Carbon Direct · Microsoft

2023 EDITION

Criteria for High-Quality Carbon Dioxide Removal

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Introduction

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

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

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 is committed to be carbon negative by 2030. This means that Microsoft will cut annual GHG emissions by more than half and remove all remaining annual emissions. By 2050, Microsoft also commits to remove the equivalent of all cumulative GHGs emitted since Microsoft was founded. In January 2021, Microsoft announced its first portfolio of 1.3 million metric tons of CDR. In March 2022, Microsoft announced an additional 1.5 million metric tons added to its CDR portfolio.

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Over the past three years, Microsoft and Carbon Direct observed a critical challenge in the emerging CDR industry: while there are many CDR projects on the market, few meet our criteria for high quality. A major contributing factor to this challenge is that CDR project developers and purchasers lack a common framework for determining what constitutes a best-in-class project. Microsoft elaborated on the need for a common framework in the January 2021 whitepaper, noting the need for clear carbon accounting standards and the development of rigorous guidelines for additionality, durability, and leakage. Microsoft updated these findings in the March 2022 whitepaper, where we discuss the lack of common standards, high prices, and insufficient supply of high-quality CDR credits.

Recent policy announcements also highlight the pressing need for evidence-based CDR criteria to guide action by both public- and private-sector actors. In the US, government entities — including the Securities and Exchange Commission and the Federal Acquisition Regulatory Council — have proposed new rules on climate risk disclosure. The Inflation Reduction Act and the Infrastructure Investment and Jobs Act provide new funding for CDR project development. And globally, as of May 2023, 62 countries have submitted long-term strategies to the UN Framework Convention on Climate Change (UNFCCC), many of which include nature-based and engineered CDR in CO_2 emissions reduction strategies. Together, these developments underscore the urgency for just, scientifically grounded CDR principles that ensure effective climate action across sectors and borders.

To help rapidly scale high-quality CDR, we developed the inaugural Criteria for High-Quality Carbon Dioxide Removal in 2021. This 2023 update is intended to achieve two key objectives:

01 **First, the updated criteria should support and guide submissions to Microsoft for CDR procurement.**

02 **Second, and more broadly, the updated criteria should help advance a common definition of high-quality CDR by providing widely applicable quality benchmarks. We hope to catalyze CDR market maturation that facilitates just, effective climate action at scale.**

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

The science of CDR is evolving, and these criteria will progress with this evolution. The 2023 edition provides updates across the essential principles as well as each of the CDR methods, including new criteria for enhanced rock weathering (ERW). This document also aims to center guidance on how to incorporate the tenets of environmental justice into CDR projects, with an emphasis on procedural equity[1] and the equitable distribution of harms and benefits. In subsequent iterations, we expect to develop additional guidance for nascent CDR pathways, potentially including macroalgae cultivation, peatland and freshwater wetland restoration, carbon dioxide utilization, and ocean alkalinity enhancement. We look forward to collaboratively refining this guidance over the coming years.

[1]As defined by the IPCC, procedural equity is “equity in the process of decision-making, including recognition and inclusiveness in participation, equal representation, bargaining power, voice and equitable access to knowledge and resources to participate.”

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 we distinguish between principles 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.

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

Harms and benefits

Minimizing harms involves avoiding negative impacts on economic, social, and environmental systems that result from CDR projects. Because concerns vary by CDR pathway and context, the harms that follow are not exhaustive, but are intended to describe some of the common negative impacts across all CDR pathways.

Beyond avoiding harm, projects can maximize benefits to local communities and ecosystems by advancing environmental justice (see below), building climate resilience, supporting alternative livelihoods, and protecting ecosystems and biodiversity.

PROJECT DEVELOPERS MUST

- Show that projects have a low risk of community health impacts and provide a strategy for mitigating any such health risks.
- Assess the likelihood and severity of project activities negatively impacting surrounding ecosystems (including but not limited to soil health, biodiversity, and water resources) and provide a mitigation strategy.
- Assess the likelihood and severity of project activities negatively impacting local communities (including but not limited to increased risk of wildfire, food insecurity, energy unaffordability) and provide a mitigation strategy.
- Prevent community displacement.
- Transparently report any use of toxic and/or persistent environmental pollutants, including agrochemicals.
- Avoid using pesticides banned in the United States or European Union.

Environmental justice

Environmental justice involves equitable distribution of environmental benefits and harms resulting from CDR project development, implementation, and ongoing MRV. Environmentally-just CDR projects empower local communities by facilitating meaningful participation throughout the CDR project lifecycle. Inclusive, accessible, and authentic community engagement includes centering perspectives from vulnerable or marginalized community members. This collaboration and/or shared project leadership starts by acknowledging past and present harms to communities of color, low-income communities, and other vulnerable communities affected by intersecting climate and racial injustice crises.

PROJECT DEVELOPERS MUST

- Show how they directly, transparently, and periodically engage with local communities throughout the project lifetime.
- Inform local communities through 'outreach' as defined by the ATSDR community engagement continuum for evaluating procedural equity.
- Explicitly describe worker compensation in project proposals and commit to pay a living wage at minimum.
- Ensure local communities that may have a stake in project lands, including Indigenous groups, are actively engaged and represented in project processes throughout the project lifetime.

PROJECT DEVELOPERS SHOULD

- Actively involve community members during project development, implementation, and subsequent monitoring (see the ATSDR community engagement continuum as a reference for evaluating procedural equity).
- Clearly articulate how the project will benefit underserved and marginalized populations, generate wealth and economic empowerment, and/or foster community involvement across the lifetime of the project.
- Ensure project benefits accrue to members of the local community, especially vulnerable and marginalized populations, and communicate these benefits to community members.
- Prioritize community needs and priorities when designing and implementing CDR projects.
- Delineate the percentage of project revenues or profits paid to community members and other local partners, the form of these payments (for example, cash payments, in kind payments, or funding for community services), and the timing of these payments.
- Avoid developing or disturbing land designated as culturally sensitive or ecologically important by community members or local stakeholders.
- Make public carbon reduction targets and clean energy transition commitments.

