COMPARISON OF BIOCHAR CARBON MARKET PROTOCOLS

Environmental Defense Fund

COMPARISON OF BIOCHAR CARBON MARKET PROTOCOLS

Authors

Anna M. Raffeld

Jocelyn M. Lavallee

Doria R. Gordon

Emily E. Oldfield

Acknowledgments

This report was supported through gifts to Environmental Defense Fund from King Philanthropies and Arcadia, a charitable fund of Lisbet Rausing and Peter Baldwin. We thank the following individuals who took the time to provide feedback and clarification on our interpretation of their protocols: Kranav Sharma and Stefan Jirka (Verra); Jon Remucal and Marissa Spence (Climate Action Reserve); Nick Lembo and Emma Marsland (Isometric); Marianne Tikkanen (Puro.earth); and Patrizia Pschera and Dominic Hafner (Carbon Standards International).

How to cite this report

A.M. Raffeld, J.M. Lavallee, D.R. Gordon, E.E. Oldfield. 2025. Comparison of Biochar Carbon Market Protocols. Environmental Defense Fund, New York, New York. [INSERT LINK]

Environmental Defense Fund

Environmental Defense Fund is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

Cover photo: Photo by Sophia Wojkowski, USDA Agricultural Research Service.

Totally chlorine free 100% post-consumer recycled paper

The complete report is available online at https://edf.org/comparison-biochar-carbon-market-protocols.

CONTENTS

EXECUTIVE SUMMARY

Biochar, a carbon-rich, highly stable form of charred organic material, has received increasing attention as a carbon removal and reduction solution over the past several years. As a result, new carbon market protocols for biochar have been published and an increasing number of biochar carbon credits have emerged in the carbon market. While biochar may offer climate mitigation benefits, ensuring the credibility of biochar carbon credits requires rigorous, transparent and consistent accounting. Current biochar protocols generally follow similar accounting steps and principles (e.g., cradle to grave emissions, durability estimates derived from the H:Corg ratio), yet they differ in the level of clarity and detail provided at each step of the accounting process, as well as on key protocol elements such as leakage, uncertainty, permanence and additionality.

These inconsistencies can undermine transparency and make it difficult to assess and compare the climate benefits of biochar projects. Clear and consistent accounting for key risks—including double counting, uncertainty and error—is essential for generating high-quality credits and fostering trust in the voluntary carbon market.

Key Challenges and Areas for Improvement:

- **Uncertainty Accounting:** Uncertainty must be better accounted for within biochar protocols. Methods to account for uncertainty, such as Monte Carlo simulations or a sensitivity analysis, could be used given that biochar protocols closely resemble Life Cycle Analyses (LCAs). Protocols could also incorporate the concept of an uncertainty deduction, which is used in other carbon crediting approaches (e.g., soil carbon protocols). Better uncertainty accounting is especially critical as biochar production scales.
- **Double Counting Risks:** Biochar's use in soil poses elevated risks for double counting if applied to land already enrolled in a soil carbon program. A centralized registry, in addition to rigorous tracking, can minimize double counting.
- **Permanence:** Biochar is highly durable, and this durability can be estimated through different models. Some protocols are moving away from

the most conservative type of permanence model. Given that credits are used to offset greenhouse gas (GHG) emissions, modelling permanence more conservatively is advisable. More research is needed to better understand biochar permanence over several centuries and under end uses beyond soil.

- **Competing feedstock uses:** Biochar feedstocks (the material used to create the biochar) may have competing uses that also have a climate mitigation impact (e.g., bioenergy) or serve an important function (e.g., residue amendments that add organic matter and nutrients to soil). More research is needed to help determine when and where biochar is the best use of feedstock from a climate mitigation perspective. Understanding this dynamic is important for establishing the baseline and determining additionality. Furthermore, diverting a feedstock from a competing use may cause GHG emissions leakage, yet protocols have different ways of accounting for these potential emissions.
- **Consistency:** Enhancing consistency and transparency across protocols will not only improve credit integrity but would also help scale adoption in ways that are equitable, science-based and climate-effective.

Although biochar offers longer term carbon stability, potential co-benefits for on-farm GHG mitigation (e.g., reductions in soil N_2O emissions) are not yet recognized in current crediting systems due to scientific uncertainty. Ongoing research will be critical to understanding and refining the scope of quantifiable benefits.

In addition to these scientific uncertainties, the viability of the current biochar voluntary carbon market (VCM) hinges on existing demand for biochar among farmers and other end users, since the biochar must be incorporated into an approved end use for a credit to materialize. Despite broad interest in the use of biochar for climate mitigation among buyers of carbon credits, demand and awareness among end users is low. This is a challenge faced by the industry and the VCM that may constrain the scalability of biochar production.

INTRODUCTION

The urgency of the climate crisis and concern regarding the longevity of certain types of climate mitigation interventions has prompted increased interest in more permanent GHG mitigation approaches, such as biochar. As a result, biochar carbon market activity has greatly expanded over the last few years, with the creation of new standards, protocols and marketplaces that aim to promote biochar's use as a carbon reduction and removal strategy.

This report reviews five existing biochar carbon market standards, which provide guidelines for the measurement, monitoring, reporting and verification (MMRV) of biochar projects. While there are similarities in the ways in which the different protocols assess biochar's climate benefit, there are also a few key ways in which they differ. Here, we focus on identifying and resolving those differences to achieve better and more consistent biochar carbon accounting.

WHAT IS BIOCHAR?

Biochar is a carbon-rich, highly stable form of charred biomass or other organic material that has been combusted in the partial or total absence of oxygen (pyrolysis). Biochar creation is considered both a carbon removal and a reduction technology (Lehmann et al., 2021). Biochar decomposes and releases CO_2 much more slowly than its parent material, or feedstock, potentially lasting centuries rather than months or years. As such, biochar's main climate benefit is attributable to the biochar itself (due to its longevity) rather than through its end use. This benefit is typically an emissions reduction, but is sometimes discussed as a carbon removal when the feedstock is biomass specifically grown to create biochar; in other words, it is a removal when CO_2 is removed from the atmosphere via photosynthesis for the purpose of biochar creation (Pirard, 2024). Note that protocols recognize biochar's climate impact as both a carbon removal and an emissions reduction.

When used as a soil amendment, biochar may reduce N_2O emissions from soil and slow decomposition of existing soil carbon, termed "negative priming" (Borchard et al., 2019; Ding et al., 2018). Biochar may also reduce enteric methane emissions when used as a livestock feed additive (Winders et al., 2019). Existing protocols currently only account for the climate benefit of biochar creation, since accounting for potential on-farm benefits, like negative priming, is too uncertain for inclusion. Therefore, credits generated under current biochar protocols are typically awarded to the biochar producer rather than its end user.

The organic carbon content of the biochar is the basis of the carbon removal calculation in all protocols. Biochar's carbon content is primarily a function of feedstock type and pyrolysis temperature (Woolf et al., 2021). Feedstocks with high lignin (for example, woody biomass and sugarcane) tend to produce biochars with higher carbon content (Rodrigues et al., 2023). High production temperatures also tend to lead to higher carbon content (Tomczyk et al., 2020).

The longevity and stability of the carbon in biochar is often discussed as biochar "permanence." The most commonly used proxy for permanence is the biochar's hydrogen to organic carbon molar ratio (H:Corg) (Anand et al., 2023). Importantly, the H:Corg ratio can be used to predict the amount of carbon remaining in the biochar after a certain number of years (Budai et al., 2013; Rodrigues et al., 2023; Woolf et al., 2021). The smaller the ratio, the more stable and long-lasting the biochar. Production temperature is an important determinant of H:Corg; higher production temperatures typically lead to smaller H:Corg ratios. Biochar products that have an H:Corg ratio greater than 0.7 are technically not considered biochar or stable enough to be credited (Budai et al., 2013). As such, the H:Corg ratio must be measured or approximated to determine whether the biochar is eligible for crediting under a protocol.

Biochar is most commonly used as a soil amendment but can also be incorporated into building materials or used for wastewater treatment, among other applications. All protocols permit a variety of end uses. While the H:Corg is an important proxy for biochar carbon stability, the end use can also impact the rate at which the biochar decays. As a result, the end use is typically accounted for in some way in the carbon removal calculation of the protocol. However, despite biochar's wide range of uses, most research has focused on soil application and there is a paucity of information on how other end uses affect durability.

THE BIOCHAR PROTOCOLS

Climate Action Reserve U.S. and Canada Biochar Protocol, v1.0

The CAR Biochar Protocol, published March 2024, is intended for the voluntary carbon market (VCM) and applicable only in the U.S. and Canada (CAR U.S. and Canada Biochar Protocol, Version 1.0, 2024). It provides guidelines to quantify and register GHG reductions and carbon removals with the Climate Action Reserve (CAR). As of June 2025, there are three biochar projects listed under CAR's U.S. and Canada Biochar Protocol.

Verra VM0044 Methodology for Biochar Utilization in Soil and Non-Soil Applications, V1.1

VM0044 is a global VCM biochar methodology developed by Verra (VM0044 Methodology for Biochar Utilization in Soil and Non-Soil Applications, Version 1.1, 2023). The methodology was first published in August 2022 and last updated in July 2023. Verra is currently revising this methodology, which is expected to be released by the end of 2025. This methodology falls under Verra's "waste handling and disposal" sectoral scope and the mitigation outcome is considered a removal, as opposed to a reduction. VM0044 is used by biochar projects listed through Verra's registry. As of June 2025, there were 10 projects in India, Indonesia, Belize, Vietnam and Switzerland, with a status of "verification approval requested," "under validation," "under development," "registration requested" or "registered." Verra's first project was officially registered in India in 2024.[1]

Puro.earth Biochar Methodology for CO2 Removal (Draft, Edition 2025 v.0.9)

The Puro.earth Biochar Methodology is a global VCM methodology that recently underwent major revisions. The revised methodology was officially made available to the public in early July 2025, but a draft version of the new methodology released in April 2025 is reviewed in this document (Puro.Earth Biochar Methodology for CO_2 Removal, Draft for Public Consultation, Edition 2025 V.0.9, 2025)[2]. The Puro.earth Biochar Methodology is developed and administered by Puro.earth which is a carbon crediting program that acts as a registry exclusively for carbon removals. As of June 2025, Puro.earth had over 50 active projects listed in its registry. These projects span a number of geographies, including the U.S., Europe, Australia, Asia and Africa.

Global Biochar C-Sink Standard, Version 3.1[3]

The Global Biochar C-Sink Standard is a global VCM protocol developed by the Ithaka Institute and administered by Carbon Standards International, most recently updated in October 2024 (Global Biochar C-Sink Standard, Version 3.1, 2024). According to Carbon Standards International, there are currently 82 projects registered under the Global Biochar C-Sink Standard.[4] All biochar certified under the Global Biochar C-Sink Standard is registered under the Global C-Sink Registry, which is owned and run by the non-profit Global Carbon Register Foundation.[5] This protocol, which is focused on requirements for carbon accounting, follows guidelines from the European Biochar Certificate (EBC) or World Biochar Certificate (WBC) Guidelines for biochar production, which include topics like biochar laboratory procedures, testing, sampling, and health and safety protocols.[6] Only biochar that fulfills the requirements of the EBC or WBC Guidelines can be credited under the Global Biochar C-Sink Standard. The EBC/WBC Guidelines are also referenced in other protocols.

Isometric Biochar Production and Storage Protocol, V1.1

The Isometric Biochar Production and Storage Protocol is a global VCM protocol published in October 2024 and most recently updated in April 2025 (*Isometric Biochar Production and Storage Protocol, Version 1.1*, 2025). It was developed by Isometric, which is a carbon registry and carbon market protocol developer. As of June 2025, Isometric had two biochar projects under validation (no credits issued yet), with a durability of 1000+ years in India and 200+ years in the U.S.

[1] https://verra.org/verra-registers-first-biochar-project/

[2] Draft version for public consultation of the revised methodology: https://7518557.fs1.hubspotusercontent-na1.net/hubfs/7518557/Biochar%20Public%20Consultation%202025/01_Puro%20Biochar%20Methodology%20-%20Edition%202025%20-%20Draft%20for%20consultation.pdf. Note that draft version has some differences from the final version. The differences between the two documents are identified here.

[3] Carbon Standards International has also published a Global Artisan C-Sink Standard, which is specifically for artisan biochar production. An artisan biochar producer is defined as a producer that prepares and controls the biomass feedstock and produces biochar manually in a Kon-Tiki-type kiln. For the purposes of this review, we focused on the Global Biochar C-Sink Standard.

[4] https://www.carbon-standards.com/en/standards/service-501~global-biochar-c-sink.html

[5] https://global-c-registry.org/

[6] https://www.european-biochar.org/media/doc/2/version_en_10_4.pdf

BIOCHAR LIFE CYCLE

Biochar carbon market protocols typically resemble life cycle analyses of the biochar product, accounting for emissions from cradle (feedstock sourcing) to grave (end use) (see Figure 1). Put simply, the tons of CO_2e stored in the biochar are calculated based on its organic carbon content, which is usually measured directly on a representative sample in a laboratory. Where access to lab technology is limited, the carbon content is often estimated based on values from the scientific literature (see Section 4.1). Emissions produced during feedstock pre-treatment and sourcing, biochar production, processing and post-processing are then subtracted to arrive at the net GHG removal estimate for the biochar. Project establishment emissions, which occur prior to any project operations (even feedstock sourcing), may also be included in the biochar life cycle. Currently, Isometric's Biochar and Production Protocol and Puro.earth's Methodology account for activities associated with project establishment, such as emissions from construction and installation, equipment and materials manufacturing, surveys and feasibility studies, and more. Sometimes, energy co-products are created during the pyrolysis process that can be used for purposes outside of biochar production. Emissions associated with these co-products are typically not counted as emissions attributed to biochar production (this is termed proportional allocation, see *Section 4. Biochar Production*). Ultimately, carbon removal credits are awarded to the project proponent/developer, which is typically the biochar producer.[7] The net climate impact of the biochar is always assessed in relation to what would have happened to the feedstock had it not been made into biochar (e.g., the baseline, or business-as-usual scenario). Quantification of emissions at each stage of the life cycle, as well as challenges and uncertainties associated with emissions quantification, are delineated in the following sections.

