Draft VCS Methodology

VM0044

BIOCHAR USE IN SOIL AND NON-SOIL APPLICATIONS

Draft Version 2.0

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Sectoral Scopes: 13 Waste Handling and Disposal,

and 17 Other Engineered Removals

Version 1.0 of this methodology was developed by Biochar Works, Delaney Forestry Services, Forliance, and South Pole. The lead authors were Hannes Etter (South Pole), Andrea Vera (Forliance), Chetan Aggarwal (South Pole), Matt Delaney (Delaney Forestry Services), and Simon Manley (Biochar Works).

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CONTENTS

1 SUMMARY DESCRIPTION

Project Category	Waste reduction and recycling Biomass-based carbon removals
Project Activity Type	Waste reduction and recycling Biochar production and application
Additionality	Project method
Crediting Baseline	Project method
Mitigation Outcome	Reductions and removals

This globally applicable methodology provides procedures and requirements to quantify greenhouse gas (GHG) emission reductions (reductions) and carbon dioxide removals (removals) from the adoption of improved waste handling and disposal of waste biomass though conversion into biochar for soil and non-soil applications. Project activities consist of three components:

- Sourcing biomass
- Producing biochar
- Using biochar for soil or non-soil applications

Project activities include the installation and operation of new (greenfield) biochar production facilities or production increases at existing biochar production facilities (see Section 9.2.2.3).

The baseline scenario is the continuation of pre-project waste handling and disposal practices, where the waste biomass would either be left to decay, be combusted for purposes other than energy production, or under certain conditions, combusted for energy purposes (see Section 4). Project proponents may quantify CH_4 emission reductions from improved waste handling and disposal practices at the sourcing stage[1] using applicable IPCC factors, peer-reviewed sources, or project-specific research (see Section 9.1.1).

[1] Excluding CH_4 emission reductions from reduced open field biomass burning

2 SOURCES

This methodology uses the following methodologies, tools, and guidelines:

- CDM *ACM0022 Alternative Waste Treatment Processes, v03.0*
- *VM0051 Improved Management in Rice Production Systems*
- *VT0008 Additionality Assessment*
- *VT0009 Combined Baseline and Additionality Assessment*
- *VT0010 Emissions from Electricity Consumption and Generation*
- CDM *TOOL03 Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion, v03.0*
- CDM *TOOL04 Emissions from Solid Waste Disposal Sites, v08.1*
- CDM *TOOL12 Project and Leakage Emissions from Transportation of Freight, v01.1.0*
- CDM *TOOL17 Baseline Emissions for Modal Shift Measures in Inter-Urban Cargo Transport, v01.0*
- CDM *Standard for Sampling and Surveys for CDM Project Activities and Programmes of Activities, v09.0*

3 DEFINITIONS

In addition to the definitions set out in the VCS *Program Definitions*, the following definitions apply to this methodology.

Anaerobic decomposition
The microbial breakdown of organic material in the absence of oxygen (e.g., in marine mud sediments or manure ponds), which emits methane (CH_4) and lesser amounts of carbon dioxide (CO_2)

Biochar
A solid and stabilized carbon material formed by thermochemical processing of biomass in an oxygen-limited environment through pyrolysis or gasification

Biochar production facility
One or a group of pyrolysis reactors that produce biochar; classified as either high-technology or low-technology

Biogenic material
A material that is produced by or originates from a living organism

Chain of custody
The process by which inputs, outputs, and associated information are transferred, monitored, and controlled through each step in a supply chain. In the context of this methodology, the chain of custody refers to tracking and documentation from the biomass sourcing stage through biochar production to biochar use in soil or non-soil applications.

End-use location
In the context of this methodology, the physical location where biochar produced in the project is used to generate carbon removals in soil or non-soil applications

Feedstock
In the context of this methodology, biogenic material used to create biochar via thermochemical conversion processes

Gasification
A technological process that converts carbon-based raw material into fuel gas, with some residual biochar as a by-product. Gasification occurs in a gasifier, generally at temperatures greater than 700 °C in the presence of controlled, but limited amounts of oxidants.

High-technology biochar production facility[2]
A biochar production facility in which:

- pyrolysis gas produced during thermochemical conversion is recovered and used for feedstock drying (where applicable), to heat pyrolysis kilns, or as a source of renewable bioenergy for external applications (i.e., pyrolysis gases are not allowed to escape into the atmosphere).
- fossil fuels are only used as startup fuels.
- pollution controls (e.g., thermal oxidizer) or other emissions controls meet the most stringent of local, national, or international emission thresholds.
- the production temperature is measured and reported.

Kon tiki kiln
A type of biochar-producing kiln that does not require external fuel for start-up and combusts pyrolysis gases in the flame curtain before their emission to the atmosphere[3]

Long-lived biochar product
Non-soil biochar application in which carbon is demonstrably stored for at least 100 years

Low-technology biochar production facility
A biochar production facility that does not meet the definition of high-technology biochar production facility

[2] Adapted from European Biochar Certificate (2022)

[3] Adapted from Cornelissen et al. (2023)

Non-soil application
In the context of this methodology, use of biochar for purposes other than as a soil amendment (e.g., as an additive in long-lasting products like cement, concrete, asphalt, or any other non-soil application with demonstrated long-term use and persistence)

Organic carbon content
The amount of organic carbon as a mass proportion (in percent) based on dry weight

Production lot
A continuous aggregation of biochar produced within a period of up to twelve consecutive months using the same biochar production technology, with process temperature varying by no more than ±50 °C, residence time varying by no more than ±10%, and feedstock composition varying by no more than ±10% of total input (dry mass-based). Continuous aggregation does not preclude short interruptions in production (e.g., for maintenance).

Pyrolysis
The thermochemical decomposition of biogenic material or compounds in an oxygen-deficient environment (oxidants are excluded), which produces a mixture of CO, H_2, CH_4, CO_2, N_2, and other higher hydrocarbons

Soil application
In the context of this methodology, use of biochar as a soil amendment through direct application to the soil surface or integration into subsoil, either as pure biochar or in a mixture (e.g., compost-biochar blend)

4 APPLICABILITY CONDITIONS

This methodology is applicable to project activities that entail installation and operation of new (greenfield) biochar production facilities or production increases at existing biochar production facilities by:

- sourcing biomass,
- producing biochar, and
- using biochar in soil or non-soil applications.

Where an existing biochar production facility increases its output, the increase may be eligible as a new project or as a new project activity instance in a grouped project.

This methodology is applicable under the following conditions:

4.1 Feedstock

1) The feedstock used to produce biochar:
    a) is purely biogenic biomass.
    b) would otherwise be used for one of the following:
        i) Left to decay
        ii) Combusted for purposes other than energy production.
        iii) combusted for energy purposes where one of the following applies:
            - In the baseline scenario, the feedstock is substituted for fossil diesel fuel to maintain the baseline level of energy output.
            - Bioenergy production continues without disruption in the baseline and without depleting feedstock resources as described in Appendix 1 Step (3)a).
    c) is eligible according to Table 1 or conforms to biomass sustainability criteria in a reputable biomass certification scheme (e.g., the Roundtable on Sustainable Biomaterials (RSB), International Sustainability and Carbon Certification (ISCC), or other certification program approved or endorsed by a relevant legislative body or international body such as the European Union,[4] CORSIA,[5] or national/state governments).

[4] Annex IX of EU Directive 2018/2001 of the European Parliament and of the European Council of 11 December 2018 on the promotion of the use of energy from renewable sources sets out the minimum requirements for certifying waste and residues.

[5] The International Civil Aviation Organization (ICAO) under its Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) approves certifications for eligible biofuels produced from eligible biomass to be used in international aviation to reach emission reduction targets.