Additionality and baselines

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

PROJECT DEVELOPERS MUST

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

PROJECT DEVELOPERS SHOULD

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

Carbon accounting & Monitoring, reporting and verification (MRV)

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

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

PROJECT DEVELOPERS MUST

- Develop a credible MRV plan prior to the start of the project.
- Adapt the MRV plan throughout the project by incorporating the best available science and evolving industry practices.
- Use peer-reviewed and scientifically supported carbon accounting methods to quantify the net volume of removals claimed, and disclose the specific methods used.
- Where an LCA is provided, use a cradle-to-grave LCA and specify the use of either attributional or consequential LCA.
- Incorporate uncertainty conservatively to avoid overstating the estimated CDR from a project.
- Separately quantify removed, reduced, and avoided emissions, including delineating by greenhouse gas type.
- If applicable, use models that are calibrated and validated for the specific conditions in which the project will operate.
- If applicable, specify model assumptions that cannot be calibrated or revised due to practice constraints. Developers should periodically review MRV measurements and other scientific advancements to revise all other assumptions.

PROJECT DEVELOPERS SHOULD

- Use regionally appropriate sampling and data collection methods to quantify emissions and removals associated with a project instead of solely model-based or statistical methods.
- Ensure that the project’s MRV plan is certified or endorsed by a third party (e.g., via a registry).

- Obtain third-party verification of calculated net removal volumes (e.g., via a registry).
- Directly measure carbon removed and stored throughout the duration of the project to the maximum practical extent possible. Store this data in a shared repository or facilitate data access to advance CDR MRV and accelerate market development.

Durability

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

PROJECT DEVELOPERS MUST

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

PROJECT DEVELOPERS SHOULD

- Site projects in areas with low risk of reversal and implement ongoing risk mitigation measures to minimize the impact of future reversal events, including future risks associated with climate change.

- Ensure that agreements 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, which:
  - Reflect a scientifically substantiated, conservative risk of reversal, including possible increases in risks associated with climate change.
  - Dictate that intentional reversals must be entirely remediated, even exceeding all buffer pool contributions from the project.
  - Retire a project's buffer pool credit contributions at the end of the project's life.

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 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 leakage caused by the project or conclusively demonstrate the project avoids any leakage.

PROJECT DEVELOPERS SHOULD

- Diminish leakage risk in project design.

NATURE-BASED

Forestation & Agroforestry

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

Given the large amount of degraded land globally, forestation and agroforestry offer substantial opportunities to remove carbon from the atmosphere while simultaneously providing essential co-benefits to communities and nature. Given the complex and place-based social, ecological, and economic dynamics of land use, developers should site projects where socially or environmentally appropriate. The following principles for forestation and agroforestry projects build upon those described previously under Essential principles for high-quality carbon dioxide removal.

Harms and benefits

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

PROJECT DEVELOPERS MUST

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

PROJECT DEVELOPERS SHOULD

- Prioritize biodiversity and resilience by growing diverse native species, pursuing ecological restoration or natural regeneration of formerly forested areas where possible, and choosing species and seedling sources which maximize biodiversity and are capable of flourishing under future local climatic conditions.
- Prioritize local seed stock collection methods that do not harm natural forests or reduce production of non-timber forest products and utilizes local infrastructure and seed supply chains (per Kew's 10 Golden Rules for Reforestation).
- Expand the volume of seeds available to ensure adequate supply for pre-existing demand as well as accommodate increased demand from new CDR project activity.
- Consider the impacts on biodiversity (both benefits and costs) when selecting species for forestation.

Environmental justice

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

PROJECT DEVELOPERS MUST

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

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.
- Where displacement of existing activities occurs, even activities that may be deemed destructive or illicit, ensure alternative livelihoods substitute for the displaced activities.
- Actively promote long-term sustainable livelihoods and economic opportunities for local communities (e.g., support local workforce development programs and initiatives).

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

- Determine the natural regeneration baseline using the best available science to predict natural seedling establishment and forest growth in the absence of tree planting.
- Avoid damaging, destroying, or harvesting pre-project trees during site preparation.
- Ensure pre-project trees are excluded from crediting and monitored through the crediting period.
- Demonstrate that forestation or agroforestry activities are a result of carbon finance or could not occur otherwise (for projects with non-carbon finance streams, such as from expected timber sales or conservation funds).

PROJECT DEVELOPERS SHOULD

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

Carbon accounting and MRV

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

PROJECT DEVELOPERS MUST

- Justify the models and assumptions used to quantify carbon accumulation in the above-ground biomass, below-ground biomass and (when the pool is included) organic soil pools.
- 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 statistically valid sampling methods and best-available models (for example, species-specific and region-specific allometric equations) for quantifying above-ground carbon.
- Use data from in-situ sampling or conservative root:shoot ratios (that is, use smaller ratios to mitigate uncertainty) to quantify changes in below-ground carbon, where this pool is included.
- Measure and monitor changes in soil carbon when claiming removals in soils, using the criteria for high-quality soil carbon.

PROJECT DEVELOPERS SHOULD

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

Durability

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

PROJECT DEVELOPERS MUST

- Take active and ongoing measures to mitigate identified risks (e.g., forest thinning in fire-prone areas).

PROJECT DEVELOPERS SHOULD

- Use the best available information to forecast future risks of disturbance to planted forests and situate projects in areas of lower risk. Salient disturbance risks include, but are not limited to, direct and indirect impacts of climate change, drought, fire, insects, disease, financial insolvency of the project operator, land theft, timber theft, and social disturbances.
- Use resilient plant material with appropriate genetic variability and provenance.
- Where appropriate, select species adapted to future climate conditions and apply planting patterns that foster resistance to disturbance.
- 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 beekeeping, sustainable wood production, and ecotourism to ensure that forests are protected and maintained over time.
- Leverage early-warning systems to detect and respond to reversals, particularly wildfire.