[7] While the entity that receives credits is most commonly the biochar producer, this is not always the case. For example, under CAR, the "project developer" is the entity that submits a project and is responsible for all reporting and verification. The biochar producer is the default project developer because their actions transform carbon into a more long-lasting state and they have direct influence over the end use of the biochar. However, the project developer can be another entity involved in the project (e.g., the end user) as long as there is a documented agreement that conveys ownership of the carbon credits between the biochar producer and the other entity.

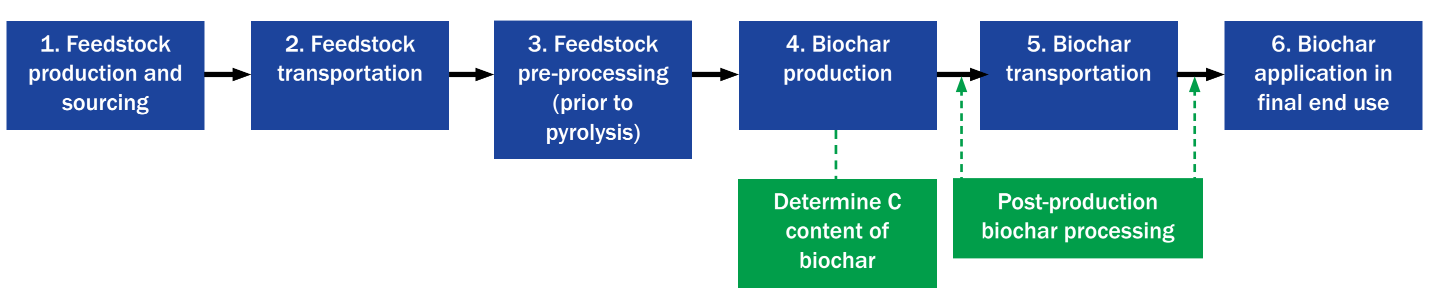
FIGURE 1.

Biochar Life Cycle

Project establishment emissions are not included in the figure as only the Isometric protocol accounts for them. However, it is worth noting that these emissions can contribute to biochar's carbon footprint, depending on how the GHG boundary is defined in a project. The biochar "carbon sink" is realized once the biochar is in its end use. The baseline is shown as a separate, parallel scenario to biochar production since it is what would have happened to the feedstock in the absence of biochar production.

Baseline Scenario: What would have happened in the absence of biochar production
The feedback would have been left to decay or would have been combusted for purposes other than energy production; zero emissions or removals/reductions assumed. This assumption is considered conservative, since decomposition and combustion cause emissions.

Biochar Production Scenario



A "carbon sink" is created
The biochar has been created and is used in soil or other approved end use. While the creation of the biochar is technically the point at which carbon has been sequestered and made more stable, the "carbon sink" is not officially recognized as such until the biochar is in its end use. The project developer (often the bichar producer) can now receive credits.

BIOCHAR EMISSIONS ACCOUNTING OVERVIEW

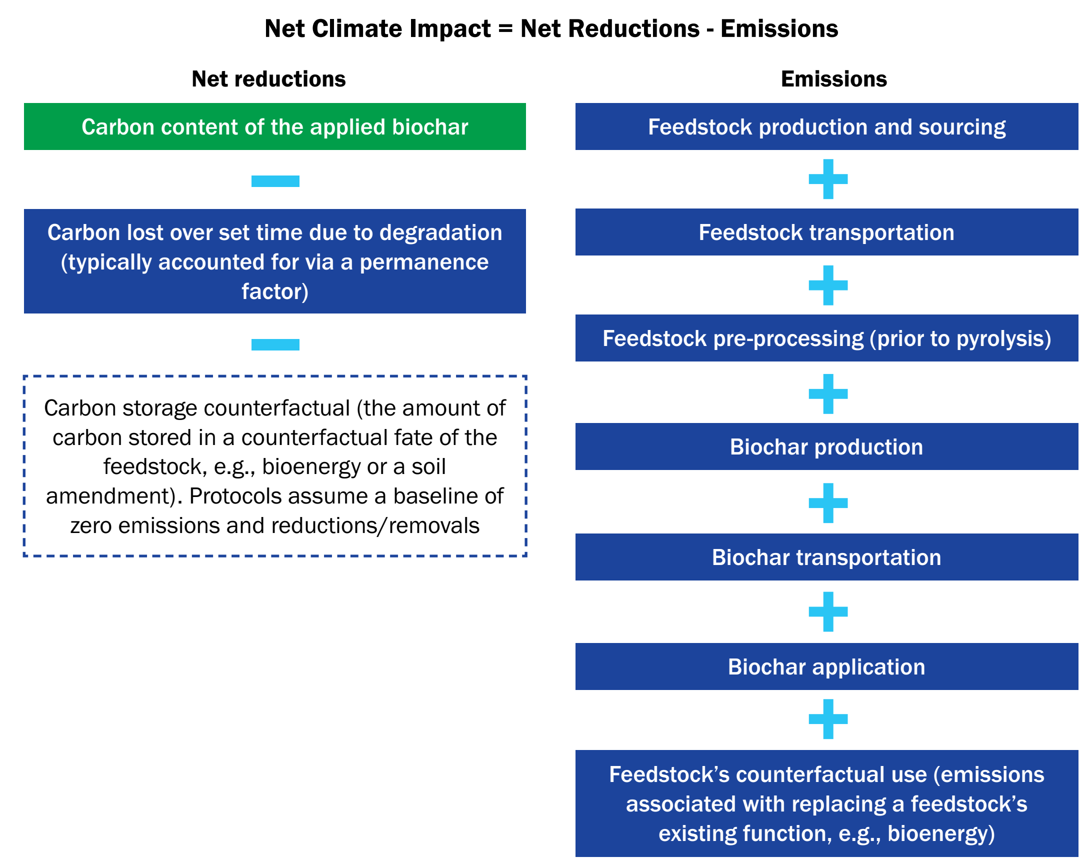
Figure 2 summarizes how each of the steps in Figure 1, which are described in further detail in subsequent sections, come together to determine biochar's net climate impact. Figure 2 is based on CarbonPlan's Biochar CDR Verification Framework.[8]

The biochar's carbon content is the carbon sequestered in the biochar without considering any other emissions, counterfactual scenarios and biochar degradation over time. In order to estimate the net carbon drawdown of the biochar, carbon lost from the biochar due to degradation must be subtracted from the carbon content. If the feedstock's counterfactual scenario would have resulted in carbon storage, this carbon should theoretically be accounted for and subtracted since it represents carbon that is not additional. However, protocols assume a baseline of zero emissions (and carbon

[8] CarbonPlan's Biochar CDR Verification Framework: https://carbonplan.org/research/cdr-verification/biochar

FIGURE 2.

Estimating biochar's net climate impact



storage), meaning that the potential carbon storage in the counterfactual is not explicitly accounted for.

Once drawdown is determined, any emissions that are part of the life cycle must be subtracted, including any emissions associated with replacing a feedstock's existing function (for example, emissions from increased fossil fuel use caused by diverting biomass from bioenergy generation).

0. Establishing a baseline

All carbon removal quantification begins by establishing an emissions baseline, which serves as the counterfactual or "business-as-usual" scenario. The baseline is defined as any emissions and/or reductions/removals that would have occurred in the absence of the biochar project. All protocols assessed in this report assume a baseline of zero emissions. This is often described by the protocols as a conservative assumption since there would likely be emissions associated with the fate of the feedstock in the absence of the project activity—e.g., wood residue that would have been left to decay or combust, releasing CO_2.

However, this assumption may not always be conservative if it fails to account for other potential feedstock fates that would have had emissions benefits. Feedstocks could be used to lower emissions in ways other than biochar production or provide benefits that, when removed, result in increased emissions. For example, feedstocks could be used to generate bioenergy in areas with high dependence on fossil energy, potentially providing a greater climate benefit than biochar production (Woolf et al., 2010). Accounting for the feedstock's counterfactual use is crucial to fully understanding biochar's climate impact. While this is still an emerging area of research, several studies indicate that using feedstocks for bioenergy production may have a greater climate benefit than biochar production in areas that are highly dependent on fossil fuels and have higher soil fertility, assuming the biochar is applied to soil (Ericsson et al., 2017; Lefebvre et al., 2021; Woolf et al., 2010).[9]

One way to ensure that a baseline of zero is a truly conservative assumption is to require project developers to 1) identify any alternative feedstock uses; 2) if there are alternative uses, determine whether the feedstock is supply limited in the relevant geography such that its use for biochar would divert it from other uses; and 3) if it is supply-limited, prohibit the feedstock's use in the biochar project. Several protocols currently follow a similar process to ensure a zero baseline. VM0044 requires project developers to show evidence that the type of biomass was not used for alternative purposes in the five years preceding the project start date. If the feedstock source cannot be identified, then developers must demonstrate that there is "an abundant, unutilized surplus of the same or similar type of biomass in the project region." Similarly, CAR's Biochar Protocol requires that the project developer characterize the typical fate of the feedstock to prove that the feedstock did not have an alternative, "productive" use and that the feedstock is not supply-limited. The Isometric protocol includes feedstock criteria to avoid situations in which the biomass could have been used for bioenergy production. For example, non-forestry feedstock must not have been grown for the purpose of energy production and project proponents must demonstrate that less than 50% of the total harvested biomass is allocated for energy production. These steps can help prevent potential competition of feedstocks among different uses.

1. Feedstock production and sourcing

The type of feedstock used to create the biochar will determine how emissions are quantified at the production and sourcing stage. Feedstocks can be placed into two general categories: purpose-grown feedstocks (biomass feedstocks grown for biochar production, e.g., miscanthus) and waste feedstocks—examples include crop residue, food and forestry waste products, and animal waste. Protocols typically include a list of feedstocks that are acceptable for biochar creation. Across all protocols, if feedstocks are classified as waste products, no emissions are assumed during the production and sourcing stage. Among protocols that permit purpose-grown feedstocks, emissions quantification is required for the sourcing and production of these feedstocks (see Table 1). Emissions at this stage may come from fertilizer and

[9] Areas with high soil fertility may not benefit from biochar's enhancement of soil productivity as much as areas with low soil fertility. When biochar is applied to areas of low soil fertility, CO_2 removal by photosynthesis is enhanced, resulting in a greater mitigation benefit.

TABLE 1.

Assumptions and/or data required by each protocol for emissions quantification during feedstock production and sourcing

Protocol	Purpose-Grown Feedstock[10]				Waste Feedstock
	Fertilizer use	Pesticide use	Equipment use	Direct land use change	
CAR Biochar Protocol	Captured with a standardized emissions factor based on crop type.	Not explicitly addressed	Captured with a standardized emissions factor based on crop type.	Not applicable. Biomass must be grown on marginal land or a reclaimed mining site and grown under conditions where there is little to no ecosystem carbon loss.[11]	No emissions assumed, however, feedstock must have been otherwise left to decay or combusted for purposes other than energy production.
Global Biochar C-Sink [12]	Captured with the following conversion: 100 kg N = 1 t CO_2e	A flat value of 94 CO_2e kg/ha is applied.	2.7 kg CO_2e per liter diesel	Purpose-grown biomass must not decrease the total carbon stock of the system in which the biomass had been grown (e.g., clear cutting a forest).	No emissions assumed
VM0044	Not applicable. No purpose-grown feedstocks permitted. This protocol's sectoral scope is classified as "waste handling and disposal."	Not applicable	Not applicable	Not applicable	No emissions assumed, however, to qualify for use, feedstocks must have 1) been otherwise left to decay or combusted for purposes other than energy production; 2) not been imported from other countries; and 3) meet certain feedstock-specific sustainability criteria listed in the protocol.[13]
Puro.earth Methodology	Yes, but details on data and calculations not included in the methodology. Calculation templates are delivered to projects after registration with Puro.earth.	Yes, but details on data and calculations not included in the methodology. Calculation templates are delivered to projects after registration with Puro.earth.	Yes, but details on data and calculations not included in the methodology. Calculation templates are delivered to projects after registration with Puro.earth.	Emissions from a change in land cover or management at the cultivation site must be quantified. Often, direct land use changes are given a value of zero, which must be justified adequately with a reference situation.	No emissions assumed
Isometric Biochar Production and Storage Protocol	Not applicable. No purpose-grown feedstocks permitted.	Not applicable	Not applicable	Not applicable	No emissions assumed provided all eligibility criteria related to leakage and counterfactual carbon storage, in the Biomass Feedstock Accounting Module are met.[14]

[10] In addition to quantifying for GHG emissions, purpose-grown feedstocks can have additional requirements to qualify for biochar production. For example, CAR stipulates that purpose grown biomass must be a native species or sterile hybrid if non-native, must not replace existing commodity crops and that harvest activities must involve minimal soil disturbance. Furthermore, biomass cannot be grown on lands that were used to produce commodity crops, underwent a land use change from natural or native vegetation, or were converted from a vegetation type with a higher carbon-density three years prior to biochar feedstock cultivation.

[11] CAR considers Land Capability Classes 5 or 6 to be marginal, as defined by the U.S. Department of Agriculture- Natural Resources Conservation Service and Agriculture and Agri-Food Canada.