Table 1. Feedstock eligibility criteria

Sourcing category	Eligibility criteria	Feedstock examples
Agricultural waste biomass directly from fields	One of the following applies: 1) Project activity would not lead to a decline in soil carbon stocks or a reduction in crop productivity. 2) In the baseline, the feedstock would be burned without energy production (e.g., open burning of stubble). 3) Feedstock removal by the project would not exceed 50% of total residues to protect against soil degradation (Andrew 2006; Battaglia et al. 2020).	Tree, vine, and shrub pruning Harvest residues (e.g., straw, leaves, stalks, husk, pomace, kernels) Fruit and vegetable residues
Food processing residues from food processing facilities	Facility production of residues does not increase specifically to produce biochar for the project.	Material from washing, cleaning, peeling, centrifugation, and separation processes Expired food residues Residues from processing in the food industry (e.g., coffee, tea, cocoa, tobacco)
Forestry and other wood processing	All of the following apply: 1) Feedstock from forests (as opposed to by-products of mill processing) is from a sustainable source and does not lead to deforestation or degradation, according to sustainable management plans approved by a relevant state or regional authority or forestry certification (e.g., Programme for the Endorsement of Forest Certification, PEFC or Forest Stewardship Council, FSC) or by meeting the VCS Program definition of renewable biomass. 2) Processed timber feedstock used for soil applications does not contain any paint residues, solvents, potentially toxic impurities, or other contaminants outside the definition of biogenic material.[6]	Cut-offs, sawdust, and other material produced as a by-product of forest management or harvesting operations Thinning from forest wildfire fuel reduction activities or areas designated by state, provincial, or federal authorities as overstocked[7] Burned woody biomass Any by-product from forest-based industries (e.g., wood pallets, wood waste, wastepaper, cardboard) Material from pruning or thinning of woody vegetation

[6] See Section 3.

[7] An overstocked forest has so many stems of a given species and size that severe competition for resources has reduced growth and put trees at risk of insect, disease, or wildfire mortality (Helms 1998).

	3) Creosote-treated wood feedstock does not exceed thresholds referred to in the most recent version of IBI *Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil* or EBC *Guidelines for a Sustainable Production of Biochar*.	(not including merchantable timber) (e.g., shade trees, orchards, windbreaks, stream buffers, silvopasture, invasive removal on rangeland) Diseased trees felled during plantation or woodland management (including from horticulture or pomiculture)
Recycling economy waste biomass	All of the following apply: 1) Feedstock does not exceed relevant thresholds for heavy metals and other contaminants as outlined in the most recent version of the World Biochar Certificate (WBC) *Guidelines for a Sustainable Production of Biochar and its Certification*. 2) The feedstock is the non-fossil fraction of industrial or municipal waste (CDM EB23 Annex 18). 3) Feedstock used for soil applications does not contain any paint residues, solvents, potentially toxic impurities, or other contaminants outside the definition of biogenic material.[6]	Urban/rural green cuttings Non-hazardous municipal solid waste Biosolids or sewage sludge from wastewater treatment Paper mill sludge Digestate from anaerobic digestion
Aquaculture plants	Feedstock is from the Plantae kingdom and a by-product of aquaculture.	Seaweed and algae
Animal manure	Feedstock is a by-product of animal husbandry.	Manure from swine, cattle, horse, and poultry farms
Invasive terrestrial and aquatic plants	All of the following apply: 1) The feedstock is an invasive species in the jurisdiction where plant harvesting would occur, as defined in the applicable version of the *VCS Program Definitions.* Appendix 4 lists some invasive species databases. 2) The feedstock supplier has an invasive species removal management plan approved by relevant authorities that addresses at least the following: a) Differentiation of invasive species from other species to avoid unintended clearing of native vegetation b) Prevention of invasive species from spreading into areas inside and/or outside of the removal operation site (e.g., by spreading seeds during harvest)	Invasive trees and shrubs (e.g., Russian olive *Elaeagnus angustifolia* in much of California and other Western states of the USA) Invasive aquatic plants (e.g., water hyacinth *Eichhornia crassipes* in Bangladesh and Vietnam)

	c) Prevention of invasive species regrowth after harvesting d) Minimization of negative side effects (e.g., soil erosion, damage to native or non-invasive plants, damage to waterways) e) Containment of propagules in an appropriate manner on site and during transport	

2) Feedstock for kon tiki kilns has less than 25% moisture content.[8]

3) Feedstock is sourced from the project host country or imported from countries that are in the same or a higher country income group as defined by the World Bank.[9]

4) The feedstock and resulting biochar is transported via electric train, diesel train, marine transport, light truck (less than 3.5 t), heavy truck, and/or motorbike.

5) Mineral additives (e.g., lime, rock minerals, ash) do not collectively exceed 10% of the total dry weight of the biochar, unless the final product meets IBI *Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil* (hereinafter referred to as the IBI Biochar Testing Guidelines) or EBC *Guidelines for a Sustainable Production of Biochar* thresholds for organic and inorganic contaminants.

4.2 Technological Scope

6) Either low- or high-technology biochar production facilities are used to produce biochar.

7) Where low-technology biochar production facilities are used, emissions of CH_4 and airborne particulates (especially black carbon) are minimized.[10]

8) The biochar producer has a health and safety program to protect workers from airborne pollutants and other hazards.

4.3 Post-Production and End-Use Application

9) Prior to end use in soil or non-soil applications, biochar is safely stored in line with the EBC *Guidelines for a Sustainable Production of Biochar* or WBC *World Biochar Certificate – Guidelines for a Sustainable Production of Biochar and its Certification* to minimize the risk of loss due to fire, wind, or other causes.

[8] To minimize CH_4 emissions (Cornelissen et al. 2023)

[9] Available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

[10] Examples of low-technology systems that meet the criteria for minimizing CH_4 and soot are those that harness natural convection to create a combustion zone above the pyrolysis zone. Otherwise, excess methane may be produced, particularly at start-up and shut-down, and may counter the long-term sequestration benefits of biochar.

10) Biochar is used in accordance with relevant national or local regulations.

11) Biochar used in soil applications:

   a) is used as a soil amendment on cropland, grassland, constructed wetlands, vegetated urban soils, or forest.

   b) is used in accordance with best practices and recommendations for biochar soil applications.[11]

   c) does not exceed local or national thresholds for application of biochar to soils, where such thresholds exist.

   Note – Where overlapping regulations exist, thresholds established in regulations closest to the project location or at the smallest geographical scale should take precedence.

   d) for surface application, is mixed with other substrates such as compost, manure, or digestate from anaerobic digestion.

   e) for subsurface application, is applied either as pure biochar or mixed with other substrates.

12) Biochar used in non-soil applications is:

   1) produced in high-technology biochar production facilities.

   2) not combusted at the end of life of the product in which the biochar is used.

13) Non-soil biochar-based products or materials are classified as long-lived biochar products and biochar will be protected from microbial decomposition over the product lifetime. Evidence to demonstrate this may include:

   a) Recycling/reutilization chains for equivalent products (e.g., traditional cement) that demonstrate that the carbon-containing material will be recovered and remain in the product for at least 100 years. Current recycling rates of the equivalent product in the jurisdiction where the biochar-based product will be applied must be above 50% (mass or unit-based).

   b) National waste management statistics specific to the type of material disposed of, showing the material is landfilled or otherwise disposed of at its end of life in a way that leads to less than 50% loss of carbon based on current practices

   c) Peer-reviewed literature that demonstrates that the product will remain in service for at least 100 years, including anticipated future changes in technologies or other developments that may impact the useful life of products

14) Where the non-soil biochar-based product has a lifespan shorter than 100 years,[12] the carbon remains securely stored for 100 years with no significant risk of its release into the atmosphere. Evidence to demonstrate this must include one of the following:

[11] For example, IBI (2010)

[12] For example, asphalt has a typical lifetime of 15–30 years.

a) Life cycle analysis

b) Credible modelling approaches (e.g., peer-reviewed dynamic material flow analysis models or infrastructure durability models)

c) Monte Carlo simulation methods

Note – Tools such as the LiVES database or the Product Lifetimes & Durability Portal are not sufficient evidence of forward-looking product lifetimes in any given jurisdiction.

15) Non-soil applications of biochar meet the eligibility criteria listed in Table 2.