Leakage

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

PROJECT DEVELOPERS MUST

- Provide robust and conservative estimates of leakage rates and justify the methods used to quantify the leakage rate.
- Ensure proper accounting for leakage deductions. This includes quantifying leakage when project activities displace any existing economic activities, and these existing economic activities shift outside the project boundaries.
- When claiming low leakage rates, provide evidence that project lands are degraded, have low economic value, or that project activities do not significantly displace existing land uses. Evidence must show that either:
    - There has been minimal agriculture land cover over the preceding decade, the project is not sited in an area of active land cover change, and that the lands are predicted to have low likelihood of future use for agriculture.
    - Tree planting is integrated into ongoing agricultural practices using sustainable agroforestry systems.

PROJECT DEVELOPERS SHOULD

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

Other considerations

PROJECT DEVELOPERS MUST

- Work with experienced local partners to select project locations, species, and planting approaches.
- Pilot restoration in small plots before scaling when restoration is first-of-its kind locally.
- Develop planting and monitoring plans to maximize the probability of tree survival during the critical three- to five-year establishment phase, including physical infrastructure and human capacity considerations.
- Use cost-effective forestation techniques such as applied nucleation, direct seeding, or assisted natural regeneration.
- Work to abide by Kew Gardens' 10 Golden Rules for Reforestation.

NATURE-BASED

Mangrove forestation

Mangrove forestation, including reforestation and afforestation, involves growing trees to establish mangrove forests. Carbon-dense mangrove forests exist along the intertidal zones of most tropical and subtropical coastlines. Many of these mangrove forests are threatened and have experienced historically high rates of deforestation. The unique ecology of mangroves warrants different guidance from the forestation and agroforestry guidelines provided above.

The carbon held in mangrove forests is commonly referred to as coastal blue carbon, which also refers to carbon held in tidal marshes, seagrasses, and other coastal ecosystems. Mangroves also generate substantial co-benefits for people and nature, such as storm surge protection and fish nursery support. Given the complex and place-based social, ecological, and economic dynamics of land use, developers should only site projects where socially and environmentally appropriate. The following principles for mangrove forestation build upon those described previously under Essential principles for high-quality carbon dioxide removal.

Harms and benefits

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

PROJECT DEVELOPERS MUST

- Avoid the destruction of non-vegetated coastal ecosystems, such as natural tidal mudflats, which are important and threatened ecosystem types across the globe.
- Avoid damaging, destroying, or harvesting any pre-project mangroves during site preparation activities.

- Prioritize mangrove restoration in areas that protect communities from storm surge, prevent coastal erosion, and support fish nursery habitat.
- 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.

Environmental justice

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

PROJECT DEVELOPERS MUST

- Articulate the land tenure of the enrolled project areas, including community management status.
- Avoid project development on land with unclear or insecure land tenure to reduce risk. Mangroves commonly exist on public land with customary tenure, raising the risk of tenure disputes and disenfranchisement of local communities.
- Respect local or traditional approaches to land ownership and management.

PROJECT DEVELOPERS SHOULD

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

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

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

PROJECT DEVELOPERS SHOULD

- Demonstrate that mangrove forestation activities are a result of carbon finance or could not occur otherwise (for projects with non-carbon finance streams, such as from expected timber sales or conservation funds).
- Establish control plots to directly measure natural regeneration over the course of the project.
- Use historical time series of remotely sensed data when claiming a negligible natural regeneration baseline to show that natural recovery of mangrove forest is very unlikely to occur.
- Quantify baseline GHG fluxes and any GHG fluxes associated with site preparation or other changes in management strategy.

Carbon accounting and MRV

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

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

PROJECT DEVELOPERS SHOULD

- Compare and justify expected carbon accumulation numbers against benchmark figures, such as standing carbon stocks in proximal mature mangrove stands, global maps of mangrove carbon, or meta-analyses of carbon accumulation in planted mangroves from scientific literature.
- Employ validated and regionally calibrated methods and/or use ground inventories to validate remotely sensed measurements of above-ground biomass changes.
- Use site-specific data and/or collect data needed to parametrize models used to estimate biomass changes (such as species-specific allometries and wood density measurements).

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

Durability

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

PROJECT DEVELOPERS MUST

- Plant mangroves in appropriate locations where they are likely to persist and flourish.
- Integrate projections of sea level rise when choosing sites for forestation.
- Implement active and ongoing measures (i.e., adaptive management plans) to mitigate identified risks to the durability of carbon held in mangrove forests (e.g., direct and indirect impacts from sea level rise, storm surge, or watershed management).
- Determine the hydrological status of the site and address any impacts to site hydrology that might prevent successful mangrove forestation.
- Identify and mitigate human drivers of mangrove loss throughout the project life.

PROJECT DEVELOPERS MUST

- Identify potential policy conflicts for long-term management of forests due to unclear demarcations of intertidal zones and overlapping jurisdictions of national or local governments (e.g., Ministry of Marine Resources and Ministry of Forests).
- When initiating projects that involve harvesting, incorporate harvested biomass into long-lived wood products, either traditional (such as lumber or polewood) or emerging (such as biochar).

- Plant species adapted to future climate conditions and apply planting patterns that foster resistance to disturbance, including plans to mitigate "coastal squeeze," i.e., the phenomenon by which mangroves cannot migrate landwards with sea level rise due to impermeable surfaces such as paved urban areas.