[12] The Global Biochar C-Sink also accounts for methane emissions due to feedstock storage. If moist feedstocks are stored for a long time, the feedstock can start to degrade and result in GHG emissions. Drying the feedstock (<20% moisture) can prevent these emissions.

[13] Projects may demonstrate compliance with waste biomass sustainability criterion by following the Roundtable on Sustainable Biomaterials (RSB), International Sustainability and Carbon Certification (ISCC) or other equivalent national/international schemes

[14] Isometric's Biomass Feedstock Accounting Module: https://registry.isometric.com/module/biomass-feedstock-accounting/1.2#introduction

pesticide use, as well as any fossil fuel-powered equipment.

When using crop residue feedstocks, protocols typically require demonstrating that soil carbon has not decreased as a result of residue removals or that no more than a certain percentage of residue is removed from the field. However, ensuring that the soil carbon stock does not decrease would require soil sampling. This can present a practical and logistical challenge for the project developer, as sampling soil to determine soil carbon stocks can be time intensive and costly (however, see Bradford et al., (2023)). Requiring a limit to the amount of residue that can be removed could be a more cost-effective and practical way to ensure that the soil carbon stock is not greatly impacted by residue removal. Several protocols address this issue by requiring removal rate thresholds (see Table 2).

While seemingly minor, it is important to draw a distinction between residue removal rate and percent soil cover. Most research studying the impacts of residue removal on soil quality and properties use removal rates or weight of tissue removed, while management practices and conservation programs track percentage of soil covered by residue (Andrews, 2006; Johnson et al., 2014). Importantly, removal rate and soil cover are not the same, e.g., a 30% removal rate is not the same as 70% soil cover. While they are positively related, the exact relationship varies by residue quality, climate, soil type and management practices (e.g., N fertilization rate) (Andrews, 2006). Since percent soil cover may be easier for farmers to measure, requiring a threshold for percent soil cover, rather than removal rate, could be a more feasible protocol requirement (DeDecker, 2014). If removal rates are given, the corresponding percent soil cover or a resource for conversion should be provided.

2. Feedstock Transportation

Emissions associated with any type of transportation are typically straightforward to quantify. They can be based on fuel records (volume of fuel) and an emissions

TABLE 2.

Approach used by each protocol to minimize soil organic carbon stock declines from residue removal

Protocol	Residue removal approach
CAR Biochar Protocol	Residue removal is limited to no more than 30% of total residues on the field.
Global Biochar C-Sink Standard	Requires that the removal of residues does not decrease soil organic carbon stocks, although an exact amount is not specified.
VM0044	Requires documentation showing that the project is not leading to a decline in soil carbon stocks or reduction in crop productivity, or that in the baseline scenario the residue was burned without energy production. Alternatively, in the absence of documentation, residue removal is limited to no more than 50% of total residues.
Puro.earth Methodology	Harvesting of residues must preserve soil quality and carbon stocks, using methods that leave a significant amount of residues in the soil (e.g., roots left in place, adjusted cutting height). Exact amount not specified. Requires at least one of the following: 1) Primary evidence from the feedstock supplier detailing methods in place to preserve soil quality and carbon stocks and/or 2) Existence and enforcement of local residue harvesting plans, policies, programs, regulations or laws related to soil quality and carbon stocks, which include some level of monitoring.
Isometric Biochar Production and Storage Protocol	Amount of residue left on the field is not specified. However, biomass that would have led to carbon storage in the counterfactual scenario (e.g., residues on fields that would have led to increases in soil organic carbon) may be ineligible for use under this protocol. Recommends, but does not require, sourcing residues for which the rate of harvest does not exceed the sustainable rate of removal.

factor or conversion factor for the fuel type, or records indicating transportation type, mass of material (the feedstock, at this stage), distance travelled and an emission factor for the transportation type if fuel records are not available (see Table 3).

3. Feedstock pre-processing

Biochar feedstocks must typically be processed prior to pyrolysis (see Table 4). Processing can include processes such as chipping and grinding to reduce the feedstock into smaller pieces or drying to ensure low moisture content prior to pyrolysis.

4. Biochar Production

The process of producing biochar, or pyrolysis, can result in three general categories of GHG emissions (see Table 5). Emissions may come from auxiliary fossil fuels or electricity required to run the pyrolysis process and/or methane emissions resulting from pyrolysis. In some cases, the pyrolysis process may produce co-products that can be used as energy sources. Protocols often ensure that emissions are distributed proportionally across all pyrolysis products so that the biochar project is not penalized for emissions that could be attributed to another project. Accounting for these co-products is termed proportional allocation in life cycle analyses.

4.1 Carbon stored in biochar

The organic carbon content of the biochar is the basis for determining its carbon storage potential and is typically determined through laboratory analysis. Multiple samples are taken and composited, and then sent to an accredited (e.g., by the International Standards Organization (ISO)) laboratory. While laboratory analysis is the

TABLE 3.

Information and data required by each protocol for emissions quantification during transportation

Protocol	Approach/method to estimate transportation emissions
CAR Biochar Protocol	Requires either volume of fuel consumed and emissions factor or transportation type, mass of feedstock transported, distance travelled and emissions factor for transportation type.
Global Biochar C-Sink Standard	For consumption of diesel or benzine fuel, requires fuel consumed and a conversion factor of 2.7 CO_2e per kg diesel fuel. Distance travelled must also be tracked.
VM0044	Emissions associated with combustion of fossil fuel are accounted for with the Clean Development Mechanism (CDM) Tool 12 via two different ways: 1) volume of fuel consumed; and 2) default emissions factors for vehicle type (light vs. heavy), distance travelled and mass of feedstock transported.[15] Emissions are considered *de minimis* if the distance between the sourcing site and production facility is <200 km.
Puro.earth Methodology	Biomass transport should include fuel emissions, but also vehicle and road infrastructure emissions. Project developers may use transport distances reported by the transporter and a national or regional average emissions factor from peer-reviewed databases and literature. Calculation templates are delivered to projects after registration with Puro.earth.
Isometric's Biochar Production and Storage Protocol	Two approved methods for calculating transportation emissions are provided in the Transportation Emissions Module.[16] The distance-based method requires the distance traveled and load weight with an associated emissions factor. The energy usage method requires direct measurement of fuel or energy usage and an associated emissions factor. The energy usage method must always be prioritized. Emissions from transportation infrastructure must also be accounted for. Where vehicles and/or infrastructure is not utilized explicitly for the CO_2 removal project, a proportional approach to embodied emissions accounting can be taken.

[15] See https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf. This tool provides guidance on how to calculate emissions from transportation.

[16] Isometric's Transportation Emissions Accounting Module: https://registry.isometric.com/module/transportation/1.0#introduction

TABLE 4.

Information and data required by each protocol for emissions quantification during feedstock pre-processing

Protocol	Approach/method to estimate feedstock pre-processing
CAR Biochar Protocol	Requires total mass or volume of fuel type consumed for feedstock pre-processing and an emissions factor for the fuel type; or total amount of electricity consumed for feedstock processing purposes for the reporting period and an emissions factor for electricity at the feedstock processing location; or total mass of feedstocks and an emissions factor based on the feedstock processing type.
Global Biochar C-Sink Standard	For consumption of diesel or benzine fuel, a conversion factor of 2.7 kg CO_2e per liter diesel fuel is applied. For consumption of electricity, the conversion into CO_2e is based on information provided by the energy provider or the average CO_2e value of the regional electricity mix.
VM0044	Emissions associated with the grid-connected electricity used for pre-treatment, as specified in CDM Tool 05.[17] Emissions associated with combustion of fossil fuels used for pre-treatment, as specified in CDM Tool 03.[18]
Puro.earth Methodology	Accounting is required for pre-processing emissions from processes like drying, chipping, comminution and/or sieving of the biomass, but additional details on data and calculations are not included. Project developers may use a national or regional average emissions factor from peer-reviewed databases and literature. Calculation templates are delivered to projects after registration with Puro.earth.
Isometric's Biochar Production and Storage Protocol	Any embodied, energy and transport emissions associated with feedstock pre-processing must be included, in line with the Energy Use Accounting Module, the Embodied Emissions Accounting Module and the Transportation Emissions Accounting Module.[19, 20, 21] This includes emissions related to the following activities as a minimum: processing equipment, motors, drives and instrumentation; biomass pre-treatment, drying, densification or particle size reduction; equipment such as fork trucks or loaders, feedstock conveyors, augers, feed bins, support structures and facilities; and infrastructure, including steel platforms, framing, supports, concrete footings and building structures.

[17] See https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-05-v3.0.pdf. This tool provides guidance on how to calculate emissions from electricity usage.

[18] See https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-03-v3.pdf. This tool provides guidance on how to calculate emissions from fossil fuel combustion.

[19] Isometric's Energy Use Accounting Module: https://registry.isometric.com/module/energy-use-accounting/

[20] Isometric's Embodied Emissions Accounting Module: https://registry.isometric.com/module/embodied-emissions

[21] Isometric's Transportation Emissions Accounting Module: https://registry.isometric.com/module/transportation

TABLE 5.

Information and/or data required by each protocol for emissions quantification during biochar production

Protocol	Fossil fuel consumption	Electricity consumption	Methane from pyrolysis	Energy co-production during pyrolysis
CAR Biochar Protocol	Requires mass or volume of fuel type consumed for biochar production and an emissions factor for the fuel type.	Requires the total amount of electricity consumed and an emissions factor for the electricity at the processing location.	Requires an emissions factor for the pyrolysis system type, mass of biochar produced, GWP100 of CH_4 and an adjustment factor for proportional allocation of emissions from co-production.	If coproducts are generated, an adjustment factor for "proportional allocation" of emissions is calculated based on verifiable data from the facility and applied to the emissions calculations. The adjustment factor ensures that emissions are distributed proportionally across all useable pyrolysis products (e.g., bio-oil) from a facility. If the project developer is unable to provide the necessary data, then an allocation factor of 100% is applied, in which case all emissions are attributed to the biochar.
Global Biochar C-Sink Standard	Requires the amount of fuels used to heat the pyrolysis reactors per biochar batch and an emissions factor to convert to CO_2e by fuel type.	Requires the amount of electricity used and a conversion to CO_2e based on information provided by the energy provider; or the average CO_2e value of the regional electricity mix; or average literature values.	Requires either two methane emissions tests per pyrolysis unit with the same feedstock representing the typical operation of the unit or the pyrolysis unit type must be certified by EBC or WBC.[22] This certification assigns a methane emissions value for pyrolysis systems use, by measuring at least three of the same type of pyrolysis systems from the same manufacturer.	If coproducts are generated and generate substantial income (no less than 30% of the income generated with biochar), emissions can be distributed proportionally across all products on a pro-rata basis. Otherwise, all emissions are attributed to the biochar. Any extra energy produced by the pyrolysis facility cannot count towards project emissions reductions.
VM0044	Calculated with the CDM Tool 03 for both low and high technology systems.[23]	Calculated with the CDM Tool 05 for both low and high technology systems.	Yes. For low tech systems where kiln type is not listed, a default average emissions factor of 0.049 t CH_4/tonne biochar may be used; also requires using the latest methane GWP listed in the VCS standard. For high technology systems, net emissions are considered *de minimis*.	No proportional allocation is permitted in an effort to be conservative.
Puro.earth Methodology	Yes, but details on data and calculations are not included in the methodology. Calculation templates are delivered to projects after registration with Puro.earth.	Yes, but details on data and calculations are not included in the methodology. Calculation templates are delivered to projects after registration with Puro.earth.	Pyrolysis gases must be combusted through an engineered process that negates or makes methane emissions negligible. Any non-negligible residual methane emissions must be quantified.[24]	For coproducts that are not used in the pyrolysis process and have an alternative, "meaningful use," an energy allocation determined by the project developer can be applied. Evidence for the alternative use must be provided and relevant properties must be determined for the calculation of allocation factors. If coproducts are not deemed important, then no adjustment allocation is made and all emissions are attributed to the biochar.
Isometric Biochar Production and Storage Protocol	Electricity consumption is specified in the Energy Use Accounting Module (see Isometric section in Table 4 for additional details).	Fuel consumption is specified in the Energy Use Accounting Module (see Isometric section in Table 4 for additional details).	1) If directly venting into atmosphere, flow rate and composition of the vented gas stream must be measured. 2) If venting through an emissions control unit (e.g., flare stack), flow rate and composition of the vented gas stream immediately upstream of the point of emission must be measured. 3) If gas is combusted within the project to provide thermal energy for the pyrolysis unit, flow rate and composition of the flue gas from the heating source for the pyrolysis unit must be measured. 4) If gases go to a downstream consumer for third party use, follow coproduct emissions allocation procedure.	Projects can take several approaches to emissions allocation: 1) all emissions are allocated to the biochar (most conservative approach, since all burden is placed on biochar); 2) divide the production process into sub-processes involved in the creation of the coproduct (certain eligibility criteria must be met); 3) use the substitution method to account for the avoided emissions associated with production of the coproduct. The burdens of the substituted product, representing emissions that were avoided from production of the coproduct, may be subtracted from the emissions accounting for the overall system; or 4) proportionally allocate emissions based on carbon mass balance in instances where coproducts lead to crediting with Isometric.

[22] Additional clarifications on direct methane measurements can be found here: https://www.carbon-standards.com/docs/transfer/4000203EN.docx?t=82159. Proxy emission values (CO) can be used instead.