Table 2. Eligible non-soil applications of biochar

Material	Eligibility	Justification
Concrete and other cementitious materials (excluding gypsum)	Eligible where any alteration of physical or chemical properties due to incorporation of biochar adheres to all applicable national and international safety and building regulations	Long-lived durable product in which biochar is protected from microbial decomposition. Soil permanence factors are conservative estimates of permanence.
Asphalt	Eligible where not used as a fuel or for conversion to a fuel, either initially or as waste	Long-lived durable product in which biochar is protected from microbial decomposition. Biochar considered unlikely to be mineralized during product recycling.
Permanent storage structures (e.g., spent oil or gas wells, subsurface mines, dedicated biochar landfill)	Eligible where not used in enhanced oil or gas recovery and where complying with all relevant environmental laws, regulations, and standards	Permanence is expected to be at least as long as in soils.
Gypsum, plaster, and other materials (excluding plastics, polymers, steel, and filtration media)	To be reviewed on case-by-case basis	Currently limited or no evidence in peer-reviewed scientific literature. Evidence must be provided to support: 1) the longevity of the material. 2) that biochar will remain encapsulated within the material for its entire lifetime where it will be protected from microbial decomposition. 3) that permanence of the biochar's organic carbon within the material is at least as high as that in soils.

		4) that production of the material is additional.

This methodology is not applicable under the following conditions:

16) Biomass is purpose-grown for use as feedstock.

Note – Harvest residues (e.g., straw, husks) from crops purpose-grown for energy are allowed provided they are listed on the World Biochar Certificate (WBC) feedstock positive list.[13]

17) The production of biochar uses torrefaction and/or hydrothermal carbonization processes.

18) Biochar is used for energy generation, burned as a fuel (e.g., as a substitute for charcoal or coke), or used in other soil or non-soil applications where it is not demonstrated to provide long-term carbon storage.

19) Substantial amounts of biochar are oxidized during application (e.g., burned or used as a reduction agent in steel production, processed into activated carbon, or other uses that are fossil fuel-intensive).

20) Biochar is used as a soil amendment on natural wetlands.[14]

21) Non-soil applications of biochar include any of the following:

    1) Plastics and polymers

    2) Steel

    3) Filtration media

22) Pure, unblended biochar is distributed through retail sales that do not maintain chain of custody and geolocation data for the final point of application.

5 GENERAL IMPLEMENTATION

5.1 Project Start Date

The project start date must be established in accordance with the applicable versions of the *VCS Standard* and *VCS Program Definitions*.

[13] Available at: https://www.carbon-standards.com/en/standards/service-514~production-of-biochar.html.

[14] Natural wetlands differ from managed wetlands which are created through human activity (e.g., damning a river) or in which the water table is artificially changed (e.g., rice paddies).

When determining the project start date, the following types of actions must be considered, as applicable:

1) Signing contract to construct biochar facility
2) Signing contract to purchase equipment for biochar production
3) Beginning of construction or initiation of on-site fabrication of kilns

5.2 Initial Crediting Period Start Date

The initial crediting period start date is determined by the date on which biochar production under the project activity starts. For project activities involving production increases, this corresponds to the operational start date of the increase. Where multiple new facilities and/or production increases are included, the initial crediting period start date is the earliest production start date of these activities.

Project proponents must provide verifiable evidence of production start dates (e.g., production logs, equipment commissioning records, dated operational reports).

Where biochar production has not commenced before project validation, the project proponent must provide an estimated start date and determine the actual initial crediting period start date once biochar production has begun.

5.3 Crediting Period Renewal

Project proponents must renew the project crediting period in accordance with the VCS Program rules.

Note — Under the VCS Standard, projects may be eligible for additional crediting period renewals where specified in the applied methodology. Verra may revise this methodology to allow further crediting period renewals under specific conditions, such as high operating costs and no or limited revenues other than from carbon credit sales.

5.4 Methodology Transition

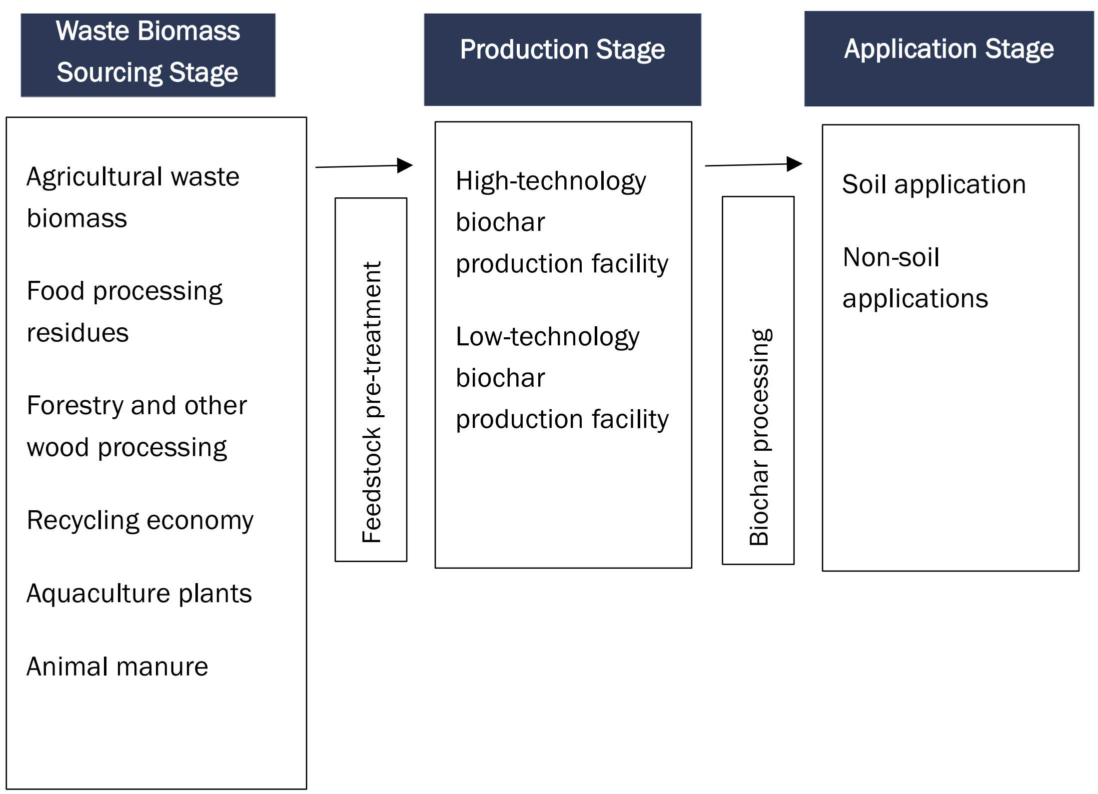
Projects transitioning from earlier versions of *VM0044* to this version must follow the VCS Program rules. Those seeking to quantify reduced CH_4 emissions from improved waste handling and disposal must reassess the baseline scenario in accordance with Section 7.

6 PROJECT BOUNDARY

The spatial extent of the project boundary (Figure 1) encompasses the geographic area in which:

1) biomass is sourced,
2) biomass is treated through eligible thermochemical technologies to produce biochar, and
3) soil or non-soil application of biochar occurs.

Figure 1. Project boundary



The greenhouse gases included in or excluded from the project boundary are shown in Table 3 below.