Leakage

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

PROJECT DEVELOPERS MUST

- Provide robust and conservative estimates of leakage rates and defend the methods used to determine the reported rate.
- Ensure leakage deductions are taken and properly accounted for. Leakage should be accounted for when project activities displace any existing economic activities that could be shifted outside the project boundaries and result in higher emissions.
- When claiming low leakage rates, provide evidence that project lands have low economic value, or that project activities do not significantly displace existing land uses. They must demonstrate this by showing that there has been minimal past agriculture or aquaculture use over the preceding decade, they are not operating in an area of active land use change, and that the lands are predicted to have low likelihood of future agriculture or aquaculture land use.

PROJECT DEVELOPERS SHOULD

- Use remotely sensed land use data to determine leakage estimates, especially when coupled with models of land-use change.

Other considerations

PROJECT DEVELOPERS SHOULD

- Develop seedling planting and monitoring plans to maximize the probability of tree survival during the critical three- to five-year establishment phase, including physical infrastructure and human capacity considerations.
- Use cost-effective and equitable forestation techniques such as Community-Based Ecological Mangrove Restoration, or the engagement of local communities in removing barriers to natural regeneration such that mangrove forests naturally return.
- Consider the impacts on biodiversity (both benefits and costs) when selecting species for mangrove forestation.
- Appropriately match species to positions in the intertidal zone and avoid planting solely generalist mangrove species (e.g., Rhizophora species).

NATURE-BASED

Improved Forest Management (IFM)

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

Harms and benefits

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

PROJECT DEVELOPERS MUST

- Transparently report any use of toxic and/or persistent environmental pollutants, including agrochemicals used for suppression of non-crop plants.
- Ensure that the project minimizes major risks to the health and safety of workers, especially risks present in forest management operations.

PROJECT DEVELOPERS SHOULD

- Implement forestry practices that are regionally appropriate and designed to foster habitat for indicator species and encourage biodiversity broadly.
- Prioritize IFM projects that support local and regional industry, livelihoods, and long-term sustainable forestry.

Environmental justice

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

PROJECT DEVELOPERS MUST

- Ensure that when projects occur on public lands or communally owned or lands with customary tenure, and carbon rights are transferred to a third party, the benefits of the project are shared among members of the community by actively including land stakeholders in planning, execution, and operation.

PROJECT DEVELOPERS SHOULD

- Avoid increasing natural disturbance hazards that may directly or indirectly impact local communities.

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

- Reflect initial carbon stocks and trends in carbon stocks over at least the past decade or reflect typical management on similar parcels in the region.

- Are informed by previous forest management practices, as documented in previously written management plans. In the absence of these plans, developers must provide evidence that the baseline is realistic for the owner and property in question.
- 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.
- Are project-specific, rather than relying on regional forest carbon stock averages.

PROJECT DEVELOPERS MUST

- 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).

Carbon accounting and MRV

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

PROJECT DEVELOPERS MUST USE THE BEST AVAILABLE TOOLS TO MEASURE AND VERIFY CHANGES IN CARBON STORAGE, INCLUDING:

- Statistically representative field inventories and/or remote sensing.
- Allometry based on published regional- and species-specific data.
- Reporting carbon pools with increased storage only where data and measurements can be well substantiated (for example, ignoring increases in soil carbon when uncertainty is high).
- Reporting all carbon pools with decreased storage resulting from project activities.

WHEN USING SENSED DATA, PROJECT DEVELOPERS SHOULD

- Validate measurements with field inventories.

Durability

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

PROJECT DEVELOPERS SHOULD MAXIMIZE THE DURABILITY OF CARBON STORAGE BY:

- Improving forest health and reducing disturbance hazards (such as wildfire, insects, drought) on project lands, including decreasing the risk of disturbance-induced mortality associated with historical management practices such as fire suppression and adverse species selection.
- Designing projects that are on land with a lower natural reversal risk.
- Incorporating 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).
- Including forward-looking projections of climate risk when accounting for reversal risks.

Leakage

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

PROJECT DEVELOPERS MUST

- For projects that reduce timber harvesting, use conservative leakage assumptions, and robustly defend these estimates, accounting for domestic and international leakage.
- Establish contractual agreements that prevent activity leakage.

PROJECT DEVELOPERS MUST

- Deduct market leakage at the same time as when increased stocks are credited, even if existing offset protocols do not require this standard.
- Design projects that minimize leakage risks by avoiding large reductions in harvested wood products relative to the baseline.

- Ensure that leakage risks are properly quantified. Leakage risks are likely highest:
  - In regions where mills are running at capacity due to high demand in wood product markets and timber supply is responsive to price changes.
  - In regions where large amounts of non-participating lands can produce similar timber products.
  - Where the wood products that would otherwise be produced on the project lands are highly substitutable.

Other considerations

Project types

PROJECT DEVELOPERS SHOULD

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

NATURE-BASED

Soil Carbon

Soil carbon CDR involves adoption of new conservation and/or regenerative agricultural management practices that increase the amount of carbon stored in soil. These practice changes can stem the substantial global loss of soil carbon2 and associated GHG emissions resulting from the inception of human agriculture.

Agriculture both contributes to GHG emissions and is especially vulnerable to the impacts of climate change. Soil carbon projects can minimize these adverse climate change impacts by improving long-term sustainability and increasing the climate resilience of agricultural operations. The following principles for rigorous and credible soil carbon projects build upon those described previously under Essential principles for high-quality carbon dioxide removal.

Harms and benefits

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

PROJECT DEVELOPERS MUST

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

PROJECT DEVELOPERS SHOULD

- Account for farmers' needs to adapt to future climate conditions in the development of management plans and contracts.

Environmental justice

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

PROJECT DEVELOPERS MUST

- Equitably distribute benefits resulting from improved soil health to all project participants, including both landowners and operators.
- Compensate workers with living wages and protect the health and welfare of farm laborers.
- Avoid developing, disturbing, or restricting access to land that has been identified as culturally sensitive or ecologically important by community stakeholders.