[23] High Technology Production systems must meet the following criteria, according to VM0044: "(a) the pyrolytic greenhouse gases produced during pyrolysis must be recovered or combusted—greenhouse gases are not allowed to escape into the atmosphere; (b) at least 70% of the heat energy produced by pyrolysis must be used (taking into consideration heat transfer inefficiencies) to ensure that energy is recovered as well as biochar; (c) pollution controls such as a thermal oxidizer or other emissions controls are present that meet local, national or international emission thresholds; and (d) production temperature is measured and reported. If any of these conditions are not met, the facility is categorized as a low technology production facility."

[24] In order for emissions to be deemed non-negligible, the pyrolysis system must meet certain criteria outlined in section 3.5.17 of the revised draft for public consultation.

standard, VM0044 allows low technology production facilities to adopt organic carbon values based on the feedstock type and production process from the scientific literature or IPCC (2019) (see Table 6).

The H:Corg ratio is also an important lab-measured biochar property, used not only to determine biochar eligibility for crediting, but also as a proxy for long-term durability of the carbon in the biochar. As such, H:Corg is often incorporated into the biochar carbon storage calculation in the form of a permanence or persistence factor, which determines the amount of carbon remaining in the biochar over a specified number of years (see Table 6). The CAR Biochar Protocol, VM004, Global Biochar C-Sink Standard, and Isometric's Biochar Production and Storage Protocol all provide detailed requirements for sampling and laboratory analysis of carbon content, H:Corg and additional biochar properties.

5. Biochar post-processing (preparation of biochar for final use)

Sometimes biochar must be ground, sifted or blended with another material before it can be applied to its end use, which often

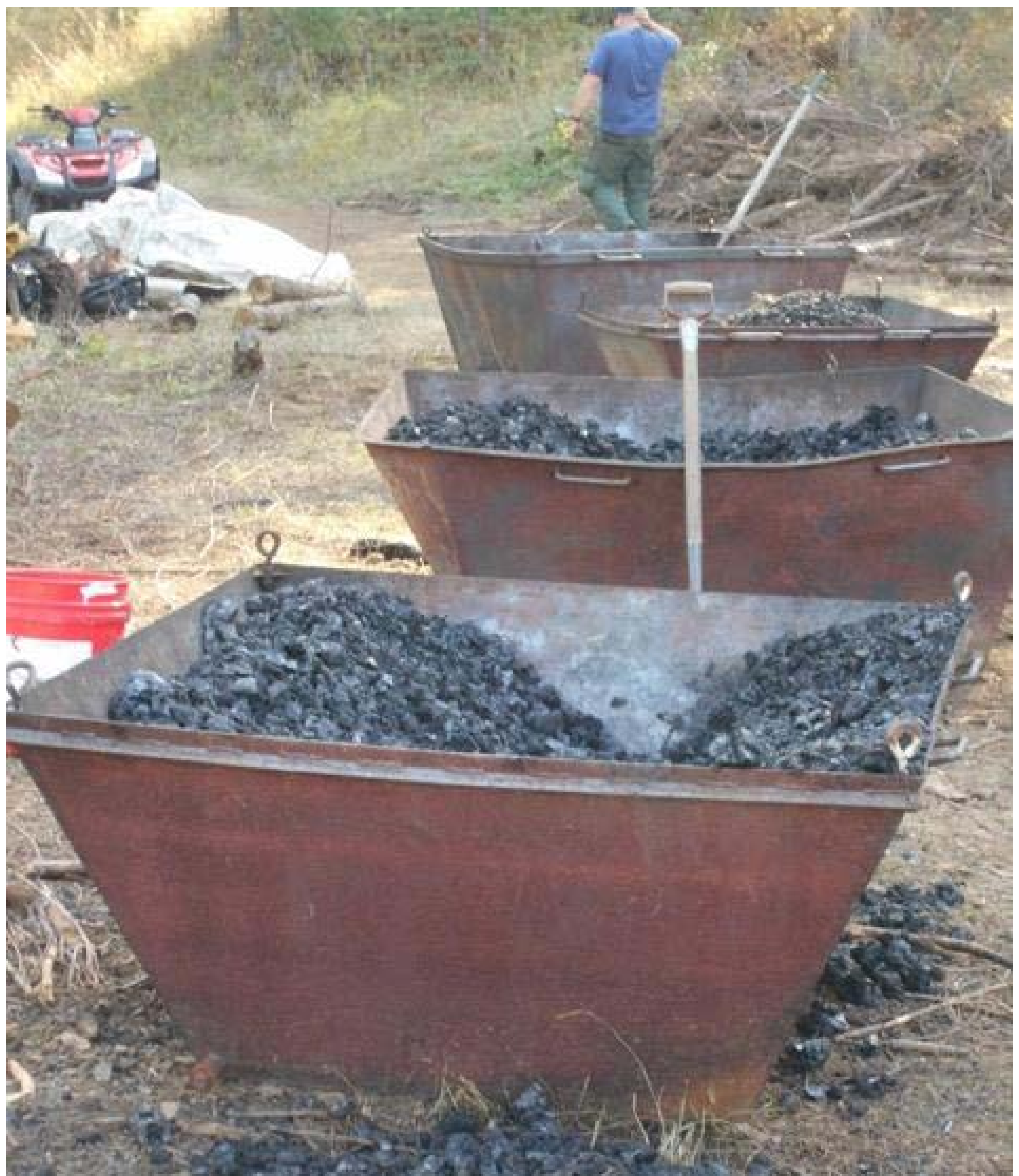


TABLE 6.

Information and/or data required by each protocol for determining the carbon stored in biochar over a specified duration

Protocol	Biochar Carbon Storage	Units
CAR Biochar Protocol	Wet mass of biochar (metric tonnes), organic carbon content (percent, based on the lower bound of 95% CI), permanence factor for end use (percent), weighted average dry matter content for biochar, conversion factor from carbon (C) to CO_2e. The permanence factor for soil and similar applications is based on the H:Corg ratio (the upper bound of the 95% confidence interval of the mean H:Corg) and soil temperature of the end use location. If soil is not the end use, an end use specific permanence factor from the end use eligibility list is applied: the permanence factor must be adjusted if the biochar is stored for longer than one year prior to application, with the adjustment based on the soil permanence factor and number of years biochar is stored prior to end use application. This is to account for any degradation that may occur if biochar is stored prior to its application.	Tonnes CO_2
Global Biochar C-Sink Standard	The initial amount of carbon in the biochar is calculated by multiplying the mass proportion (%) by the dry mass of the biochar. The amount of carbon remaining in the biochar after a certain number of years can then be calculated by multiplying this initial value by a persistence factor, which is referred to as "specific persistence" in the protocol (this is a nondimensional value, based on the biochar H:Corg, the end use and the number of years). For soil applications, the persistence factor for biochar with H:Corg < 0.4 is based off the assumption that the biochar has a persistent aromatic carbon (PAC) fraction of 75% and semi-persistent carbon (SPC) fraction of 25%, while biochar with H:Corg > 0.4 is assumed to have no PAC fraction (Schmidt et al., 2022).[25] For biochar used in concrete construction, the persistence factor can be assumed to be 100% for the first 60 years (average lifespan if a concrete building). After 60 years, the C-sink can typically be calculated following the equation for soil-based application. The soil-based persistence factor is also applied to other end uses. To assess the short to medium term climate effect of a biochar C-sink, the average annual biochar C-sink over a certain number of years can be calculated by summing the carbon remaining each year after application and dividing by the number of years. This number is converted to CO_2 and used for credit trading purposes.[26]	Tons CO_2 per year
VM0044	Mass of biochar (dry metric tonnes), organic carbon content (percent; on dry weight basis), and permanence adjustment factor for soil application (dimensionless and based on pyrolysis temperature; values are from IPCC (2019), Table 4AP.2 and Woolf et al., (2021)). For non-soil end uses, if there is no scientifically robust information on the permanence of the organic content, the soil end use values given in the protocol must be used. Where the scientific literature proposes different values of permanence, the lower value must be adopted to ensure conservativeness.	Tonnes C
Puro.earth Methodology	Mass of biochar (dry metric tonnes), organic carbon content (dry weight of organic carbon over dry weight of biochar), permanence factor (percent; based on the H:Corg ratio, soil temperature and a time horizon of 200 years) (Azzi et al., 2024; Li et al., 2024; Sanei et al., 2025; Woolf et al., 2021), conversion factor from C to CO_2. For non-soil applications, the same methodology is used.	Tonnes CO_2e
Isometric's Biochar Production and Storage Protocol	Can be calculated for either a blend of biochars or individual batches of biochar. Mass of biochar (dry tonnes) stored in a single batch or each batch within the blended batch, organic carbon content of a single batch or each batch within the blended batch (percent; on weight basis), conversion factor from C to CO_2e. The end use determines the permanence factor (percent; noted as Fdurable in the Agricultural Soil and Low Oxygen Burial Environments Modules). The permanence factor can be calculated for either a 200- or 1,000-year durability for an agricultural soil end use and 1,000 years in low oxygen landfill environments.[27, 28] For the 200-year durability, the permanence factor is based off soil temperature and H:Corg (Woolf et al., 2021). For the 1,000 year-durability for any end use, the permanence factor is based on the random reflectance value of the biochar, which must pass the 2% benchmark, outlined in Sanei et al., (2024).[29] Isometric is the only protocol that currently permits this measurement as an indicator of permanence.	Tonnes CO2e

[25] The Global Biochar C-Sink defines SPC as the part of the soil-applied biochar that may decay within the first 1,000 years of soil application and has a mean residence time of 69 years. PAC is thought to persist for more than 1,000 years. As such, the persistence factor for low H:Corg biochars is based off the assumption that 75% of the carbon is persistent for more than 1,000 years (PAC fraction) and that the SPC fraction has a mean residence time of 69 years. While the PAC fraction is incorporated into the persistence factor calculation, the biochar is still credited on a 1-to-100-year basis.

[26] The Global Biochar C-Sink Standard does not subtract production emissions from the carbon stored. Most protocols sell credits as the "net" storage, which subtracts project emissions from carbon stored in the biochar. The Global Biochar C-Sink is different in that it instead requires all production emissions to be recorded in an "emissions portfolio," which must be offset with a geological carbon sink (e.g., the PAC fraction of soil-applied biochar) registered through their registry. Project emissions (specifically CO2 and N2O) must be offset by retiring/removing a portion of the durable carbon before the credits can be validated in the Global C-Sink Registry.

[27] Agricultural Soil Module: https://registry.isometric.com/module/biochar-storage-agricultural-soils

[28] Low Oxygen Burial Environments Module: https://registry.isometric.com/module/biochar-storage-low-oxygen/

[29] Random reflectance is a relatively new indicator for quantifying the most long-lasting pool of carbon in biochar.

requires use of fuel and/or electricity. Biochar post-processing may occur at the production facility following pyrolysis or at the site of end use prior to application. Regardless of when post-processing occurs, there can be emissions associated with this step (see Table 7).

6. Biochar transportation

Typically, the biochar must be transported from the site of production and/or post-processing to its final application location. Where applicable, these transportation emissions must be accounted for as part of the life cycle analysis. The data and information required for this stage of the life cycle is the same as that of the feedstock transportation stage (see Table 3).

7. Biochar application

Protocols do not typically describe how to account for emissions associated with the application of the biochar into the soil or other end use (for example, emissions associated with using machinery required to apply or incorporate biochar into its end use). The Global Biochar C-Sink requires tracking of all post-production GHG emissions, including from application, through a digital Monitoring, Reporting and Verification (dMRV) system; however, explicit quantification guidelines for application emissions are not given.[32] Puro.earth requires accounting for emissions from the handling of the biochar until it is in its end use, which could include application emissions, but also does not describe how to quantify these emissions in the methodology. VM0044 considers emissions associated with utilization of biochar (e.g., from fossil fuel combustion or mixing of biochar with fertilizer products) to be negligible. Isometric's protocol requires quantification of any embodied and energy emissions associated with biochar spreading and machinery use during application. CAR does not explicitly discuss application emissions.

[32] A digital tracking system that follows the biochar and its emissions from the factory gate to its end use.

Although application emissions may not contribute significantly to the total emissions, failing to include them misses a step in the biochar life cycle that creates direct GHG emissions. Accounting for all direct emissions sources is especially critical if there are minimal measures to account for the uncertainty associated with these estimates (see Uncertainty in Key accounting principles, below).

7.1 The biochar end use

Although the main climate benefit of biochar lies in its creation (e.g., avoiding decomposition by creating a more stable form of carbon), the benefit is officially recognized by the protocols once it is in an end use that ensures its long-term persistence. Protocols permit various end uses (see Table 8).

TABLE 7.

Information and/or data required by each protocol for determining emissions from post-processing

Protocol	Approach/method to estimate post-processing emissions
CAR Biochar Protocol	Electricity: the total amount of electricity consumed for processing (kwh) and the emissions factor for electricity at the processing location (tCO_2e/kwh). Fossil fuels: the total mass or volume of fuel type and the emissions factor for the fuel type (tCO_2e/mass or volume unit).
Global Biochar C-Sink Standard	For consumption of diesel or benzine fuel, a conversion factor of 2.7 kg CO_2e per liter of diesel fuel is applied. For consumption of electricity, the conversion into CO_2e is based on information provided by the energy provider or the average CO_2e value of the regional electricity mix.
VM0044	Emissions associated with the grid-connected electricity utilized for processing biochar for application are calculated using CDM 05. Emissions associated with the combustion of fossil fuels utilized for processing of biochar for application are calculated using CDM 03.
Puro.earth Methodology	Requires accounting for all GHG emissions from handling of the biochar until it is in its end use (e.g., incorporation into soil or other product). Details on data and information required for this stage are not included in the methodology. Calculation templates are delivered to projects after registration with Puro.earth.
Isometric's Biochar Production and Storage Protocol	Any embodied and energy emissions associated with post-processing of biochar must be included, in line with the Energy Use Accounting Module and the Embodied Emissions Accounting Module.[30, 31] This must also include emissions relating to biochar storage, sampling required for MRV, staff travel, surveys and any miscellaneous activities not captured in these categories. End-of-life of project facilities must also be considered.