Table 3. GHG sources and sinks accounted for as baseline, project, and leakage emissions

	Source/Sink	Type	Gas	Included?	Justification/Explanation
Baseline	Carbon stored in feedstock	Sink	CO_2	Yes	Major sink
			CH_4	No	Conservative to exclude
			N_2O	No	Conservative to exclude
			Other	No	No other greenhouse gases
	Feedstock production	Source	CO_2	No	Feedstock is considered renewable, per eligibility conditions in Section 4.
			CH_4	No	
			N_2O	No	
			Other	No	
	Waste handling and disposal	Source	CO_2	Yes	Included
			CH_4	Optional	May be included where project avoids biomass waste landfilling, rice straw burning, or anaerobic manure management.
			N_2O	No	Conservative to exclude
			Other	No	No other greenhouse gases
	Feedstock transportation	Source	CO_2	No	Conservative to exclude
			CH_4	No	Conservative to exclude
			N_2O	No	Conservative to exclude
			Other	No	No other greenhouse gases
	Combustion, and anaerobic and aerobic decomposition of feedstock	Source	CO_2	No	Possible emissions from decay or combustion of feedstock in absence of project activity are excluded. Baseline emissions conservatively assumed to be zero.
			CH_4	No	
			N_2O	No	
			Other	No	
Project	Carbon stored in feedstock	Sink	CO_2	Yes	Major sink
			CH_4	No	Conservative to exclude
			N_2O	No	Conservative to exclude
			Other	No	No other greenhouse gases
	Waste handling and disposal	Source	CO_2	No	Excluded as carbon is permanently stored in biochar
			CH_4	Optional	May be included where project avoids biomass waste landfilling, rice straw burning, or anaerobic manure management
			N_2O	No	Excluded

			Other	No	No other greenhouse gases
	Feedstock production	Source	CO_2	No	Feedstocks eligible under this methodology conform to the definition of renewable biomass. Purpose-grown crops are ineligible so there are no emissions from feedstock production.
			CH_4	No	
			N_2O	No	
			Other	No	
	Feedstock transportation	Source	CO_2	Yes/No	Considered per CDM *TOOL12 Project and Leakage Emissions from Transportation of Freight, v01.1.0.* Must be included where return trip transportation distance is greater than 200 km; de minimis otherwise.
			CH_4	Yes/No	
			N_2O	Yes/No	
			Other	No	No other greenhouse gases
	Pyrolysis or thermochemical conversion in high-technology biochar production facility	Source	CO_2	No	High-technology biochar production facilities have pollution controls including avoidance of GHG emissions.
			CH_4	No	
			N_2O	No	
			Other	No	
	Pyrolysis or thermochemical conversion in low-technology biochar production facility	Source	CO_2	No	Project proponents must use a default value from Cornelissen et al. (2016).
			CH_4	Yes	
			N_2O	No	
			Other	No	
	Electricity and/or fossil fuels consumed during eligible thermochemical process	Source	CO_2	Yes	Emissions associated directly with project activity
			CH_4	No	Excluded as per provisions of CDM *TOOL03 Tool to Calculate Project or Leakage CO_2 Emissions from Fossil Fuel Combustion, v03.0* and VCS tool *VT0010 Emissions from Electricity Consumption and Generation*
			N_2O	No	
			Other	No	No other greenhouse gases
	Biochar transportation	Source	CO_2	Yes/No	Considered per CDM *TOOL12.* Must be included where return trip transportation distance is greater than 200 km; de minimis otherwise.
			CH_4	Yes/No	
			N_2O	Yes/No	
			Other	No	No other greenhouse gases
	Pre-treatment of feedstock (e.g., grinding, drying)	Source	CO_2	Yes	Emissions associated directly with project activity
			CH_4	No	Excluded as per provisions of CDM *TOOL03*
			N_2O	No	Excluded as per provisions of CDM *TOOL03*
			Other	No	No other greenhouse gases

	Biochar use	Source	CO_2	No	Emissions resulting from fossil fuel combustion or mixing of biochar with fertilizer products or other substrates considered de minimis
			CH_4	No	Excluded as per provisions of CDM *TOOL03*
			N_2O	No	Excluded as per provisions of CDM *TOOL03*
			Other	No	No other greenhouse gases
Leakage	Leakage emissions	Source	CO_2	No	Leakage emissions are considered zero in this methodology.
			CH_4	No	
			N_2O	No	
			Other	No	

7 BASELINE SCENARIO

7.1 Identifying Alternative Baseline Scenarios

The baseline scenario is where, in the absence of the project activity, biomass is used for the purposes outlined in Section 4.1(1)(b).

For projects involving production increases at existing biochar production facilities, plausible alternative baseline scenarios must include the continuation of current operations without increase (i.e., “business-as-usual” operation at pre-existing production levels). In addition, project proponents must consider alternative scenarios that reflect evolving market conditions, including potential increases or shifts in demand for biochar or competing uses of feedstock. The alternative scenarios must include quantification of any changes in the baseline biochar production rate that would have happened independent of the production increase in the project.

Project proponents must use the procedures in Section 7.2 to identify which of the alternative scenarios are relevant to the project.

7.2 Selecting the Baseline Scenario

Project proponents must provide credible and verifiable evidence demonstrating which of the alternative scenarios identified in Section 7.1 is the most plausible and realistic given the project context. Evidence of the alternative scenarios must cover a period of at least the three years preceding the project start date, unless a shorter timeframe is justified. Such evidence must be provided in one or more of the following forms, listed in descending order of preference:

1) Records of a waste disposal or biochar production facility
2) Records from relevant government agencies
3) Signed attestations from local experts (e.g., regulatory or agricultural agencies)
4) Existing literature, reports, or survey data from industries in the region
5) Novel survey or research by the project proponent

Where the project proponent seeks to quantify reduced CH_4 emissions from improved waste handling and disposal, the full procedures and requirements of the stated sections of the following methodologies and tools must be applied to establish the baseline for the feedstock used in the project:

a) For avoided rice straw burning, use Section 6 of VCS methodology *VM0051 Improved Management in Rice Production Systems* to determine baseline practices related to burning crop residues (i.e., rice straw) for at least three years preceding the initial crediting period start date or initiation of validation (defined as the start date of desk review by the validation/verification body (VVB)), whichever is earlier.
b) For avoided landfilling in solid waste disposal sites (SWDSs), use Section 5 of VCS tool *VT0009 Combined Baseline and Additionality Assessment* and paragraph 16 in Section 5.1 of CDM methodology *ACM0022 Alternative Waste Treatment Processes*[15] to determine baseline practices for treatment of fresh waste in SWDSs (e.g., disposal of fresh waste in an SWDS with partial capture and flaring of the landfill gas, disposal of fresh waste in an SWDS without a landfill gas capture system).
c) For diversion from manure management, use Section 5 of *VT0009* and Section 4.3 of CDM methodology *AMS-III.D. Methane Recovery* in *Animal Manure Management Systems* and the related Correction and Clarification document (C&C).[16] The applicability criteria in Section 3 in *AMS-III.D.* must be met.

Project proponents must explain and document transparently in the project description the biomass categories that are used in the project and the corresponding baseline scenarios. Project proponents must describe the following aspects:

i) Category (e.g., bagasse, rice husks, empty fruit bunches, agricultural waste)
ii) Source (e.g., produced on-site, obtained from an identified biomass residue producer, obtained from a biomass residue market)
iii) Fate in the absence of the project activity (see Appendix 1 for detailed procedures)
iv) Conformance to eligibility criteria for the respective category, as indicated in Table 1

For validation, an ex-ante estimation of these aspects must be provided.

[15] Available at: https://verra.org/methodologies/alternative-waste-treatment-processes/

[16] Available at: https://verra.org/methodologies/methane-recovery-in-animal-manure-management-systems/

For projects involving production increases, project proponents must justify which alternative scenario is the most plausible. This includes explaining any assumed or observed changes in supply and demand, as well as broader market dynamics that may influence biochar production levels. Broader market dynamics may include factors such as shifts in demand for biochar or its end uses, changes in feedstock availability and competing uses, price signals, policy or regulatory developments, and other relevant economic or operational conditions. Demonstration of these factors must be credible, data-driven, and representative of realistic conditions in the absence of the project.

7.3 Baseline Reassessment

Baseline reassessment must be conducted in accordance with the applicable VCS Program rules and Section 7.1.

8 ADDITIONALITY

This methodology uses the project method to demonstrate additionality. Project proponents must determine additionality using the procedure described in Sections 8.1–8.3.

8.1 Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the applicable version of the *VCS Standard*.

Where regulatory surplus is demonstrated, proceed to Section 8.2. Otherwise, the project activity is not additional.

8.2 Investment Analysis

Project proponents must follow the procedures and requirements of Step 3 in VCS tool *VT0008 Additionality Assessment* to conduct an investment analysis through either an investment comparison analysis (Option 1) or a benchmark analysis (Option 2).