PROJECT DEVELOPERS SHOULD

- Design projects to accommodate participants who both own and lease land. This should include provisions to ensure that lessees do not inadvertently experience adverse financial effects by improving soil health through regenerative practices (i.e., higher rent for more desirable land).
- Actively promote long-term sustainable livelihoods and economic opportunities for local communities.
- Specify what percentage of project revenues or profits are paid to farmers.
- Make every effort to identify how the project labor will be distributed and compensated as well as disclose that information in the project description, considering that farming and ranching operations often rely on migrant labor.

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

- Document baseline emissions from business-as-usual management using control plots to measure a baseline or at least three years of historical management and soil carbon data to document baseline trends and inform modeled baselines.
- Demonstrate that the new practice is not already a standard management practice across the farm or ranch.

PROJECT DEVELOPERS SHOULD

- Use region-specific and agricultural system-specific baselines to quantify the change in soil carbon resulting from new management practice adoption.
- Ensure that practices aimed at increasing soil carbon content account for any increases in other greenhouse gas emissions.

Carbon accounting and MRV

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

PROJECT DEVELOPERS MUST

- Account for project removals net of any material emissions increase, including increased fertilizer applications.
- Document sampling stratification by practice, soil type, crop, and other relevant environmental factors.
- Describe the analytical and calculation methods used to assess soil carbon change, including the mass/depth basis and any correction applied.
- Conduct project-specific soil sampling at project outset and at least once every five years to validate modeled estimates of soil organic carbon levels; soil sampling must be viewed as a necessary complement to modeling.
- Take soil cores to a sufficient depth to represent the impact of the implemented practice (e.g., cover crops at a minimum of 30 cm depth below the organic layer, 1 m or soil depth for some types of tillage change).

- Calculate carbon content using an equivalent soil mass basis.
- Use models that have been developed and published in peer-reviewed literature for a specific soil/climate/management context.
- Follow best practices to create confidence in model results, including appropriate methods for model calibration and validation with region- and practice-appropriate independent datasets and comprehensive assessment of model prediction uncertainty. Document model procedures and validation data sources.
- Account for both sampling error and model prediction uncertainty prior to issuing credits.

PROJECT DEVELOPERS SHOULD

- Take soil cores as deep as possible, ideally to one meter.
- Use best laboratory analysis practices to measure carbon, such as dry combustion in a carbon and nitrogen (CN) analyzer.
  - Project developers may use novel technological approaches in addition to proven methods for proof of concept; however, these methods should not replace soil sample collection and analysis.
- Provide comprehensive documentation of all soil carbon quantification methods that have been reviewed by a qualified third party.
- Share soil and management data to build a more robust global dataset. Farmer data could be aggregated and anonymized to respect privacy.

Durability

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

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.

- Account for verification methods and contracting mechanisms for ensuring new practices are implemented and maintained when determining durability.
- Demonstrate robust strategies for ensuring carbon remains sequestered, even in instances of ownership changes or extreme weather events.

Leakage

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

PROJECT DEVELOPERS MUST

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

Other considerations

Scalability

PROJECT DEVELOPERS SHOULD BE AWARE THAT

- While the on-farm implementation of management practices that sequester carbon in soils is well understood, the precise impact on soil carbon stocks is dependent on site-specific considerations such as soil type, crop, and climate.
- Soil carbon scalability depends on producer behavioral change.

HYBRID

Enhanced Rock Weathering (ERW) in Croplands

Enhanced rock weathering (ERW) in croplands involves spreading crushed silicate rocks onto agricultural fields. As these silicates dissolve, they catalyze the conversion of CO_2 into bicarbonate. This dissolved inorganic carbon drains through waterways to the ocean, a durable carbon sink. Given the large volume of silicate rock and agricultural land, ERW as a carbon removal method could rapidly scale. However, many silicates contain heavy metals and contaminants that can accumulate at high concentrations in plant matter. Further, the end oceanic bicarbonate sink cannot be tracked or verified empirically. Instead ERW MRV relies on complex models to estimate CDR.

To help minimize ERW quality concerns, developers should develop quality assurance and control plans for mineral applications, clearly report empirical sampling plans in agricultural fields, and document model initialization, calibration, validation, and uncertainty estimation. The following principles for ERW build upon those described previously under Essential principles for high-quality carbon dioxide removal.

Harms and benefits

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

PROJECT DEVELOPERS MUST

- Document and measure the impacts of silicate application on waterways.
- Quantify the risk of asbestos exposure in the mineral amendment.

- Document and define safety protocols required for silicate application and the impacts on local air quality.
- Mitigate risks associated with heavy metals by clearly documenting ongoing quality assurance and quality control processes for sampling and analyzing silicate materials, soils, and plant matter grown on fields where silicate material has been applied.
- Quantify heavy metal concentrations in mineral amendments through elemental analysis.
- Use elemental analysis results as inputs to model the expected heavy metal dissolution and accumulation in the environment.

PROJECT DEVELOPERS SHOULD

- Document the impacts of silicate application on yield, soil chemistry (organic carbon, mineral nutrients) and agrochemical applications (lime, mineral fertilizer).
- 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).

Environmental justice

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

PROJECT DEVELOPERS MUST

- Avoid contaminating drinking water supplies.
- Specify any project revenues that accrue to the farmers and communities.
- Use best practices to minimize adverse impacts to local air or water quality.
- Notify local stakeholders if adverse local ecological impacts are expected following application (e.g., air quality impacts from mineral application).
- Avoid developing, disturbing, or restricting access to land that has been identified as culturally sensitive or ecologically important by community stakeholders.