[30] Isometric's Energy Use Accounting Module: https://registry.isometric.com/module/energy-use-accounting/

[31] Isometric's Embodied Emissions Accounting Module: https://registry.isometric.com/module/embodied-emissions

TABLE 8.

Permitted biochar end uses by protocol

Protocol	Soil application	Non-soil applications
CAR Biochar Protocol[33]	Direct agricultural soil amendment. Non-food/feed soil applications: urban trees, landscaping, green roofs, etc Soil remediation and erosion control. Other agricultural or gardening applications: agricultural water filtration, compost additive, animal bedding, horticultural growth media, etc.	Permanent storage structures: spent oil/gas wells, subsurface mine remediation and landfill disposal (including as alternative daily cover and landfill solidification/stabilization). Construction/engineered materials: cement additive, gypsum additive, mineral plaster additive, clay additive, asphalt additive, wood polymer composites, etc. Other environmental remediation and wastewater sanitation: effluent polishing, septic and transpiration trenches, stormwater management, etc.
Global Biochar C-Sink Standard[34]	Agricultural soil application.	Animal feed, bedding, manure additive, etc. Incorporation into construction materials, such as cement-, lime-, clay- or geopolymer-based construction. Additive or filler in composites, thermoplastics, textiles, organic or mineral fibers, paper, filters, metal and other materials. Other end uses may be approved by Carbon Standards International.
VM0044[35]	Soil amendment (soil surface or subsurface) on land other than wetlands.	Includes but not limited to cement, asphalt and any other applications where long-term storage of the biochar is possible. Only biochar that is at least 50% carbon by dry weight basis and produced in high technology production facilities is eligible to be used in non-soil applications.
Puro.earth Methodology[36]	Soil amendment (pure or mixed with another product on agricultural, grazing, forest land, other natural areas including wetlands and peatlands). Seed coating in an agricultural context. Soil remediation for mine and quarry reclamation.	Manure additive in on-farm storage. Additive to animal bedding and animal feed. Additive to industrial compositing, anaerobic digestion facilities, and as a landfill intermediary or final cover material (biochar used to cover other waste). Construction materials (e.g., cement, asphalt). Consumer products, such as toothpaste. Industrial materials (paints, plastics, composite, batteries, etc.). "Passive" deposits (e.g., injected into non-accessible underground formations, below ground burial).
Isometric's Biochar Production and Storage Protocol[37]	Application to agricultural land, defined as permanent and arable cropland, meadows and pastureland.	Low oxygen landfill environments.

[33] List of permissible end uses: https://www.climateactionreserve.org/wp-content/uploads/2024/03/CAR-Eligible-Biochar-Feedstocks-List-2024-03-19.pdf

[34] List of permissible end uses: https://www.carbon-standards.com/docs/transfer/4000078EN.pdf?t=49508

[35] A full list of end uses not available. However, application criteria can be found in Section 4, Applicability Conditions.

[36] See Table 3.2 for categories of biochar application: https://7518557.fs1.hubspotusercontent-na1.net/hubfs/7518557/Biochar%20Public%20Consultation%202025/01_Puro%20Biochar%20Methodology%20-%20Edition%202025%20-%20Draft%20for%20consultation.pdf

[37] Isometric has two storage/end use "modules;" one for agricultural soils and one for low oxygen environments.

KEY ACCOUNTING PRINCIPLES

Uncertainty

Multiple sources of uncertainty in emissions and carbon storage estimates are inherent to the overall accounting process. First, there may be many small, indirect emissions that are difficult to directly quantify under the protocols. For example, these could be Scope 3 emissions, such as the production of bags for biochar storage and transport, and potential methane emissions during feedstock storage. Failing to account for these emissions introduces uncertainty that should be captured in the overall estimate of climate impact. Second, statistical uncertainty may be introduced from estimates derived from laboratory analyses and sampling, such as the biochar's organic carbon content and H:Corg or use of emission factors from the literature. If statistical confidence is low, there is a higher risk of over- or under-estimating the carbon stored in the biochar and therefore over- or under-crediting (CAR U.S. and Canada Biochar Protocol, Version 1.0, 2024).

Protocols address uncertainty in different ways. CAR accounts for statistical uncertainty from lab-derived measurements (organic carbon content and H:Corg ratio). They require the organic carbon content of the biochar to be based on the lower bound of the 95% confidence interval of the sample mean, while the H:Corg of the biochar must be based on the upper bound of the 95% confidence interval of the sample mean. This guards against overestimating the organic carbon content or underestimating the H:Corg ratio (the lower the value, the more stable and long lasting the biochar). The Global Biochar C-Sink requires a flat "margin of safety," which amounts to 20 kg CO_2e per ton of biochar. The primary purpose of this margin of safety is to account for GHG emissions that may not have been directly quantified during the accounting process (e.g., Scope 3 emissions). The Global Biochar C-Sink considers this to be a high, industry standard margin, noting that that the margin of safety should also account for "unavoidable imprecisions in sampling" and other analyses.

Isometric's protocol contains a comprehensive assessment of uncertainty. It requires reporting uncertainties associated with all input variables used in the net CO_2 removal calculation, which includes emissions factors, values of measured parameters (e.g., electricity usage from power meters, truck weights from weigh scales, etc.), lab analyses (e.g., carbon content) and data used to model biochar degradation. Uncertainty information must at least include the minimum and maximum values of the variable, and a sensitivity analysis must be done to demonstrate the impact of each variable's uncertainty on the overall net CO_2 removal uncertainty.

Puro.earth's 2025 protocol revisions has a new section on uncertainty, a significant improvement to the previous version of the protocol, which did not account for any type of uncertainty. This section describes procedures and methods required to account for and reduce uncertainty in the carbon reduction/removal estimate. The project developer must perform an uncertainty assessment, which follows steps outlined in a decision tree. As part of all data collection, the project proponent must record a series of attributes for each data parameter. This includes attributes such as the measurement unit, source of data (measured, estimated or calculated) and an estimation of random error associated with the measurement. A combined uncertainty percentage is calculated for all the parameters with a confidence interval of 95% or two standard deviations from the mean. The estimation of combined uncertainty can use either one of two methods to propagate uncertainty: the law of propagation of uncertainty or propagation of distributions using Monte Carlo simulations. VM0044 does not explicitly address uncertainty.

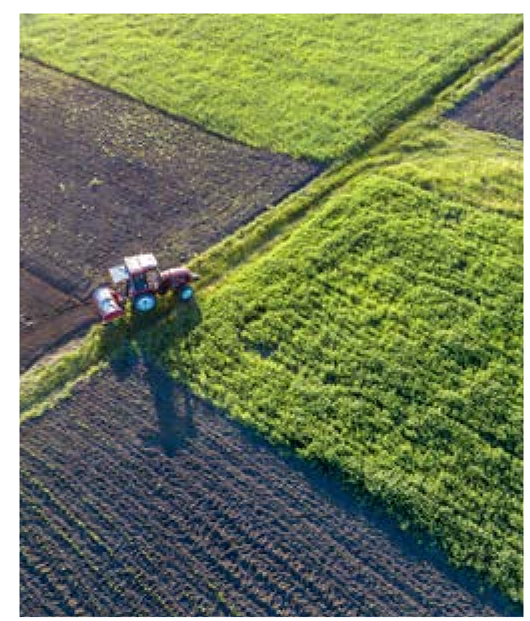
Importantly, uncertainty arises at each step of the accounting process, from determining the counterfactual feedstock scenario to estimating biochar transportation or production emissions. Yet some protocols do not account for, or safeguard against, some of these potential sources of uncertainty. LCAs are fundamentally uncertain and typically estimate uncertainty with methods like a Monte Carlo simulation or sensitivity analysis (Kane et al., 2024). Given that these protocols closely resemble LCAs, it is important for them to have more robust uncertainty calculations and clearer communication around which sources are included and their estimated contributions to overall uncertainty, as is done in Isometric's and Puro.earth's protocol.

Permanence

Biochar protocols define permanence as the persistence of the carbon in biochar over a set amount of time. Most frequently, permanence is quantified as the proportion of carbon remaining in the biochar over 100 years, which can be estimated through models if the H:Corg ratio is known. However, these permanence models are based on a soil end use, while protocols permit multiple end uses, including building materials and environmental remediation. Few studies on biochar permanence in end uses other than soil application exist and it is unclear how permanence varies depending on end use.

Under Puro.earth's protocol and VM0044, permanence models for soil application are typically applied to other protocol-approved end uses, unless there is scientifically robust evidence for use of an alternative model for the specific end use. Under CAR, certain construction or engineered materials (e.g., cement additives) and "permanent storage structures" (e.g., subsurface mine remediation) have a "permanence factor" of 100%, which assumes that no carbon is lost over the 100-year timeframe. Other end uses may have shorter lifespans, which is also reflected in the permanence factor. For example, an asphalt additive under CAR has a permanence factor of 20%, which is based on the low end of lifespan ranges for traditional asphalt road applications relative to 100 years (20 years = 20%). Under the Global Biochar C-Sink, if biochar is used as a "functional additive" in materials like asphalt, plastics and composites, it is assumed that the carbon content of the biochar persists and remains a C-sink for as long as the material itself persists, which is tracked through the dMRV system.

Nearly all protocols require biochar to have an H:Corg ratio of less than 0.7, as anything above this value is considered too unstable (i.e., will decompose rapidly). It is



important to note that the Global Biochar C-Sink Standard draws a distinction between biochar applied to soil with an H:Corg of less than or greater than 0.4. Biochar with a value of less than 0.4 is registered with a persistent aromatic carbon (PAC) pool of 75% and semi persistent carbon (SPC) pool of 25%, while that with a value greater than 0.4 is registered with an SPC of 100%. PAC is thought to persist for thousands of years in soil (a geological carbon sink), while SPC degrades within the first 1,000 years (Schmidt et al., 2022). Thus, having a higher proportion of PAC means a longer lasting, more stable biochar. This assumption around PAC and SPC is the basis for determining the amount of carbon remaining in the biochar after a certain amount of time in soil under the Global Biochar C-Sink (see section 4.1). This permanence approach differs from the one described below, suggested by Woolf et al., (2021).

Isometric requires an H:Corg of less than 0.5 to be eligible for agricultural soil application. For biochar storage in low oxygen burial environments, an H:Corg of less than 0.5 is recommended though not required. The H:Corg ratio is used to estimate permanence over 200 years. However, to assess permanence over 1,000 years, Isometric requires measuring random reflectance. Random reflectance is an indicator of the amount of persistent carbon in the biochar. A value 2% or higher is thought to be indicative of highly persistent biochar (Sanei et al., 2024). This is an emerging area of research, with other protocols acknowledging its development but not yet permitting its use.

The 100-year timeframe and two-pool exponential decay model for permanence developed and recommended by Woolf et al., (2021) is currently used across several protocols and considered to be a conservative approach.[38, 39] The 100-year timeframe was proposed Woolf et al., (2021) since a shorter timeframe could overestimate biochar's mitigation impact over policy-relevant timescales, while a longer timeframe could underestimate its impact over the next century. This timeframe is also in line with other carbon market protocols beyond biochar, leading to consistency within the marketplace. Recently, power models have been proposed as an alternative to the exponential decay models to model biochar permanence. Puro.earth's 2025 protocol revisions use a power model to assess permanence over 200 years rather than a two-pool exponential decay model over 100 years. Isometric's 1,000-year permanence is similarly based on research that uses a power model. While power models have been shown to provide good fits experimental data, they assume that biochar mineralization (the conversion of biochar carbon to CO_2) will slow down indefinitely as time passes, despite a lack of empirical data showing that this occurs. Although the more stable form of carbon in biochar decomposes very slowly, there is evidence that it can be susceptible to decomposition and is not intrinsically inert (Fuchs et al., 2011; Ling et al., 2022; Liu et al., 2015; Zimmerman & Ouyang, 2019).

Importantly, biochar permanence models are based on short-term experiments that may not capture longer-term decomposition processes (hundreds of years to millennia). Extrapolation over longer timeframes requires assumptions about how the biochar is mineralized (Lehmann et al., 2024). As such, uncertainty increases with the timeframe of model estimates (Lehmann et al., 2024). Additionally, processes impacting durability over millennia must be developed and incorporated into the models. More research is needed to accurately quantify biochar permanence over multiple centuries. This is especially important as biochar is increasingly discussed as a technology that can sequester carbon for thousands of years (Sanei et al., 2024). Given that credits are used to offset GHG emissions, modelling permanence more conservatively may be more desirable.

[38] This type of model assumes that the rate at which the biochar mineralizes (conversion of biochar carbon to CO_2) is proportional to how much biochar exists at a given time. It also assumes that there are two "types" or pools of carbon within the biochar: a more stable carbon with a lower decay rate and a less stable carbon with a higher decay rate, similar to PAC and SPC in the Global Biochar C-Sink Standard model.

[39] The Global Biochar C-Sink and Isometric's protocol are currently the only ones that issues credits with a durability of 1,000 years.

Consistency across protocols is also important, as a different durability could be assigned to very similar biochar products. As research on permanence progresses, protocols may be revised to reflect advances in knowledge while also ensuring a conservative approach.

