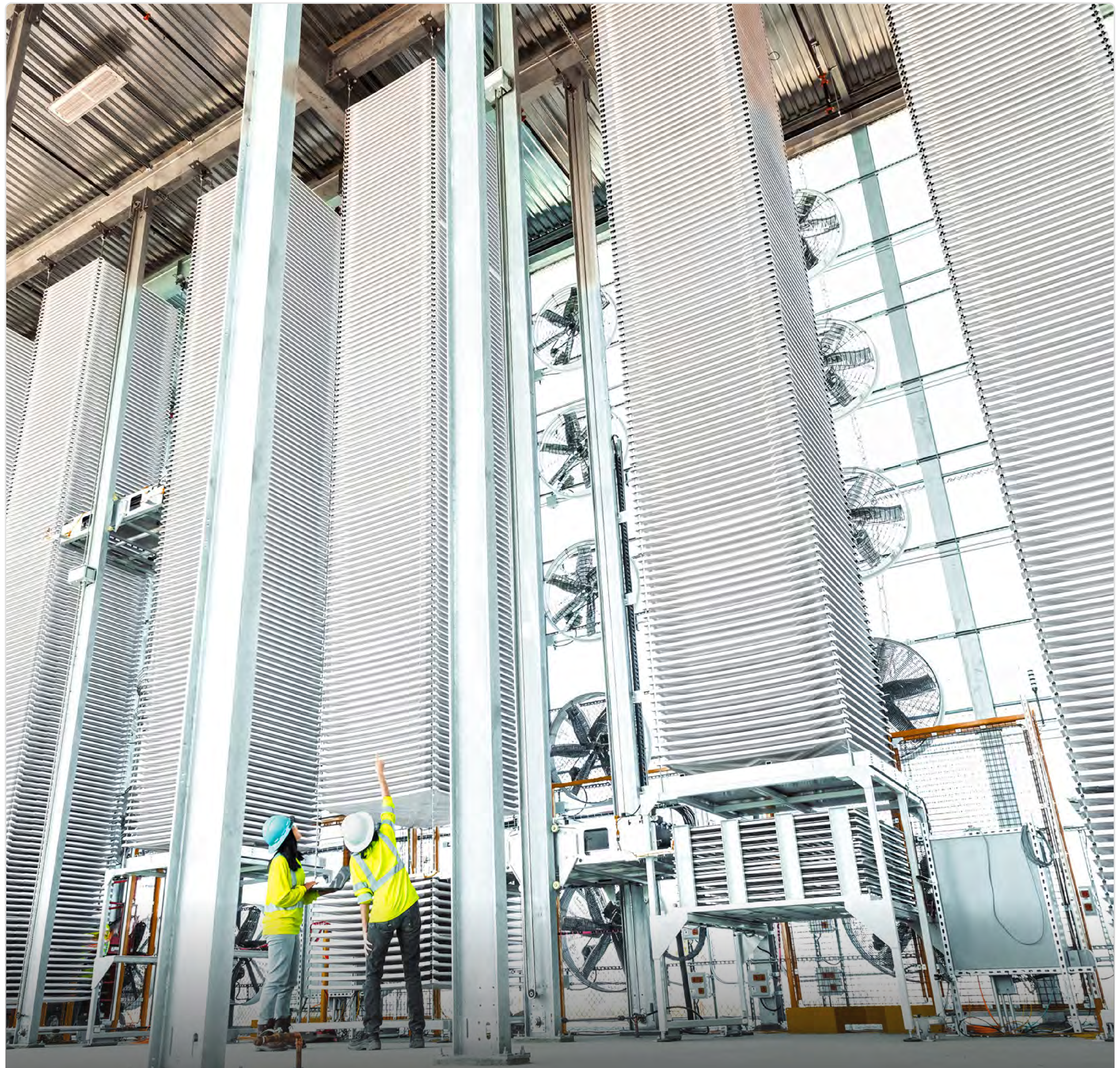
Scalability

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 are consistent with 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.
- Successfully construct and operate prototypes that can achieve at least 1,000 hours of continuous stable operation at nameplate capacity to enable validation of LCA and TEA models, for first-of-a-kind DAC technology. Show a scaleup plan that moves from lab/bench applications to pilot to commercial sizing, which builds confidence in DAC feasibility and efficacy at scale.
- Ensure vendors and subcontractors provide performance, schedule, and cost data for key DAC technologies.
- Develop and implement a risk mitigation plan for scale up and deployment technology risks (e.g., technical and commercial readiness, project management structure, and supply chain bottlenecks).
- Articulate project development aspects across a holistic technical, environmental, economical, commercial, organizational, and political (TEECOP) spectrum, providing clear and transparent plans showing the linkages of requirements and the actions planned to achieve each critical aspect.



Source: Heirloom Carbon Technologies

Glossary of technical terms for **direct air capture**

45Q: Section of the United States Tax Code outlining tax incentives for qualifying projects that capture and store or beneficially reuse CO_2.

Carbon (CO_2) utilization: The beneficial reuse of captured CO_2 as a feedstock or component in another process. Examples include CO_2-enhanced oil recovery, conversion of CO_2 into short-lived chemicals (e.g., transportation fuel, urea), or long-lived chemicals (e.g., concrete, certain polymers).

Class VI well permit: Specialized permit granted by the United States EPA (or state-level equivalent) to inject CO_2 into the subsurface for the purpose of durable storage. The permit regulates several components of the CO_2 storage process, including site characterization, well construction, and post-injection site care.

Cradle-to-grave life cycle assessment (LCA): LCA with a broad system boundary that includes all emissions from energy and material sourcing and consumption, waste treatment, construction and decommissioning, compression, transportation, and storage or reuse.

European Union CCS Directive: An established regulatory framework for the safe and responsible development and operation of CO_2 storage in the European Union.

Sorbent: Generic term for solid CO_2 capture media, typically composed of a specialized chemical coated onto a supporting material with a high surface area. CO_2 is captured through the process of adsorption to the sorbent surface, either via chemical reaction (chemisorption) or physical interaction (physisorption).

Solvent: Generic term for a liquid capture media, typically a basic (low pH) chemical dissolved into solution. CO_2 is captured through the process of absorption, where it diffuses from the gas phase into the liquid solvent in contactors and binds with the chemical absorbent in solution.

Conclusion

Thank you for engaging with Microsoft and Carbon Direct to advance development of high-quality CDR. Our collaboration builds on 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, governments (e.g., local, regional, national, and multinational) 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 carbon removal. 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.

Our goal is to contribute to rapid and just climate change mitigation. 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 this vital journey.

Acknowledgement

This fifth 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. Our contributors specialized knowledge and commitment 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.