Project proponents must clearly describe the contribution of the following key revenue streams, as applicable, to the overall financial viability of the proposed project:

1) Revenues from energy sales – total per year as well as approximate revenue per energy unit (e.g., USD/MWh or USD/GJ)
2) Revenues from material sales – total per year as well as approximate revenue per unit (e.g., USD/tonne of biochar material; USD/liter of wood vinegar)

3) Revenues from waste management service sales / tipping fees – total per year as well as approximate revenue per mass unit (e.g., USD/tonne of feedstock, moisture content as delivered)

Where all conditions of the investment analysis per *VT0008* are met, proceed to Section 8.3. Otherwise, the project activity is not additional.

8.3 Common Practice Analysis

Project proponents must assess whether the project activity is common practice, following the procedures and requirements of Step 4 in *VT0008*.

Where the project activity meets the requirements in Sections 8.1–8.2 and is not a common practice, it is deemed additional. Otherwise, it is not additional.

9 QUANTIFICATION OF REDUCTIONS AND REMOVALS

Reductions and removals are generated through the adoption of improved handling and disposal of waste biomass through conversion into biochar for soil and non-soil applications. The net climate benefit of biochar projects is influenced by many factors (e.g., feedstock, thermochemical conversion technology, pre- and post-processing, transportation).[17] Baseline and project emissions consider fluxes of CH_4 and CO_2.

To facilitate the inclusion of various feedstocks, production technologies, and biochar end-uses, quantification is set up in a framework that allows a flexible and comprehensive approach to estimate the climate impacts of the biochar value chain. This framework includes:

- sourcing, the stage in which biomass is sourced and collected (including optionally CH_4 emission reductions from improved waste handling and disposal procedures),
- production, during which biomass is prepared and thermochemically converted into biochar, and
- application, the stage in which biochar is applied to a long-term end use in soils or eligible non-soil applications.

[17] See Appendix 2 for biochar background information considered for this methodology.

9.1 Baseline Emissions

9.1.1 Sourcing Stage

Feedstock eligible under this methodology is classified as renewable biomass.[18] Although biomass decomposition or combustion would result in GHG emissions in the baseline scenario, the methodology conservatively defines default net baseline emissions at the sourcing stage ($BE_{SS,y}$) to be zero.[19]

Project proponents seeking to claim reductions from improved handling and disposal of waste biomass may optionally quantify CH_4 emission reductions using Equation (1), where the baseline scenario for the feedstock is one or a combination of the following:

1) Rice straw burning
2) Landfilling in an SWDS without CH_4 capture
3) Anaerobic manure management without CH_4 capture

$$BE_{SS,y} = BE_{RSB,y} + BE_{SWDS,y} + BE_{MM,y} \quad (1)$$

Where:

$BE_{SS,y}$ = Baseline emissions at the sourcing stage in year *y* (t CO_2e)
$BE_{RSB,y}$ = Baseline emissions from rice straw burning in year *y* (t CO_2e)
$BE_{SWDS,y}$ = Baseline emissions from landfilling in SWDSs in year *y* (t CO_2e)
$BE_{MM,y}$ = Baseline emissions from anaerobic manure management in year *y* (t CO_2e)

Procedures to estimate baseline emissions for each of the three baseline scenario use cases in are provided below. Reductions resulting from improved waste handling and disposal are quantified separately from removals resulting from biochar application (see Section 9.5).

9.1.1.1 Methane Emissions from Rice Straw Burning ($BE_{RSB,y}$)

The following equation must be used to quantify CH_4 emissions from rice straw burning, where applicable:[20]

$$BE_{RSB,y} = A \times M_{rs} \times CF_{rs} \times EF_{CH4rs} \times GWP_{CH4} \times 0.9 \times 10^{-6} \quad (2)$$

Where:

$BE_{RSB,y}$ = Baseline emissions from rice straw burning in year *y* (t CO_2e)

[18] According to the *VCS Program Definitions*

[19] This includes emissions related to transportation of biomass in the baseline scenario.

[20] Adapted from Equation 2.27 in Chapter 2, Volume 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

A	= Area burned (ha)
M_{rs}	= Mass of rice straw available for combustion (kg/ha)
CF_{rs}	= Combustion factor for rice straw as proportion of pre-fire fuel biomass consumed (fraction)
EF_{CH4rs}	= Methane emission factor for rice straw burning (g CH_4/kg dry matter burned)
GWP_{CH4}	= Global warming potential of methane (t CO_2e/t CH_4)
0.9	= Discount factor to account for the fraction of rice straw residue that remains unburned and is incorporated into the soil organic carbon pool[21]
10^{-6}	= Conversion factor for grams to tonnes

9.1.1.2 Methane Emissions from Solid Waste Disposal Sites ($BE_{SWDS,y}$)

Where applicable, CH_4 emissions from SWDSs are quantified using CDM *TOOL04 Emissions from Solid Waste Disposal Sites*[22] following the procedures for Application Type B.

9.1.1.3 Methane Emissions from Manure Management ($BE_{MM,y}$)

Where applicable, CH_4 emissions from manure management are quantified using CDM *AMS-III.D.* and the related C&C, following the procedures for baseline emissions. Projects must meet the applicability criteria in Section 3 of *AMS-III.D*.

9.1.2 Production Stage

As indicated in Section 6, no removals or emissions are considered for the production stage in the baseline scenario.

9.1.3 Application Stage

As indicated in Section 6, no removals or emissions are considered for the application stage in the baseline scenario.

[21] The default CF_{rs} for rice straw specified in IPCC (2019) is 0.8, indicating that 20% of the biomass is expected to remain unburned. This methodology conservatively assumes that half of the unburned biomass (i.e., 10%) would be incorporated into the soil organic carbon pool.

[22] Available at https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-04-v8.1.pdf

9.2 Project Emissions

9.2.1 Sourcing Stage

At the sourcing stage, projects involve the collection of renewable biomass from waste streams. Therefore, feedstock production emissions at the sourcing stage ($PE_{SS,y}$) are set to zero.

Where the return trip distance is greater than 200 km, emissions from transporting feedstock from its source location to the biochar production facility ($PE_{FT,p,y}$) must be calculated using CDM *TOOL12 Project and Leakage Emissions from Transportation of Freight,*[23] using actual fuel consumption (Option A) or default emission factors (Option B).

9.2.2 Production Stage

In the project scenario, the net GHG balance depends on the organic carbon content at the biochar production stage. Equation (3) summarizes the carbon balance at the production stage by comparing the difference between the stabilized carbon content in the biochar and the resulting project emissions from feedstock pre-treatment (where applicable) and from conversion of feedstock into biochar. The stabilized carbon content in the biochar includes emissions from energy consumption for drying and pre-processing feedstocks, and the pre-treatment emissions include other relevant emissions from the biochar production facilities.

The project removals during production at the biochar facility are calculated as follows:

$$CR_{PS,y} = \sum_{b}\left(\left(\sum_{k} SC_{b,k,y} \times \frac{44}{12}\right) - \left(\sum_{p} PE_{PS,b,p,y}\right)\right) \tag{3}$$

Where:

$CR_{PS,y}$	= Removals at production stage in year *y* (t CO_2e)
$SC_{b,k,y}$	= Sequestered organic carbon on a dry weight basis for biochar production lot *b* used for application type *k* in year *y* (tonnes)
$PE_{PS,b,p,y}$	= Project emissions at production stage for production of biochar production lot *b* at biochar production facility *p* in year *y* (t CO_2e)
$\frac{44}{12}$	= Coefficient to convert organic carbon to t CO_2e

The sequestered organic carbon ($SC_{b,k,y}$) is derived from the mass of biochar produced, its organic carbon content, and the decay rate of organic carbon in biochar over 100 years (100-year permanence value, which is based on a 100-year global warming potential horizon).