Leakage

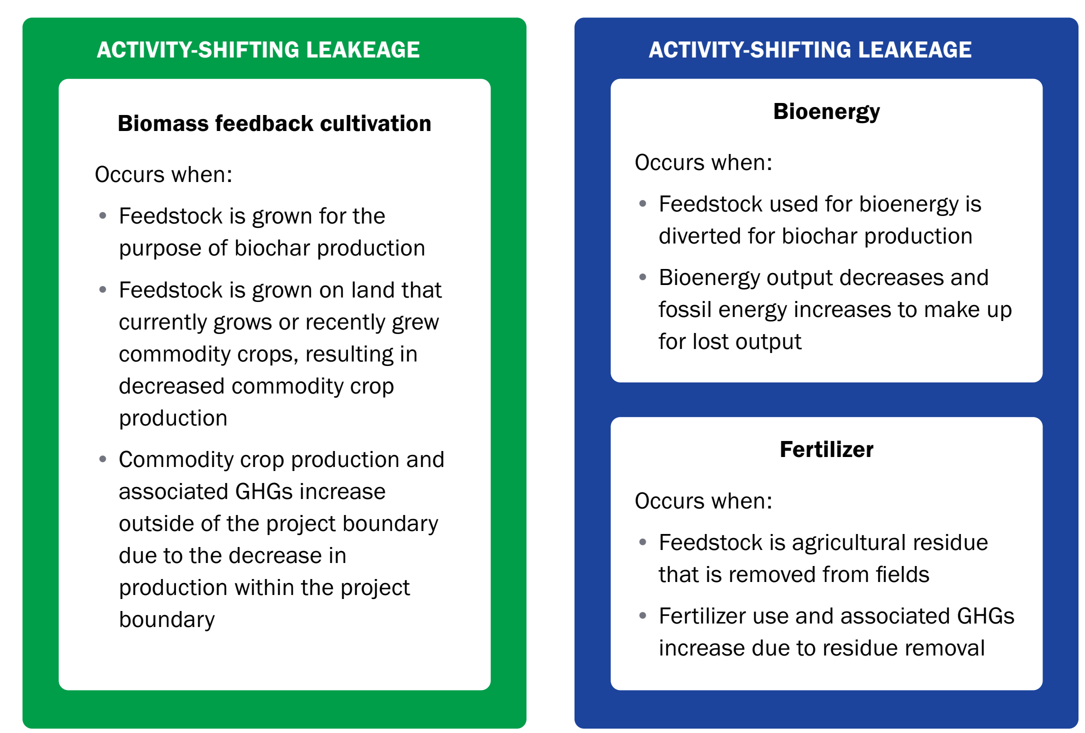
Several types of leakage can result from biochar production (see Figure 3). First, if the feedstock was diverted from an alternative use, there could be emissions resulting from the replacement of the feedstock. This can be broadly referred to as market or "replacement" leakage, of which there are two major sources. The first is the potential for an increase in fossil energy usage resulting from a decrease in bioenergy output (due to diversion of feedstock for bioenergy to biochar production) (CarbonPlan, n.d.; Lehmann et al., 2021). A similar type of leakage could result from removing crop residues from fields for biochar production: residues provide essential nutrients to crops and if removed, it is important to ensure that this nutrient source is not replaced with a more GHG intensive source, such as synthetic fertilizers (CarbonPlan, n.d.; Sarkar et al., 2020). The second category of leakage is activity shifting leakage. In the case of biochar, activity-shifting leakage could occur from the cultivation of purpose-grown feedstocks. If the cultivation of biomass for biochar production occurs on land where a commodity crop was cultivated, this could result in increases in commodity crop production elsewhere, even potentially resulting in conversion of previously non-cultivated lands (Woolf et al., 2010).

Each protocol handles leakage differently. CAR's Biochar Protocol explicitly accounts for leakage from decreased bioenergy output and activity shifting leakage. If a biochar project plans to use feedstocks from a landscape where that biomass source is

FIGURE 3.

Types of potential leakage from biochar production

Other types of leakage are possible (see discussion on Isometric's and Puro.earth's leakage accounting). This figure describes commonly referenced types of leakage in the context of biochar production.



typically used for bioenergy and that feedstock is supply-limited, the biochar project would not be eligible under CAR's protocol. If the feedstock is not supply-limited, the CAR protocol assumes no leakage would occur since bioenergy output would not be impacted by the biochar project. Second, for biochar projects resulting in a diversion of feedstock from *within a bioenergy production facility* (e.g., high carbon fly ash), "the project developer must demonstrate that bioenergy production levels are being maintained such that the energy output of the facility does not decrease by more than 5 percent annually based on average daily output."[40] If energy output decreases, these leakage emissions must be accounted for in the project.

The CAR protocol considers activity-shifting leakage to be of minimal risk since purpose grown feedstocks must be acquired either from sites that are classified as unproductive, marginal lands, sites that have not undergone conversion from a higher carbon density land-use type and sites that have not been under production for a commodity crop in the past three years.[41] Although CAR's protocol defines waste and by-product feedstocks as feedstocks that are not put to productive uses, they do permit the use of crop residue feedstock. Since crop residues can serve as a nutrient source for soils, some amount of leakage could be possible; therefore, it is important to verify that the loss/diversion of any crop residue does not result in the increased use of a more GHG-intensive fertilizer.

VM0044 does not include activity-shifting leakage or leakage from decreased bioenergy output to be a risk because only waste feedstocks are eligible (see Table 1). The latter hinges on their requirement that only biomass which would have been combusted or left to decay is utilized for biochar production; feedstocks used for alternative purposes, like bioenergy, in the five years preceding the project are not allowed (see Baseline section). However, VM0044 requires accounting for diversion of feedstock from within a bioenergy facility, like CAR's protocol: high carbon fly ash feedstock, a byproduct of bioenergy production that can be used for biochar production, cannot comprise more than 5% of the annual waste biomass throughput from the bioenergy facility for inclusion. Project proponents must demonstrate that "biomass facilities did not use fossil fuel sources to replace the loss of biomass caloric value when material was diverted to the biochar project." Like CAR's protocol, because VM0044 permits the use of crop residue as a feedstock, it is important to verify that residue removal does not result in increased emissions from a replacement fertilizer.

[40] High carbon fly ash is a by-product of bioenergy production and is typically reinjected into the bioenergy furnace. It can also be used as a biochar feedstock.

[41] CAR considers Land Capability Classes 5 or 6 to be marginal, as defined by the U.S. Department of Agriculture-Natural Resources Conservation Service and Agriculture and Agri-Food Canada.

Isometric's protocol aims to prevent leakage from decreased bioenergy output by prohibiting the use of feedstock grown for the purposes of energy production and/or feedstock that would have likely been used for energy production. The project proponent must conduct a regional analysis of feedstock uses to show that less than 50% of the total biomass is allocated for bioenergy production or that the feedstock has already fulfilled its energy generation uses (e.g., post anaerobic digestion manure). The protocol also requires calculating leakage emissions from *any* material replacement caused by biochar production, including fertilizer replacement due to residue removal.[42]

Isometric's protocol does not permit non-waste feedstocks, and as such activity shifting leakage caused by biomass cultivation is not explicitly discussed. However, land use change is still considered a potential source of leakage if feedstock sourcing affects the market price of the feedstock, leading to land use change.[43] The protocol classifies this as an "indirect" form of market leakage. To avoid this type of indirect leakage, the protocol requires demonstrating that the feedstock is either non-marketable (for forest residues), an agricultural residue/ancillary to the production of the primary marketable product or would have no marketable use in the absence of the biochar project. It is worth noting that Isometric's protocol also has measures to minimize or avoid "direct" market leakage, which they define as increases in GHG emissions resulting from payments to the feedstock supplier that directly affect that supplier's behavior (for example, if high demand for a forest residue feedstock causes the supplier to increase their timber harvesting operations).

The Global Biochar C-Sink Standard prohibits non-sustainable biomass cultivation and land use change in an effort to prevent leakage, though further details—specifically in the context of leakage—are not discussed in the protocol document. However, as part of the protocol's project design document[44], project developers are required to disclose whether the amount of biomass used by the project could be large enough to have an influence on local activities and markets (e.g., emissions resulting in activity-shifting leakage or market leakage).

The Puro.earth protocol identifies several categories of leakage, which include ecological indirect land use change, market-driven indirect land use change, leakage from competing use of biomass and/or renewable energy resources and leakage from diversion of existing processes or services.[45, 46, 47, 48] The project developer must identify and quantify the emissions from any of these potential sources of

[42] Additional details in Isometric's Biomass Feedstock Accounting Module: https://registry.isometric.com/module/biomass-feedstock-accounting/

[43] The difference between "direct" market leakage, as defined by Isometric, and activity shifting leakage is that economic forces cause the land use change (e.g., competition for resources and services could lead to changes in their price and availability, resulting in GHG emissions elsewhere), rather than a land use change caused directly by the project activity (activity-shifting leakage).

[44] Carbon Standards International's Project Design Document: https://www.carbon-standards.com/docs/transfer/4000038EN.docx?t=237001

[45] Defined by Puro.earth as occurring when direct land use changes resulting from infrastructure development for sourcing, logistics or storage facilities within the project's system boundary lead to negative effects on land and ecosystems outside of the system boundaries, either via land drainage or land cover change.

[46] Defined by Puro.earth as occurring when competing use of biomass resources may lead to activity shifting outside of the activity's system boundaries with associated land use changes.

[47] Defined by Puro.earth as occurring when the project increases the use of biomass and/or renewable energy resources within the activity's system boundary, competing with other recognized uses (e.g., decrease in nutrient inputs due to residue removal).

[48] Defined by Puro.earth as occurring when the project alters existing production processes or services which may lead to changes in the type or level of service. Requires determining the type of level of service provided in the baseline scenario and whether the project makes changes to the level of service that could lead to a net increase in emissions and/or a net decrease in removals.

leakage, which must then be avoided or mitigated as specified in the protocol. Replacement and activity shifting leakage, as defined in Figure 3, most closely fall under Puro.earth's definition of leakage from competing use of biomass and/or renewable energy resources and leakage from diversion of existing processes and services.

There can be many different sources of leakage and clearly defining and distinguishing them can be difficult. Finding a consensus on how to define different types of leakage from biochar production would help increase consistency across protocols.

Additionality

Additionality is the concept that the climate benefit of the biochar project is additional to what would have occurred without the carbon market incentive. All protocols have an assessment for additionality that requires a baseline of zero emissions and proving that there is no legal requirement (local or federal laws) for the activity. The latter is straightforward, but the former is more complex. As described in the sections "Establishing a baseline" and "Leakage," both the CAR Biochar Protocol and VM0044 require proof that the waste feedstock fate would have been decomposition or combustion and would not have been used for an alternative purpose. Both protocols typically require documentation that includes but is not limited to historical records, government reports and peer-reviewed studies. This approach results in a baseline scenario in which there are emissions (e.g., decomposition or combustion) and no climate benefit (e.g., feedstock could be used for bioenergy). Similarly, Isometric requires documentation, such as historical records or a qualitative assessment, demonstrating that the feedstock counterfactual fate would have resulted in the release of all its carbon within 15 years from the project start. Puro.earth's protocol similarly requires demonstrating additionality by providing full project financials and a counterfactual analysis of the baseline. As such, a baseline of zero is considered a reasonable assumption under these protocols.

While the Global Biochar C-Sink Standard acknowledges that other feedstock uses could have a greater climate benefit than biochar production, they note that it can be difficult to determine which scenario is better. For this reason, their protocol does not exclude the use of feedstocks due to "additionality considerations," as long as the feedstock is "carbon neutral," meaning that it did not lead to the reduction of the total carbon stock of the system from which it came.

Another important aspect of additionality involves understanding the opportunities for uptake of biochar production and barriers to scaling up. To satisfy the assumption of additionality, the carbon market incentive must be the reason for the biochar's creation (which is also why there cannot be any law that mandates the production of biochar). Currently, barriers for adoption of biochar production are large, and biochar projects may not be possible without a carbon market incentive. However, as barriers for adoption decrease and the commodity market for biochar grows, there may be less need for external incentives like carbon markets. Given this reality, VM0044 has an "activity penetration" threshold, in which the total waste biomass converted to biochar must amount to less than 5% of the total waste biomass available worldwide. There is currently not enough biochar production in any country to get to the 5% threshold, so all projects would currently satisfy this additionality requirement under VM0044. Isometric does not have an overall threshold for production but instead requires reviewing project financials to determine whether carbon crediting is required to incentivize biochar production. For example, a project may no longer satisfy additionality requirements if production costs decrease due to increased revenue from co-product sales.

Similarly, the CAR Biochar Protocol does not have an overall threshold for production, since current barriers to adoption are deemed so large. However, for pre-existing biochar operations, project developers must provide the maximum annual output of the facility during the three years immediately prior to the project start date as the benchmark for business-as-usual activities, with crediting only provided for production above that amount after the project start date.

Double Counting

With all types of carbon accounting, it is important to ensure that the carbon benefit is not claimed more than once. The most obvious example of double counting is if multiple registries credit the same biochar project. However, a less obvious risk comes from applying credited biochar to soils enrolled in a project under a soil carbon protocol (e.g., projects developed under CAR's Soil Enrichment Protocol or Verra's VM0042 Protocol). More specifically, carbon increases could be misattributed to another practice (e.g., reduced tillage) even though the increase was caused by the biochar application (due to more carbon inputs to the soil). This results in double counting if the biochar carbon was already credited through a biochar protocol. Rathnayake et al., (2024) suggest that applying credited biochar to land under a soil carbon protocol and preventing double counting could be possible as long the already certified biochar carbon is subtracted from the total soil organic carbon.