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

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

PROJECT DEVELOPERS SHOULD

- Justify expectations of zero baseline emissions, including accounting for mineral and waste handling waste requirements, initial carbonate mineral content, and ambient carbonation.
- Use control plots to measure the baseline weathering rate on agricultural land.

Carbon accounting and MRV

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

PROJECT DEVELOPERS MUST

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

- Follow best practices for model use to create confidence in model results, including the use of appropriate methods for model calibration and validation with appropriate independent datasets for the variable of interest (carbon drawdown).
  - These practices have not yet been well defined for ERW. We suggest that project developers use soil carbon protocols, which share many of the same proxy measurement and modeling issues, as a reference for developing appropriate sampling plans and modeling approaches.
- Document model initialization assumptions and how model uncertainty will be incorporated into conservative carbon removal estimates.
- Estimate losses of carbon back to the atmosphere during transport from the soil column via river networks to the ocean and estimate ultimate carbon storage efficiency.
- Provide a particle size distribution and morphology profile for any material applied to the soil.
- Use direct measurements of multiple variables to ground-truth models wherever possible.

PROJECT DEVELOPERS SHOULD

- Use the best available measurement methods to evaluate changes in soil health following silicate application.

Durability

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

PROJECT DEVELOPERS MUST

- Define the timeline of 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 monitoring, reporting, and verification plans).

Leakage

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

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 renewable energy supply chain.
- Identify alternative uses of mineral waste and demonstrate best use in terms of greenhouse gas impact.
- Evaluate and quantify the impact of the project on land use when project infrastructure requires undisturbed or high-value land.

ENGINEERED

Carbon Mineralization

Carbon mineralization transforms atmospheric CO_2 into minerals during a naturally occurring reaction. The products of mineralization are carbonate minerals, the most durable method of storing carbon. Carbon mineralization binds carbon in rock in both underground (in-situ) and aboveground (ex-situ) sites. In-situ mineralization injects CO_2 underground into rock formations capable of forming durable carbonate minerals.

Ex-situ mineralization uses aboveground reactors or industrial processes to produce carbonate minerals. This mineralized carbon can be incorporated into building products such as concrete. 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 Essential principles for high-quality carbon dioxide removal. For agricultural applications, please refer to the criteria for enhanced rock weathering (ERW) in croplands.

Harms and benefits

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

PROJECT DEVELOPERS MUST

- Minimize risk of adverse impacts on ecosystems and communities (e.g., changes in water quality, land use, and pollutant use).

Environmental justice

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

PROJECT DEVELOPERS MUST

- Engage with local communities in an ongoing and transparent manner throughout the project lifetime. In cases where the project leverages existing industrial operations, clearly describe how engagement processes are expanded to include the CDR project.

PROJECT DEVELOPERS SHOULD

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

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

- Include mass balance of carbon in all states (solid, liquid, and agas), metals that contribute to mineral carbonate formation, and alkalinity imported or exported from the project boundaries when quantifying project baselines and changes in mineralization rates.
- Account for the rate of natural mineralization when calculating the project baseline.
- Quantify the carbonate mineral content in feedstocks.

PROJECT DEVELOPERS SHOULD

- Select feedstocks with low carbonate mineral concentrations to reduce uncertainty in carbon accounting.

- Monitor feedstock carbonate mineral content throughout the project duration.
- Develop control plots to measure natural rates of mineralization before, during, and after project deployment when relevant.

Carbon accounting and MRV

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

PROJECT DEVELOPERS MUST

- Use best available measurement methods with built-in redundancy to directly measure carbon contents and fluxes.
- Use a cradle-to-grave LCA and specify the use of attributional or consequential LCA. The LCA must conservatively quantify all GHG emissions associated with the full suite of inputs and products from the project.
- Use a cradle-to-grave LCA and specify the use of attributional or consequential LCA. The LCA must conservatively quantify all GHG emissions associated with the full suite of inputs and products from the project.
- Evaluate and monitor, where appropriate, the impact of the project on other GHG pathways (such as methanogenesis, N-cycle).
- Supplement and calibrate modeling with direct physical and/or chemical evidence of mineralization.

PROJECT DEVELOPERS SHOULD

- Identify all carbon reservoirs and monitor carbon movement between reservoirs with appropriate tools (e.g., tracer, isotopic studies).
- Use cost and life cycle assessments that clearly identify and differentiate continuously produced and stockpiled industrial feedstocks.
- Include cross verification with redundancy (e.g., cross referencing gas / liquid / solid phase fluxes and mass balances).
- Identify the source of metals (such as calcium, magnesium) contributing to mineral formation, and include in MRV the carbon impact of the metal source.

Durability

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

PROJECT DEVELOPERS MUST

- Consider reversal risks for both solid- and liquid-bound carbon and include these risks in MRV plans.
- Develop release scenarios that reflect anticipated impacts of climate change and changes in land use or water reservoir development when relevant.

Leakage

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

PROJECT DEVELOPERS MUST

- Identify alternative uses of waste and demonstrate best use in minimizing environmental and climate impacts.
- Evaluate and quantify the impact of the project on land use, especially when project infrastructure encroaches on high-value land use.

Other considerations

Infrastructure

PROJECT DEVELOPERS SHOULD BE AWARE THAT

- Project infrastructure needs will depend on existing operations. Some ex-situ projects may be greenfield developments, requiring new roads, ports, or facilities. Some in-situ projects may require substantial infrastructure to capture or compress air or CO_2.

Scalability

PROJECT DEVELOPERS SHOULD

- Consider the size and distance to market or area of application for projects in the built environment.
- Account for changes in mineralization reaction rates over time due to consumption of highly reactive material and passivation of feedstock.
- Consider feedstock supply and/or subsurface reservoir capacity and injectivity when planning large-scale mineralization projects.

HYBRID

Biomass-based pathways

Biomass-based pathways for CDR involve a range of processes that convert CO_2 sequestered through photosynthesis into durable forms of carbon storage. Prominent pathways include biochar, wood harvesting and storage, and geologic sequestration of biogenic CO_2 (e.g., BECCS).