The total sequestered organic carbon content on a dry weight basis attributable to the project activity is estimated as follows:

[23] Available at https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-12-v1.1.0.pdf

$$SC_{b,k,y} = \sum_{p} \left(M_{b,k,p,y} - M_{BAU,b,k,p}\right) \times F_{Cp,b,p} \times PR_{de,b,k} \tag{4}$$

Where:

$SC_{b,k,y}$ = Sequestered organic carbon on a dry weight basis for biochar production lot *b* used for application type *k* in year *y* (tonnes)

$M_{b,k,p,y}$ = Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in year *y* (tonnes)

$M_{BAU,b,k,p}$ = Historic maximum production on a dry weight basis for biochar production lot *b* used for application type *k* produced at biochar production facility *p* during the three years immediately prior to the project start date; equal to zero for greenfield (entirely new) facility (tonnes)

$F_{Cp,b,p}$ = Organic carbon content of biochar production lot *b* produced in biochar production facility *p* per tonne of biochar, taken on a dry weight basis (percent)

$PR_{de,b,k}$ = Permanence adjustment factor due to decay of biochar per biochar production lot *b* used for application type *k* (dimensionless)

As biochar production facilities and technologies differ in terms of potential to measure and report relevant parameters, the methodology provides two options to derive the parameters for Equation (4)***Error! Reference source not found.***, based on characteristics of the technology used in the biochar production facility (high technology, Section 9.2.2.1 or low technology, Section 9.2.2.2). Further details are provided in the parameter tables in Section 10.

Emissions in the project scenario ($PE_{PS,b,p,y}$) are determined using the following equation:

$$PE_{PS,b,p,y} = \left(P_{ED,p,y} + P_{EP,p,y} + P_{EC,p,y}\right) \times \frac{\sum_b \sum_k M_{b,k,p,y}}{M_{p,y}} \tag{5}$$

Where:

$PE_{PS,b,p,y}$ = Project emissions at production stage for production of biochar production lot *b* at biochar production facility *p* in year *y* (t CO_2e)

$P_{ED,p,y}$ = Emissions associated with pre-treatment of feedstock at biochar production facility *p* in year *y*; equal to zero where renewable energy is used (t CO_2e)

$P_{EP,p,y}$ = Emissions associated with the conversion of feedstock to biochar at biochar production facility *p* in year *y*; equal to zero for high-technology biochar production facilities (t CO_2e)

$P_{EC,p,y}$ = Emissions from use of auxiliary energy for pyrolysis at biochar production facility *p* in year *y*; equal to zero where renewable energy is used (t CO_2e)

$M_{b,k,p,y}$ = Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in year *y* (tonnes)

$M_{p,y}$ = Total mass of biochar on a dry weight basis produced in biochar production facility *p* in year *y* (tonnes)

Energy consumption from non-renewable sources for pre-treatment of feedstock must be accounted for. This may include feedstock preparation (e.g., feedstock agglomeration, homogenization, pelletizing) either inside the biochar production facility or in field preparation, drying of wet biomass, and other processes.

$$P_{ED,p,y} = P_{EDE,p,y} + P_{EDF,p,y} \tag{6}$$

Where:

$P_{ED,p,y}$ = Emissions associated with pre-treatment of feedstock at biochar production facility *p* in year *y*; equal to zero where renewable energy is used (t CO_2e)

$P_{EDE,p,y}$ = Emissions associated with use of grid-connected electricity for pre-treatment of feedstock at biochar production facility *p* in year *y* (t CO_2e)

$P_{EDF,p,y}$ = Emissions associated with combustion of fossil fuels used for pre-treatment of feedstock at biochar production facility *p* in year *y* (t CO_2e)

Where external energy is required to initiate and maintain the pyrolysis reactor, it must be considered under project emissions as follows.

$$P_{EC,p,y} = P_{ECE,p,y} + P_{ECF,p,y} \tag{7}$$

Where:

$P_{EC,p,y}$ = Emissions from use of auxiliary energy for pyrolysis at biochar production facility *p* in year *y*; equal to zero where renewable energy is used (t CO_2e)

$P_{ECE,p,y}$ = Emissions associated with use of grid-connected electricity to start pyrolysis reactor at biochar production facility *p* in year *y* (t CO_2e)

$P_{ECF,p,y}$ = Emissions associated with combustion of fossil fuels used to start pyrolysis reactor at biochar production facility *p* in year *y* (t CO_2e)

9.2.2.1 Parameters Specific to High-Technology Biochar Production Facilities

This section applies only to biochar production facilities that meet the definition of a high-technology biochar production facility as defined in Section 3.

The organic carbon content of the produced biochar ($F_{Cp,b,p}$) must be derived from material analysis conducted via established laboratory and standardized methods. Project proponents must determine organic carbon content on a dry weight basis using methods described in the most recent versions of the IBI Biochar Testing Guidelines or EBC *Guidelines for a Sustainable Production of Biochar,* or other internationally or nationally accredited standards.

The permanence adjustment factor due to decay of biochar ($PR_{de,b,k}$) must be established for soil or non-soil end-use. Default decay values are provided for biochar used in soil applications. Where biochar is produced for eligible non-soil applications, the project proponent must either provide and justify a permanence value or apply conservative default factors (i.e., the soil decay value).

For soil end-use: Conservative defaults for $PR_{de,b,k}$ are calculated using Equation (8)

$$PR_{de,b,k} = c_{hc,k} - (m_{hc,k} \times HC_b) \tag{8}$$

and Table 4 below, which draw from IPCC (2019) and Woolf et al. (2021) respectively.

$$PR_{de,b,k} = c_{hc,k} - (m_{hc,k} \times HC_b) \tag{8}$$

Where:

$PR_{de,b,k}$ = Permanence adjustment factor due to decay of biochar per production lot *b* used for application type *k* (dimensionless)

$c_{hc,k}$ = Linear regression coefficient representing the intercept of the $PR_{de,b,k}$ curve, using values provided in Table 4 (dimensionless)

$m_{hc,k}$ = Linear regression coefficient representing the slope of the $PR_{de,b,k}$ curve, using values provided in Table 4 (dimensionless)

HC_b = Hydrogen to organic carbon ratio of biochar production lot *b*

Values for $c_{hc,k}$ and $m_{hc,k}$ depend on mean annual soil temperature at the end-use location (Table 4). Mean annual soil temperature should be calculated for the smallest geographic region within which biochar will be applied in the project (e.g. farm, county, country, depending on the project scope). A global average cropland soil temperature of 10.9 °C may be used as a default where the location cannot be specified more precisely. Soil temperatures can be derived from van den Hoogen et al. (2022).[24]

Where Equation (8) returns a value of $PR_{de,b,k}$ that is greater than one, a default value of $PR_{de,b,k}$ = 1.0 must be used.

Table 4. Linear regression coefficients for biochar decay curve (from Table 3 in Woolf et al. 2021)

Soil temperature (°C)	$c_{hc,k}$	$m_{hc,k}$
<7.5	1.13	0.46
7.5–12.5	1.10	0.59
12.5–17.5	1.04	0.64
17.5–22.5	1.01	0.65
>22.5	0.98	0.66

For non-soil end-use: For non-soil applications involving concrete and other cementitious materials (excluding gypsum), asphalt, or permanent storage structures, Equation (8) must be used with the most conservative values for both $c_{hc,k}$ and $m_{hc,k}$ to calculate $PR_{de,b,k}$ unless scientifically robust information is provided to justify a different value.

[24] Using the file for annual mean temperature at 0–5 cm depth

For other non-soil applications, project proponents must select a scientifically robust value for $PR_{de,b,k}$ from peer-reviewed literature. The proposed value must include any sequestration reversals expected to occur over 100 years, including during recycling or disposal of the material at the end of life. Where a range of values is given for $PR_{de,b,k}$, the project proponent must adopt the lower value to ensure conservativeness.

Applications with $PR_{de,b,k}$ of less than 0.5 are not eligible under this methodology. $PR_{de,b,k}$ may only be equal to one for concrete or asphalt applications.[25]

9.2.2.2 Parameters Specific to Low-Technology Biochar Production Facilities

This section applies to biochar production facilities that do not meet the definition of a high-technology biochar production facility in Section 3. Low-technology biochar production facilities usually have lower efficiency and often lack emissions controls. For low-technology biochar production facilities, a conservative approach is used to estimate sequestered organic carbon.