Verra's Soil Carbon Protocol, VM0042, permits the application of biochar in areas enrolled under a soil carbon project, but requires subtracting the total organic carbon content of the biochar applied from the estimated soil organic carbon stock change. CAR's Soil Enrichment Protocol similarly requires accounting of the impact of soil amendments, like biochar, on soil organic carbon. Project stacking (quantifying the climate benefits of multiple carbon projects) may be allowed if the reported GHG assessment boundaries and climate benefits do not overlap. As such, biochar credited under CAR's protocol would likely not be allowed to be applied to soils on fields enrolled in a soil carbon project, unless the increase in soil organic carbon can be directly attributed to the biochar application and is not accounted for under the agricultural project. Review and approval from CAR is required for any project stacking.

All protocols require tracking and documenting the final location of the biochar. Project verification also typically includes a comparison of a project's location relative to the locations of projects publicly available on other registries. These measures can help prevent double counting. Still, a

central system that ensures robust, cross-registry documentation and tracking of all projects is necessary to further decrease the risk of double counting. A centralized registry like this could more easily identify and prevent biochar credited under one protocol from being applied to land under another protocol. Third-party initiatives such as the Climate Action Data Trust are attempting to close this critical gap.[49]

Reversals

Since the main climate benefit of the biochar can be attributed to the making of the biochar and because the biochar's physical and chemical properties allow it to persist in the environment for a long time, the risk of reversal is generally considered low. The primary cause of a reversal would come from direct combustion of the biochar. Although none of the protocols permit combustion as an end use, it is possible for combustion to occur accidentally post application. CAR's protocol considers the remaining combustion risk post-application (for example, due to a fire) to be negligible and therefore does not account for it. VM0044 requires that biochar applied on surface soils be mixed with other substrates to minimize the impact of natural reversals (e.g., fire). Isometric's protocol is the only one that requires a buffer pool as a precaution against unknowns and reversals. Biochar projects that meet the eligibility criteria of Isometric's Biochar Storage in Agricultural Soils Module and Biochar Storage in Low Oxygen Burial Environments Module are categorized as having a very low risk of reversal, which corresponds to a buffer pool of 2% of credits. Under the Puro.earth protocol, reversal risk is considered minimal for applications to agricultural and forest land, construction materials and burial in below ground pits or similar structures (see sections 3.6 and 4.2 in Puro.earth's 2025 draft methodology). The Puro.earth protocol acknowledges that reversals (e.g., combustion) could occur prior to the biochar reaching its final location, however, they attempt to minimize this risk by requiring evidence that the biochar has reached its end use and that no accidents have occurred along the distribution chain. The Global Biochar C-Sink Standard does not explicitly discuss reversal risks.

Environmental and social safeguards

Environmental and social safeguarding often includes topics such as contaminant thresholds in the feedstocks and biochar, as well as protections against hazardous working conditions. Contaminants that may be found in biochar include heavy metals, Polychlorinated Biphenyls (PCBs), Aromatic Hydrocarbons (PAHs) and Dioxins/Furans (PCDD/Fs). Protocols require adherence to local and federal regulations pertaining to worker safety, environmental quality and contaminant thresholds for certain end uses (e.g., soil amendments, animal feed). Protocols may often contain additional environmental and social safety measures that may not be required by law. The amount of detail provided by each protocol varies (see Table 9).

[49] https://climateactiondata.org/about/

Table 9.
Environmental and social or human health safeguards by protocol

Protocol	Environmental Safeguards					Social and/or Human Health Safeguards
	Biochar Contaminants				Environmental Impact Assessment	
	PCBs	Heavy Metals	PAHs	Dioxins/Furans		
CAR Biochar Protocol	Yes	Yes	Yes	Yes	Required to complete an Environmental and Social Safeguards Assessment Form, describing any significant impacts (positive or negative) that the whole project might have on other environmental issues such as air and water quality, endangered species and natural resource protection, and environmental justice.	A worker safety plan must be provided for field-based biochar production if one is not required by law Projects must comply with local and national laws pertaining to worker health and safety.
	Notes: Contaminants must be below a threshold specified by the protocol or legal requirements based on end use. Certain production conditions that may minimize the risk of certain contaminants may preclude testing. These conditions are specified in the protocol.					
Global Biochar C-Sink Standard (EBC/WBC Guidelines)[50]	Yes	Yes	Yes	Yes	Not explicitly stated, although biochar certification classes "guarantee that biochar was produced with minimal environmental impact."	Producers must comply with local and national laws pertaining to fire and dust protection. Protective measures identified via a risk assessment is required. Workers must be equipped with proper protective clothing and masks where necessary. Workers must be informed in writing and trained on the risks and dangers of production.
	Notes: Contaminants must not exceed values provided in the EBC/WBC documentation based on the end use/certification class. For end uses where there is no possibility of leaching, heavy metals do not need to be tested. Specific feedstocks also have contaminant thresholds. Feedstocks used for certain end uses cannot contain any paint residues, solvents or other potentially toxic impurities.					
VM0044	Yes	Yes	Yes	Yes	Not explicitly stated, although all feedstocks must meet certain sustainability criteria based on the feedstock type.	Must have a health and safety program to protect workers from airborne pollutants and other hazards. Social risks, such as community resistance or non-acceptability are considered minimal since only waste feedstocks are eligible. Competing uses for feedstock are assumed not to exist. Benefits for communities through a new livelihood/revenue stream through biochar production are assumed.
	Notes: For soil application, biochar must meet the IBI Biochar Testing Guidelines, EBC/WBC Production Guidelines or relevant national regulations for avoiding soil contamination. Specific feedstocks also have contaminant thresholds. For example, processed timber used for biochar production cannot contain paint residues or solvents due to health and safety reasons					
Puro.earth Methodology	Yes	Yes	Yes	Yes	If regulation does not require an environment impact assessment, conducting an environmental impact assessment is encouraged as best practice but is not a strict prerequisite. Must fill out the Puro.earth Environmental and Social Safeguards Questionnaire.	Producers must take measures to ensure a safe working environment, such as providing a Material Safety Data Sheet, personal protective equipment, post-production quenching and cooling of biochar, and flue gas treatment systems. Project developer must provide a stakeholder engagement report alongside evidence detailing the stakeholders identified, consultation activities conducted, the outcomes of the consultations and plans on how dialogue with the stakeholders will continue over the course of the crediting period. Must fill out the Puro.earth Environmental and Social Safeguards Questionnaire.
	Notes: Where there are no legal requirements for biochar end use (e.g., for soil application), thresholds from the WBC/EBC Guidelines must be used.					
Isometric's Biochar Production and Storage Protocol	Yes	Yes	Yes	Yes	The project developer must assess environmental risks and describe a mitigation plan, if necessary, for the entire project. This assessment can take a variety of forms but should follow the safeguards outlined in the ICVCM Core Carbon Principles.[51] A formal Environmental Impact Assessment conducted by a third party is required if impacts are significant or required by the host jurisdiction.	Producers must demonstrate that no net social harm exists. This assessment should follow the safeguards outlined in the ICVCM Core Carbon Principles. A full Social Impact Assessment conducted by a third party is required if impacts are significant or required by the host jurisdiction. Active stakeholder engagement must be demonstrated through a Stakeholder Input Process. A plan for information sharing, emergency response, and conditions for stopping or pausing project deployment is required. Where relevant and feasible, producers must show how the project is consistent with relevant Sustainable Development Goals (SDG) objectives of all jurisdictions in which they operate.
	Notes: Biochar must meet thresholds set by the WBC Production Guidelines for the agricultural soil end use if there are no regulatory requirements for contaminant limits. For low oxygen burial environments, the biochar application site must be monitored for contaminants.					

[50] The EBC/WBC Guidelines contains information on topics like biochar laboratory procedures, testing, sampling, and health and safety protocols

[51] ICVCM Core Carbon Principles, Section 4, Sustainable Development Benefits and Safeguards: https://icvcm.org/wp-content/uploads/2024/02/CCP-Section-4-V1.1-FINAL-15May24.pdf

CONCLUSION

Overall, all biochar protocols tend to follow the same carbon accounting steps (e.g., cradle to grave emissions accounting) and are based on similar principles (for example, permanence derived from the H:Corg ratio). The biggest differences among the protocols stem from; 1) the amount of detail provided at each accounting step; and 2) lack of clarity and/or different approaches to key carbon accounting concepts, such as leakage, uncertainty, permanence or additionality. While being too prescriptive may pose challenges for biochar project developers, a lack of instruction creates transparency issues that make it difficult to understand how climate benefits are ultimately calculated. Biochar carbon projects—like all crediting projects—must account for additionality, potential leakage, error and uncertainty, and double counting clearly and consistently (Mitchell et al., 2024; Oldfield et al., 2022). Rigorous, transparent and consistent accounting of these issues can help ensure that the credits generated are high quality and help promote trust in the voluntary carbon market more broadly.

One area for improvement and standardization is accounting for error and the resulting uncertainty. Some of the information required for biochar carbon accounting is relatively straightforward and may not incur much error and uncertainty (for example, emissions estimates derived from fuel records or electricity consumption). However, lab measurements and sampling are always associated with some degree of error, which should always be quantified, presented and addressed. Furthermore, other types of error (such as misreporting or data gaps) can be introduced at any step of the accounting process. Since biochar protocols resemble LCAs, uncertainty could be estimated with methods like a Monte Carlo simulation or sensitivity analysis, as is required by Isometric and Puro.earth. Biochar protocols could also incorporate strategies to mitigate uncertainty common in other crediting arenas, such as the uncertainty deductions used in soil carbon crediting protocols (e.g., Climate Action Reserve Soil Enrichment Protocol, Verra's VM0042). An uncertainty deduction on overall net CDR of a project, somewhat akin to the margin of safety employed by Global Biochar C-Sink or to the buffer pool in Isometric's protocol, can help ensure the principle of conservativeness to prevent over-crediting. More rigorous measures to account for uncertainty and error are especially critical as biochar projects are scaled up.

A potential challenge moving forward in the biochar crediting space may involve how to estimate permanence/durability and account for associated uncertainties related to permanence timeframes. Research on biochar permanence is evolving, and new models and measurement methods to estimate durability have been introduced in recent years. While both two-pool exponential decay and power models have been shown to provide good fits to the available short-term data (typically around three years or less) (Lehmann et al., 2024), there are concerns that the power model may not be sufficiently conservative over longer timeframes due to its underlying assumption that biochar decay rates will slow indefinitely. While decay rates may slow over time, there are also processes that could counteract this (e.g., biological processes that decompose the most stable form of carbon in biochar (Fuchs et al., 2011; Zimmerman & Ouyang, 2019)) and uncertainties increase the further into the future the models predict. Furthermore, available models are based on biochar soil applications, even though there are many other acceptable applications and end uses for biochar. Ultimately, to improve the models and reduce associated uncertainties, we need more research spanning longer timeframes and over a greater variety of end uses.

As the carbon crediting landscape continues to evolve and expand, the risk of double counting may also grow. If biochar is used as a soil amendment on land under a soil carbon crediting protocol, extra assurance must be taken to prevent its application or subtract the carbon added in the biochar from the soil carbon. This requires rigorous tracking of the biochar product. While double counting within a registry may be minimal, additional measures to prevent double counting across registries, such as a centralized registry, are necessary.

Biochar has been identified as a mitigation strategy with high potential (Buma et al., 2024) and its production has increased over 200% from 2021 to 2023 (International Biochar Initiative & U.S. Biochar Initiative, 2023). Yet barriers to scaling and more widespread adoption remain. According to the 2023 Global Biochar Market Report, the top three barriers to expanding biochar production included low awareness of biochar, insufficient demand for biochar and limited access to capital. Biochar credits typically go to the biochar producers, with some protocols allowing credit ownership to be transferred to the end user. While it makes sense for credits to be awarded to biochar producers, this system does not provide as much incentive for incorporation of biochar into agricultural soils, building materials or other substrates. Due to the structure of the carbon market, demand from both biochar users and credit buyers is necessary.

Although the carbon market can help support the operations of biochar producers, participation rates are low, with nearly 60% of biochar producers surveyed in the 2023 Global Biochar Market Report indicating no income from carbon credits (International Biochar Initiative & U.S. Biochar Initiative, 2023). Potential reasons cited for low participation included cost and difficulty of participation and additionality requirements (e.g., some projects may be considered business-as-usual if the facility has already been producing biochar). Addressing barriers stemming from additionality criteria could involve taking an approach similar to that of CAR's Biochar Protocol, in which prior production does not make a project ineligible but instead requires establishing a benchmark for business-as-usual activities based on prior production. Finding the balance between reducing barriers while maintaining rigorous standards requires continued feedback from biochar producers, researchers, project developers and other carbon market participants.

One of the benefits of biochar is that the risk of reversals is minimal, unlike other nature-based climate solutions, such as soil carbon sequestration. Furthermore, biochar may have additional GHG mitigation benefits other than carbon reduction and removal, such as N2O emissions reductions from soils or methane reduction when used as a manure additive or livestock feed additive (Harrison et al., 2024; Lehmann et al., 2021; Winders et al., 2019). However, these potential benefits are not yet quantified by biochar protocols, as they are highly uncertain given the current state of the science. Additional research is necessary to determine how to quantify and assess the scale of other potential GHG benefits that may confer credits to biochar users. As research continues to advance, these benefits could eventually be incorporated into the protocols. With proper accounting and increased consistency and transparency across biochar crediting protocols, biochar can serve as an effective, long-lasting carbon reduction or removal technology, particularly in regions where energy generation is increasingly reliant on renewable sources.

CITATIONS

Anand, A., Gautam, S., & Ram, L. C. (2023). Feedstock and pyrolysis conditions affect suitability of biochar for various sustainable energy and environmental applications. *Journal of Analytical and Applied Pyrolysis*, 170, 105881. https://doi.org/10.1016/j.jaap.2023.105881

Andrews, S. S. (2006). *Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations*. USDA-Natural Resource Conservation Service.