These biomass carbon removal and storage (BiCRS) technologies can result in sizable and highly durable CDR. Some pathways may also generate a co-product such as electricity or hydrogen. The feedstock for biomass-based CDR can be grown directly for CDR projects or can be a byproduct of other uses (such as forest or agricultural residues). The following principles for biomass-based CDR build upon those described previously under Essential principles for high-quality carbon dioxide removal.

Harms and benefits

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

PROJECT DEVELOPERS MUST

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

Environmental justice

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

PROJECT DEVELOPERS MUST

- Prevent community displacement when selecting facility location.

PROJECT DEVELOPERS SHOULD

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

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

- Identify the current use, if any, or other fate of biomass resources intended for the project.
- Identify the most likely counterfactual for biomass resources in question over the length of the project (see Biomass sustainability section below).
- Explain the economic additionality of the project with or without the requested investment and/or CDR procurement, and the role of tax, regulation, or policy incentives (for example, in the United States 45Q, Clean Fuel Standards, and the Inflation Reduction Act) in that viability.

Carbon accounting and MRV

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

PROJECT DEVELOPERS MUST

- Ensure that CDR claims are consistent with a net carbon negative outcome based on a cradle-to-grave life cycle assessment (LCA), including biomass feedstock, process emissions, and product transportation.
- For waste feedstocks, provide detailed accounting and justification of counterfactuals.
- Implement guidance for MRV listed under Process-specific considerations (below).

PROJECT DEVELOPERS SHOULD

- Conduct both attributional and consequential life cycle assessments.
- Adjust carbon accounting to reflect trends in forest carbon stocks over time in the project feedstock sourcing woodshed where forest biomass is used.
- Clearly outline allocation methods for co-products, including a sensitivity analysis on allocation assumptions and different scenarios employed.

Durability

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

PROJECT DEVELOPERS MUST

- Create storage sites that are as permanent as possible using established permitting processes (e.g., Class Ia, Class II, or Class VI for deep injection wells in the United States) or alternatively meet ISO 27914:2017 standard for CO_2 storage.

PROJECT DEVELOPERS MUST

- Quantify and report expected changes in the amount of carbon sequestered over time, e.g., through decay or leakage.
- Base durability projections on empirical measurements, rather than models, whenever possible.

Leakage

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

PROJECT DEVELOPERS MUST

- Quantify the likely carbon emissions that result from project consumption or displacement of local and regional energy supplies (e.g., parasitic load for capture and compression of CO_2.)

PROJECT DEVELOPERS SHOULD

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

Process-specific considerations

Biochar project developers

- Must verify that biochar is not used for combustion applications or other applications that would lead to rapid release of CO_2 to the atmosphere.
- Must provide biochar elemental analysis (C, H, O) to substantiate storage durability and account for biochar recalcitrance and carbon loss over a 100-year time frame based on best available models.
- Must provide a cradle-to-grave LCA to quantify net-negativity of biochar (e.g., European Biochar Certificate C-Sink with CarbonFuture, Puro) and make appropriate deductions to calculate net CDR.
- Must ensure that biochar is tested to minimize environmental harms (e.g., adhere to guidelines from the International Biochar Initiative or European Biochar Certificate).

- Must prove that the production of biochar results from affirmative practices, or the deliberate modification of an existing facility to produce biochar, for the purposes of additionality.
- Should measure biochar decay rates after application and share this data to improve decay models, including decay rates for recalcitrant and labile fractions.

Wood harvesting and storage developers

- Must bury only coarse woody material until sufficient scientific consensus is reached on decay rates of fine woody biomass in abiotic conditions.
- Must bury wood in a burial chamber surrounded by a layer of low permeability material.
- Must provide a cradle-to-grave LCA that includes all relevant portions of the supply chain, including disturbed topsoil and transport of biomass feedstock.
- Must use in-situ sensors, gas sampling of CH4, sample excavations, and/or site maintenance for MRV.
- Should create conditions that achieve an anoxic environment, inhibiting biological degradation.
- Should minimize the risk of disturbance by biotic agents like termites and deep-rooted plants.

Developers who rely on geologic storage of CO_2 (e.g., BECCS) must follow guidance set forth for durability of direct air capture (DAC) in this document.

Other considerations

Biomass sustainability

PROJECT DEVELOPERS MUST

- Avoid sourcing biomass from primary forests and areas with high conservation value.
- Utilize biomass from sources with operational integrity and oversight through strong governance, management standards, and supply chain transparency (e.g., through certified forest management).
- Source forest biomass only from regions with stable or increasing forest carbon stocks, unless carbon accounting transparently and conservatively incorporates decreases in those stocks.
- Source biomass that does not distort markets for agriculture or forestry products (e.g., avoid biomass from roundwood that would otherwise be used for long-lived wood products).

PROJECT DEVELOPERS SHOULD

- Propose projects that have a minimum Technology Readiness Level (TRL) of 7, corresponding to a "system prototype demonstrated in a plant environment," as defined by the National Academies, 2019. Specifically, technology should have:
  - Demonstration of an actual system prototype in a relevant environment.
  - Final design virtually complete.
  - Demonstration-scale prototype, defined as 5–25 percent of final scale or design, or a 50-250 t/d dry biomass plant.
  - Undergone large pilot-scale testing using dry biomass feedstock at a scale equivalent to approximately 50-250 t/d (excluding projects that have demonstrated full-scale mobile/modular processing units).
- Describe key business model risks, including the structure and stability of subsidies, and technical risks, including a reasonable plan to mitigate those risks.