Where there is open burning in the baseline and kon tiki kilns are used, feedstock moisture must be reduced to acceptable levels following the *Global Artisan C-Sink Guidelines for Carbon Sink Certification for Artisan Biochar Production*.[26]

The organic carbon content ($F_{Cp,b,p}$) is determined in one of two ways:

1) In a qualified laboratory following IBI Biochar Testing Guidelines or EBC *Guidelines for a Sustainable Production of Biochar*
2) Using F_{Cp} default values from Woolf (2021) for different feedstocks and production types (Table 5) or alternative values from peer-reviewed literature or third-party analysis for feedstocks not included in Table 5

Table 5. Values for organic carbon content in biochar (from Table 2 of Woolf et al. 2021)

Feedstock	F_{Cp} as a function of pyrolysis temperature			
	Low	Medium	High	Gasification
Bagasse	0.57	0.62	0.64	0.43
Bamboo	0.66	0.72	0.75	0.51
Herbaceous	0.60	0.65	0.66	0.38
Maize stover	0.63	0.68	0.70	0.45
Manure	0.39	0.39	0.39	0.14
Paper sludge	0.39	0.41	0.42	0.12
Pits, shells, stones	0.67	0.73	0.76	0.52
Rice residues	0.46	0.48	0.48	0.20
Sewage sludge	0.35	0.37	0.38	0.10

[25] This may be revised as additional research on asphalt permanence becomes available.

[26] Available at: https://www.ceres-cert.de/en/services/service-625~global-artisan-c-sink.html

Wheat straw	0.59	0.64	0.65	0.38
Wood	0.70	0.77	0.81	0.63

Conservative defaults for the permanence adjustment factor due to decay ($PR_{de,b,k}$) are provided in Table 6, based on the mean annual soil temperature at the end-use location where biochar is applied and the pyrolysis temperature of biochar production. Mean annual soil temperature should be calculated for the smallest geographic region within which biochar will be applied in the project (e.g., farm, county, country, depending on the project scope). A global average cropland soil temperature of 10.9 °C may be used as a default where the location cannot be specified more precisely. Soil temperatures can be derived from van den Hoogen et al. (2022).[27] Where pyrolysis temperature is not measured and controlled, values for low temperature pyrolysis must be used.

Table 6. Permanence adjustment factor ($PR_{de,b,k}$) as a function of soil temperature and pyrolysis temperature (from Table 3 in Woolf et al. 2021)

Soil temperature	$PR_{de,b,k}$ as a function of pyrolysis temperature		
	Low	Medium	High
<7.5	0.84	0.89	0.94
7.5–12.5	0.72	0.79	0.88
12.5–17.5	0.63	0.71	0.82
17.5–22.5	0.57	0.67	0.79
>22.5	0.54	0.64	0.76

Emissions associated with conversion of feedstock to biochar ($P_{EP,p,y}$) are required for Equation (5) and are calculated using Equation (9). Where direct measurements of the parameters in Equation (9) are not available, data from peer-reviewed literature may be used. Project proponents are encouraged to measure and record CH_4 emissions with emerging digital measurement, reporting, and verification (MRV) technologies.

$$P_{EP,p,y} = \sum_b \sum_k \left(F_e \times GWP_{CH4} \times M_{b,k,p,y}\right) \tag{9}$$

Where:

$P_{EP,p,y}$ = Emissions associated with the conversion of feedstock to biochar at biochar production facility *p* in year *y* (t CO_2e)

F_e = Average methane emissions from producing one tonne of biochar in year *y* (t CH_4/tonne)

GWP_{CH4} = Global warming potential of methane (t CO_2e/t CH_4)

[27] Using the file for annual mean temperature at 0–5 cm depth

$M_{b,k,p,y}$ = Mass on a dry weight basis of biochar production lot *b* used for application type k and produced at biochar production facility *p* in year *y* (tonnes)

9.2.2.3 Adjustment for Production Increase Projects

Where the project activity includes production increases to existing pre-project facilities of low- or high-technology biochar production facilities, only the incremental production above baseline levels is eligible for crediting. Project proponents must determine the maximum annual biochar production during the three years immediately prior to the initial crediting period start date as a minimum of the business-as-usual benchmark.

The historic maximum production ($M_{BAU,b,k,p}$) is defined as the maximum annual dry-weight biochar output achieved at biochar production facility *p* for production lot *b* used for application type *k* across the three calendar years immediately prior to the project start date:

$$M_{BAU,b,k,p} = \mathrm{MAX}\left(M_{b,k,p,y=-1}, M_{b,k,p,y=-2}, M_{b,k,p,y=-3}, M_{BL}\right) \tag{10}$$

Where:

$M_{BAU,b,k,p}$ = Historic maximum production on a dry weight basis for biochar production lot *b* used for application type *k* produced at biochar production facility *p* during the three years immediately prior to the project start date (tonnes)

$M_{b,k,p,y=-1}$ = Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in the calendar year immediately prior to the project start date ($y = -1$) (tonnes)

$M_{b,k,p,y=-2}$ = Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in calendar year $y = -2$ (tonnes)

$M_{b,k,p,y=-3}$ = Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in calendar year $y = -3$ (tonnes)

$M_{b,k,p,BL}$ = Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in the most plausible baseline scenario (as determined in Section 7) (tonnes)

Where the project activity involves a greenfield (entirely new) facility, $M_{BAU,b,k,p}$ is equal to zero.

9.2.3 Application Stage

Equation (11) determines the GHG emissions associated with processing and using biochar at the application stage.

$$PE_{AS,y} = \sum_{b}\sum_{k}\left(EP_{b,k,y} + ET_{b,k,p,y}\right) \tag{11}$$

Where:

$PE_{AS,y}$ = GHG emissions at application stage in year *y* (t CO_2e)

$EP_{b,k,y}$ = Emissions from processing of biochar production lot *b* used for application type *k* in year *y*; equal to zero where renewable energy is used or where there is no processing of biochar (t CO_2e)

$ET_{b,k,p,y}$ = GHG emissions from transport of biochar production lot *b* from biochar production facility *p* to end-use location of application type *k* in year *y* (t CO_2e)

Where biochar undergoes further processing (e.g., sizing, grinding, sifting) before final soil or non-soil application, the project proponent must quantify related emissions. This methodology does not account for emissions related to the production or generation of materials with which biochar is mixed or infused for non-soil application (e.g., biochar-amended concrete or biochar-amended asphalt).

$$EP_{b,k,y} = P_{EPE,b,k,y} + P_{EPF,b,k,y} \tag{12}$$

Where:

$EP_{b,k,y}$ = Emissions from processing of biochar production lot *b* used for application type *k* in year *y* (t CO_2e)

$P_{EPE,b,k,y}$ = Emissions associated with grid-connected electricity used to process biochar production lot *b* used for application type *k* in year *y* (t CO_2e)

$P_{EPF,b,k,y}$ = Emissions associated with combustion of fossil fuels used to process biochar production lot *b* used for application type *k* in year *y* (t CO_2e)

Project emissions from the transportation of biochar from the biochar production facility to the end-use location ($ET_{b,k,p,y}$) may include transport from the biochar production facility to a processing facility or transport from the biochar production facility to the end-use site, depending on the end-use application.

9.3 Leakage Emissions

Leakage emissions (LE_y) are considered to be zero under this methodology.

9.4 Reversal Risk Mitigation

This methodology considers reversal risk of verified biochar carbon sequestration negligible, given the mitigation measures for natural and non-natural risks in both soil and non-soil applications described in Appendix 5.