Azzi, E. S., Li, H., Cederlund, H., Karltun, E., & Sundberg, C. (2024). Modelling biochar long-term carbon storage in soil with harmonized analysis of decomposition data. *Geoderma, 441*, 116761. https://doi.org/10.1016/j.geoderma.2023.116761

Borchard, N., Schirrmann, M., Cayuela, M. L., Kammann, C., Wrage-Mönnig, N., Estavillo, J. M., Fuertes-Mendizábal, T., Sigua, G., Spokas, K., Ippolito, J. A., & Novak, J. (2019). Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: A meta-analysis. *Science of The Total Environment*, 651, 2354–2364. https://doi.org/10.1016/j.scitotenv.2018.10.060

Bradford, M. A., Eash, L., Polussa, A., Jevon, F. V., Kuebbing, S. E., Hammac, W. A., Rosenzweig, S., & Oldfield, E. E. (2023). Testing the feasibility of quantifying change in agricultural soil carbon stocks through empirical sampling. *agriRxiv*, 2023, 20230393987. https://doi.org/10.31220/agriRxiv.2023.00200

Budai, A., Zimmerman, A., Glaser, B., Masiello, C., Shields, F., Lehmann, J., Arbestain, M. C., Williams, M., Sohi, S., & Joseph, S. (2013). *Biochar Carbon Stability Test Method: An assessment of methods to determine biochar carbon stability*. https://www.semanticscholar.org/paper/Biochar-Carbon-Stability-Test-Method%3A-An-assessment-Budai-Zimmerman/1a2d68574780067f3ce396df882bb5ddae122047

Buma, B., Gordon, D. R., Kleisner, K. M., Bartuska, A., Bidlack, A., DeFries, R., Ellis, P., Friedlingstein, P., Metzger, S., Morgan, G., Novick, K., Sanchirico, J. N., Collins, J. R., Eagle, A. J., Fujita, R., Holst, E., Lavallee, J. M., Lubowski, R. N., Melikov, C., … Hamburg, S. P. (2024). Expert review of the science underlying nature-based climate solutions. *Nature Climate Change*, 1–5. https://doi.org/10.1038/s41558-024-01960-0

CAR *U.S. and Canada Biochar Protocol, Version 1.0*. (2024). Climate Action Reserve. https://www.climateactionreserve.org/wp-content/uploads/2024/04/CAR-US-and-Canada-Biochar-Protocol-V1.0.pdf

CarbonPlan. (n.d.). *Biochar CDR Verification Framework*. Retrieved June 2, 2025, from https://carbonplan.org/research/cdr-verification

DeDecker, J. (2014, October 30). *Measure residue cover to protect the soil*. MSU Extension. https://www.canr.msu.edu/news/measure_residue_cover_to_protect_the_soil

Ding, F., Van Zwieten, L., Zhang, W., Weng, Z. (Han), Shi, S., Wang, J., & Meng, J. (2018). A meta-analysis and critical evaluation of influencing factors on soil carbon priming following biochar amendment. *Journal of Soils and Sediments*, 18(4), 1507–1517. https://doi.org/10.1007/s11368-017-1899-6

Ericsson, N., Sundberg, C., Nordberg, Å., Ahlgren, S., & Hansson, P.-A. (2017). Time-dependent climate impact and energy efficiency of combined heat and power production from short-rotation coppice willow using pyrolysis or direct combustion. *GCB Bioenergy*, 9(5), 876–890. https://doi.org/10.1111/gcbb.12415

Fuchs, G., Boll, M., & Heider, J. (2011). Microbial degradation of aromatic compounds—From one strategy to four. *Nature Reviews Microbiology*, 9(11), 803–816. https://doi.org/10.1038/nrmicro2652

Global Biochar C-Sink Standard, Version 3.1. (2024). Ithaka Institute.

Harrison, B. P., Moo, Z., Perez-Agredano, E., Gao, S., Zhang, X., & Ryals, R. (2024). Biochar-composting substantially reduces methane and air pollutant emissions from dairy manure. *Environmental Research Letters*, 19(1), 014081. https://doi.org/10.1088/1748-9326/ad1ad2

International Biochar Initiative, & U.S. Biochar Initiative. (2023). *Global Biochar Market Report*. https://biochar-international.org/wp-content/uploads/2024/06/Global-Biochar-Market-Report-2023-%E2%80%93-Public.pdf

Isometric Biochar Production and Storage Protocol, Version 1.1. (2025, April 25). https://registry.isometric.com/protocol/biochar#summary

Johnson, J. M. F., Novak, J. M., Varvel, G. E., Stott, D. E., Osborne, S. L., Karlen, D. L., Lamb, J. A., Baker, J., & Adler, P. R. (2014). Crop Residue Mass Needed to Maintain Soil Organic Carbon Levels: Can It Be Determined? *BioEnergy Research*, 7(2), 481–490. https://doi.org/10.1007/s12155-013-9402-8

Kane, S., Bin Thaneya, A., Gursel, A. P., Fan, J., Bose, B., Hendrickson, T. P., Nordahl, S. L., Scown, C. D., Miller, S. A., & Horvath, A. (2024). Uncertainty in determining carbon dioxide removal potential of biochar. *Environmental Research Letters*, 20(1), 014062. https://doi.org/10.1088/1748-9326/ad99e9

Lefebvre, D., Williams, A., Kirk, G. J. D., Meersmans, J., Sohi, S., Goglio, P., & Smith, P. (2021). An anticipatory life cycle assessment of the use of biochar from sugarcane residues as a greenhouse gas removal technology. *Journal of Cleaner Production*, 312, 127764. https://doi.org/10.1016/j.jclepro.2021.127764

Lehmann, J., Abiven, S., Azzi, E., Fang, Y., Singh, B. P., Sohi, S., Sundberg, C., Woolf, D., & Zimmerman, A. R. (2024). Persistence of biochar: Mechanisms, measurements, predictions. In *Biochar for Environmental Management* (3rd ed.). Routledge.

Lehmann, J., Cowie, A., Masiello, C. A., Kammann, C., Woolf, D., Amonette, J. E., Cayuela, M. L., Camps-Arbestain, M., & Whitman, T. (2021). Biochar in climate change mitigation. *Nature Geoscience*, 14(12), 883–892. https://doi.org/10.1038/s41561-021-00852-8

Li, H., Azzi, E. S., Sundberg, C., Karltun, E., & Cederlund, H. (2024). Can inert pool models improve predictions of biochar long-term persistence in soils? *Geoderma*, 452, 117093. https://doi.org/10.1016/j.geoderma.2024.117093

Ling, L., Luo, Y., Jiang, B., Lv, J., Meng, C., Liao, Y., Reid, B. J., Ding, F., Lu, Z., Kuzyakov, Y., & Xu, J. (2022). Biochar induces mineralization of soil recalcitrant components by activation of biochar responsive bacteria groups. *Soil Biology and Biochemistry*, 172, 108778. https://doi.org/10.1016/j.soilbio.2022.108778

Liu, L., Zhu, C., Fan, M., Chen, C., Huang, Y., Hao, Q., Yang, J., Wang, H., & Sun, D. (2015). Oxidation and degradation of graphitic materials by naphthalene-degrading bacteria. *Nanoscale*, 7(32), 13619–13628. https://doi.org/10.1039/C5NR02502H

Mitchell, E., Takeda, N., Grace, L., Grace, P., Day, K., Ahmadi, S., Badgery, W., Cowie, A., Simmons, A., Eckard, R., Harrison, M. T., Parton, W., Wilson, B., Orgill, S., Viscarra Rossel, Raphael A., Pannell, D., Stanley, P., Deane, F., & Rowlings, D. (2024). Making soil carbon credits work for climate change mitigation. *Carbon Management*, 15(1), 2430780. https://doi.org/10.1080/17583004.2024.2430780

Oldfield, E. E., Eagle, A. J., Rubin, R. L., Rudek, J., Sanderman, J., & Gordon, D. R. (2022). Crediting agricultural soil carbon sequestration. *Science*, 375(6586), 1222–1225. https://doi.org/10.1126/science.abl7991

Pirard, R. (2024). Is biochar a carbon dioxide removal? *BOIS & FORETS DES TROPIQUES*, 361, 1–8. https://doi.org/10.19182/bft2024.361.a37562

Puro.earth Biochar Methodology for CO2 Removal, Draft for Public Consultation, Edition 2025 V.0.9. (2025). https://7518557.fs1.hubspotusercontent-na1.net/hubfs/7518557/Biochar%20Public%20Consultation%202025/01_Puro%20Biochar%20Methodology%20-%20Edition%202025%20-%20Draft%20for%20consultation.pdf

Rathnayake, D., Schmidt, H.-P., Leifeld, J., Bürge, D., Bucheli, T. D., & Hagemann, N. (2024). Quantifying soil organic carbon after biochar application: How to avoid (the risk of) counting CDR twice? *Frontiers in Climate*, 6. https://doi.org/10.3389/fclim.2024.1343516

Rodrigues, L., Budai, A., Elsgaard, L., Hardy, B., Keel, S. G., Mondini, C., Plaza, C., & Leifeld, J. (2023). The importance of biochar quality and pyrolysis yield for soil carbon sequestration in practice. *European Journal of Soil Science*, 74(4), e13396. https://doi.org/10.1111/ejss.13396

Sanei, H., Petersen, H. I., Chiaramonti, D., & Masek, O. (2025). Evaluating the two-pool decay model for biochar carbon permanence. *Biochar*, 7(1), 9. https://doi.org/10.1007/s42773-024-00408-0

Sanei, H., Rudra, A., Przyswitt, Z. M. M., Kousted, S., Sindlev, M. B., Zheng, X., Nielsen, S. B., & Petersen, H. I. (2024). Assessing biochar's permanence: An inertinite benchmark. *International Journal of Coal Geology*, 281, 104409. https://doi.org/10.1016/j.coal.2023.104409

Sarkar, S., Skalicky, M., Hossain, A., Brestic, M., Saha, S., Garai, S., Ray, K., & Brahmachari, K. (2020). Management of Crop Residues for Improving Input Use Efficiency and Agricultural Sustainability. *Sustainability*, 12(23), Article 23. https://doi.org/10.3390/su12239808

Schmidt, H.-P., Abiven, S., & Hagemann, N. (2022). Permanence of soil applied biochar. An executive summary for Global Biochar Carbon Sink certification. *The Biochar Journal*, 69–74.

Tomczyk, A., Sokołowska, Z., & Boguta, P. (2020). Biochar physicochemical properties: Pyrolysis temperature and feedstock kind effects. *Reviews in Environmental Science and Bio/Technology*, 19(1), 191–215. https://doi.org/10.1007/s11157-020-09523-3

VM0044 Methodology for Biochar Utilization in Soil and Non-Soil Applications, Version 1.1. (2023). Verra. https://verra.org/wp-content/uploads/2023/07/VM0044-Methodology-for-Biochar-Utilization-in-Soil-and-Non-Soil-Applications-v1.1.pdf

Winders, T. M., Jolly-Breithaupt, M. L., Wilson, H. C., MacDonald, J. C., Erickson, G. E., & Watson, A. K. (2019). Evaluation of the effects of biochar on diet digestibility and methane production from growing and finishing steers. *Translational Animal Science*, 3(2), 775–783. https://doi.org/10.1093/tas/txz027

Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., & Joseph, S. (2010). Sustainable biochar to mitigate global climate change. *Nature Communications*, 1(1), Article 1. https://doi.org/10.1038/ncomms1053

Woolf, D., Lehmann, J., Ogle, S., Kishimoto-Mo, A. W., McConkey, B., & Baldock, J. (2021). Greenhouse Gas Inventory Model for Biochar Additions to Soil. *Environmental Science & Technology*, 55(21), 14795–14805. https://doi.org/10.1021/acs.est.1c02425

Zimmerman, A. R., & Ouyang, L. (2019). Priming of pyrogenic C (biochar) mineralization by dissolved organic matter and vice versa. *Soil Biology and Biochemistry*, 130, 105–112. https://doi.org/10.1016/j.soilbio.2018.12.011

Environmental Defense Fund

Headquarters
257 Park Avenue South
New York, NY 10010
T 212 505 2100
F 212 505 2375

Austin, TX
301 Congress Avenue
Austin, TX 78701
T 512 478 5161
F 512 478 8140

Bentonville, AR
1116 South Walton Boulevard
Bentonville, AR 72712
T 479 845 3816
F 479 845 3815

Boston, MA
18 Tremont Street
Boston, MA 02108
T 617 723 2996
F 617 723 2999

Boulder, CO
2060 Broadway
Boulder, CO 80302
T 303 440 4901
F 303 440 8052

Raleigh, NC
4000 Westchase Boulevard
Raleigh, NC 27607
T 919 881 2601
F 919 881 2607

Sacramento, CA
1107 9th Street
Sacramento, CA 95814
T 916 492 7070
F 916 441 3142

San Francisco, CA
123 Mission Street
San Francisco, CA 94105
T 415 293 6050
F 415 293 6051

Washington, DC
1875 Connecticut Avenue, NW
Washington, DC 20009
T 202 387 3500
F 202 234 6049

Beijing, China
C-501, Yonghe Plaza
28 East Andingmen East Road
Dongcheng District
Beijing 100007, China
T +86 10 6409 7088
F +86 10 6409 7097

La Paz, Mexico
Revolución No. 345
E/5 de Mayo y Constitución
Col. Centro, CP 23000
La Paz, Baja California Sur, Mexico
T +52 612 123 2029

London, UK
3rd Floor, 41 Eastcheap,
London EC3M 1DT
T +44 203 310 5909