ENGINEERED

Direct Air Capture

Direct air capture (DAC) projects involve mechanical and chemical systems that remove and concentrate CO_2 from ambient air. This CO_2 is then used as a feedstock or returned to a long-term carbon sink. DAC projects typically do not require rare or critical materials and could be sited in many geographies (including near CO_2 storage resources and low-cost or stranded low-carbon energy assets).

Net-negative DAC projects rely on large amounts of low-carbon energy, both heat and electricity, which may limit deployment speed and scale. The following principles for DAC build upon those detailed previously under Essential principles for high-quality carbon dioxide removal.

Harms and benefits

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

PROJECT DEVELOPERS MUST

- Assess potential impacts from sorbent or solvent slip downwind of the facility, even if compliant with general health and safety guidelines and all applicable local/regional regulations.
- Articulate a strategy to measure and mitigate any material impacts to air, water, and land quality, including emissions due to solvent or sorbent slip and discharge into local air, water, and land.

PROJECT DEVELOPERS SHOULD

- Minimize need for new inputs (e.g., energy, construction materials, sorbents/solvents) by applying best practices in reuse and circularity.
- Monitor and improve material and process efficiency.

Environmental justice

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

PROJECT DEVELOPERS MUST

- Avoid development or disturbance of land that has been identified as culturally sensitive or ecologically important by community stakeholders. This includes land used directly for DAC facilities, land used for renewable energy installations to power DAC facilities, and land used for CO_2 transport or geological storage.
- Prevent community displacement by ensuring that any new or expanded pipelines, roads, wells, or other infrastructure do not inequitably impact historically disadvantaged or marginalized communities.
- Evaluate and mitigate any adverse impacts from increased water consumption. These may include increased water prices and/or decreased local water quality, including discharges from capture facilities and sorbent/solvent manufacturing facilities.

PROJECT DEVELOPERS SHOULD

- Pay a living wage and actively promote long-term economic opportunities for local communities by providing training programs that develop a pipeline of skilled local workers skilled at DAC management and operation.
- Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

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

- 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 (for example in the United States 45Q, or in some EU countries state auctions for carbon removals).
- Quantify baseline GHG fluxes and expected GHG fluxes from energy consumption, site preparation, carbon storage/utilization, decommissioning and end-of-life.

Carbon accounting and MRV

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

PROJECT DEVELOPERS MUST

- Account for all sources of emissions through the entire project lifecycle, such as direct and indirect land-use change, concrete and steel production and construction, procurement of capture media and chemicals, disposal of waste products, and energy use during DAC operations.
- For a project using fossil-fuel energy sources, include full lifecycle impacts encompassing both upstream leakage and downstream usage in their carbon accounting considerations (regardless of whether co-capture is involved in the process).
- Include full lifecycle impacts of the electricity powering operations, including grid-related emissions from grid-connected power purchase and use.
- Present a valid and viable MRV plan that adheres to key regulatory requirements (for example, Class VI well permits) for either subsurface storage or carbon utilization products.
- Demonstrate displacement of high carbon-intensity products or processes for DAC projects coupled to CO_2 utilization.

PROJECT DEVELOPERS MUST

- Design a project that emits less than 0.3 tonnes of CO_2e per tonne CO_2 removed.
- Use energy with low associated emissions.
- If applicable, clearly demonstrate new, low-carbon electricity generation was added to the grid (or grid balancing-area) that serves the project. If the project proposes to purchase electricity from the grid, it should provide a copy of its power purchase agreement including the electricity emissions factor and provide the latest emissions factor for the local Transmission System Operator.
- Ensure measurements include emissions throughout the entire value chain of a project (from upstream to operational emissions) across all types of greenhouse gases, including fugitive emissions from compression, transport, and storage of CO_2.

Durability

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

PROJECT DEVELOPERS MUST DEMONSTRATE

- Sufficient CO_2 storage capacity for the entire project lifetime identified and developed as part of the project; or sufficient physical CO_2 offtake identified and contracted with credible third-party providers.
- Sufficient injectivity at storage site, including well count.
- Low CO_2 release risk as estimated by the methodologies outlined in the WRI's guidelines for CO_2 capture, transport and Storage, Section 4.3.1.2
- An MRV plan, consistent with best practices for the chosen storage location, to detect unplanned physical leakage or reversals.

Leakage

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

PROJECT DEVELOPERS MUST

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

Other considerations

Materials

PROJECT DEVELOPERS MUST

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

PROJECT DEVELOPERS SHOULD

- Use earth-abundant inputs, such as magnesium, calcium, silicates, sodium hydroxide, or other such inputs appropriate for a given process.
- For solvent-based systems, produce, transport, store, and manage solvent and solvent degradation products with low risk to operators, neighboring communities, and the environment.
- For sorbent-based systems, demonstrate the ability to synthesize sorbent at 1 metric ton per year scale or at a scale consistent with the project timeline, and present a viable strategy for sorbent recycling or disposal.

Infrastructure

PROJECT DEVELOPERS SHOULD

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

Scalability

PROJECT DEVELOPERS MUST

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

PROJECT DEVELOPERS MUST

- For first of a kind DAC technology, successfully construct and operate prototypes that build confidence in DAC feasibility and efficacy at scale.
- Ensure vendors and subcontractors provide performance, schedule, and cost data for key DAC technologies.

Conclusion

Thank you for engaging with Microsoft and Carbon Direct on high-quality carbon dioxide removal (CDR). Our collaboration builds upon the previous years' work, incorporating the latest research findings and industry insights. This iteration of the guidance reflects these advancements, while also setting the stage for future improvements. We are committed to regularly updating and refining these recommendations to ensure that we can provide the most relevant and actionable information for a rapidly evolving industry.

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

To foster the growth of the CDR market and facilitate the development of high-quality projects, we call upon the support of financial institutions, project developers, and the wider CDR community. It is through increased investment, collaboration, and community engagement that we can collectively build a strong foundation for the future of 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.

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

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