9.5 Net Reductions and Removals

GHG emission reductions occur when CH_4 emissions from landfilling, manure management, or rice straw burning at the sourcing stage are lower in the project than in the baseline scenario. Net reductions are quantified as follows:

$$ER_{SS,y} = (BE_{SS,y} - PE_{SS,y})(1 - DF_{SS}) \tag{13}$$

Where:

$ER_{SS,y}$ = Net reductions at sourcing stage in year *y* (t CO_2e)
$BE_{SS,y}$ = Baseline emissions at sourcing stage in year *y* (t CO_2e)
$PE_{SS,y}$ = Project emissions at sourcing stage in year *y*; assumed to be zero (t CO_2e)
DF_{SS} = Discount factor for uncertainty at sourcing stage; see Section 9.6 (dimensionless)

Net removals are calculated as follows:

$$CR_y = (CR_{PS,y} - PE_{FT,p,y} - PE_{AS,y})(1 - DF_{CR}) \tag{14}$$

Where:

CR_y = Net removals in year *y* (t CO_2e)
$CR_{PS,y}$ = Removals at production stage in year *y* (t CO_2e)
$PE_{FT,p,y}$ = GHG emissions at sourcing stage from transportation of feedstock to biochar production facility *p* in year *y* (t CO_2e)
$PE_{AS,y}$ = GHG emissions at application stage in year *y* (t CO_2e)
DF_{CR} = Discount factor for uncertainty of removals; see Section 9.6 (dimensionless)

9.6 Uncertainty Assessment

Project proponents must identify, quantify, and conservatively address all material sources of uncertainty in the estimation of net reductions and removals in the project description. The uncertainty assessment must follow the stepwise approach described below.

9.6.1 Step 1: Identification of Key Sources of Uncertainty

Project proponents must identify all material input parameters that contribute the most to overall uncertainty. A sensitivity analysis may be used combined with an assessment of the type of data and sources, considering the following:

1) **Default factor uncertainty:** There can be variability in published default factors, including factors sourced from IPCC, national inventories, and peer-reviewed literature. Project proponents must cite the specific version and publication date of each factor used. Where the conservative end of a published range is used, the uncertainty of the parameter is considered to be addressed and does not need to be included in uncertainty propagation.

2) **Measured parameter uncertainty:** Measurement error can occur in instrumentation such as weighing scales (e.g., for $M_{b,k,p,y}$ and M_{rs}), temperature sensors, and flow meters used during production. This data type is generally very precise. However, low-technology biochar production facilities with limited instrumentation must apply conservative adjustments to account for higher measurement uncertainty.

3) **Laboratory analysis uncertainty:** There can be inter-laboratory and intra-test variability in the determination of organic carbon content ($F_{Cp,b,p}$) and the hydrogen to organic carbon ratio (HC_b) used to calculate the permanence adjustment factor ($PR_{de,b,k}$). Analyses must be conducted by accredited laboratories in accordance with the IBI Biochar Testing Guidelines or EBC *Guidelines for a Sustainable Production of Biochar*. Where multiple test results are available for the same biochar production lot, uncertainty must be quantified. Where the lowest credible values of $F_{cp,b,p}$ and $PR_{de,b,k}$ are used, these parameters may be excluded from uncertainty propagation, consistent with the principle of conservativeness.

4) **Unknown uncertainties:** Residual uncertainty not captured by the above categories – including model structural uncertainty in Woolf et al. (2021) – must be addressed using conservative, scientifically defensible parameter ranges justified with peer-reviewed literature or expert judgment. Where literature proposes a range of values for $PR_{de,b,k}$, the lower bound must be applied.

Project proponents must transparently document any use of conservative values and exclude these from the propagation of uncertainty.

9.6.2 Step 2: Estimation and Propagation of Uncertainty

For each material parameter, project proponents must include the following in the project description:

1) The point estimate
2) The lower and upper limit of the 90% confidence interval (or provide the percentage relative to the point estimate)
3) The basis for the confidence interval (i.e., instrument specifications, calibration records, laboratory certificates, or published literature)

Combined uncertainty must be assessed using one of the following methods:

a) Linear error propagation[28]

b) Monte Carlo simulation

Project proponents must justify the choice of method employed. The combined uncertainty must be expressed separately for reductions and removals, as the half-width of the 90% confidence interval as a percentage of the point estimate of net reductions and as the half-width of the 90% confidence interval as a percentage of the point estimate of net removals.

9.6.3 Step 3: Treatment and Deduction

The combined uncertainty calculated in Step 2 (Section 9.6.2) is translated into a discount factor using the following equations:

$$DF_{SS} = U_{SS} \times \frac{t_{\alpha\ 33\%}}{t_{\alpha\ 10\%}} \tag{15}$$

$$DF_{CR} = U_{CR} \times \frac{t_{\alpha\ 33\%}}{t_{\alpha\ 10\%}} \tag{16}$$

Where:

DF_{SS} = Discount factor for uncertainty at sourcing stage (dimensionless)

DF_{CR} = Discount factor for uncertainty of removals (dimensionless)

U_{SS} = Combined uncertainty associated with reductions, represented as the half-width of the 90% confidence interval as a percentage of the mean estimate (%)

U_{CR} = Combined uncertainty associated with removals, represented as the half-width of the 90% confidence interval as a percentage of the mean estimate (%)

$t_{\alpha\ 33\%}$ = t-value for a one-sided 66.67% confidence interval, approximately 0.4307 (absolute value; dimensionless)

$t_{\alpha\ 10\%}$ = t-value for the two-sided 90% confidence interval, approximately 1.6449 (absolute value; dimensionless)

[28] Following Approach 1 in Chapter 3, Volume 1 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (first order Taylor series, variance method, or root-sum-of-squares for independent parameters)

10 MONITORING

10.1 Data and Parameters Available at Validation

Data/Parameter	GWP_{CH4}
Data unit	t CO_2e/t CH_4
Description	Global warming potential of methane
Equations	(2), (9)
Source of data	*IPCC Sixth Assessment Report*[29]
Value applied	27
Justification of choice of data or description of measurement methods and procedures applied	The *VCS Standard* requires that CH_4 is converted to CO_2e using the 100-year global warming potential derived from the most recent IPCC Assessment Report.
Purpose of data	Calculation of project emissions
Comments	None

Data/Parameter	$PR_{de,b,k}$
Data unit	Dimensionless
Description	Permanence adjustment factor due to decay of biochar per biochar production lot type *b* used for application type *k*
Equations	(4)**Error! Reference source not found.**, (8)**Error! Reference source not found.**
Source of data	**For low-technology biochar production facilities:** Woolf et al. (2021) **For high-technology biochar production facilities:** • For all soil applications and for non-soil applications involving concrete and other cementitious materials (excluding gypsum), asphalt, or permanent storage structures, $PR_{de,b,k}$ is calculated using Equation (8) • For all other non-soil applications, peer-reviewed literature

[29] Intergovernmental Panel on Climate Change (2023). *AR6 Synthesis Report: Climate Change 2023*. Available at: https://www.ipcc.ch/report/sixth-assessment-report-cycle/ https://www.ipcc.ch/report/ar5/syr/

Value applied	**For low-technology biochar production facilities:** Default values are provided in Table 6. **For high-technology biochar production facilities:** See "Source of data" row above.
Justification of choice of data or description of measurement methods and procedures applied	The decay rate considers how much of the original carbon will remain in the biochar and may be accounted as a carbon sink after final application.
Purpose of data	Calculation of project emissions
Comments	Where value is calculated using Equation (8), a parameter table for $PR_{de,b,k}$ should not be included in the project description or monitoring reports.

Data/Parameter	F_e
Data unit	t CH_4/t
Description	Average methane emissions from producing one tonne of biochar in year *y*
Equations	(9)
Source of data	Default values from Table 3 in Cornelissen et al. (2016)
Value applied	For unknown kiln type: 0.049 For known kiln type: value from Table 3 in Cornelissen et al. (2016); use unknown kiln type default if the known kiln type does not appear in Cornelissen et al. (2016).
Justification of choice of data or description of measurement methods and procedures applied	Methane emissions must be accounted for as methane is the main gas released from low-technology biochar production facilities. The value applied is derived from peer-reviewed literature and is conservative.
Purpose of data	Calculation of project emissions for low-technology biochar production facilities
Comments	None

Data/Parameter	$M_{b,k,p,y=-1}$ $M_{b,k,p,y=-2}$

	$M_{b,k,p,y=-3}$ $M_{b,k,p,BL}$
Data unit	tonnes
Description	Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in the calendar year immediately prior to the project start date ($y = -1$) Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in calendar year $y = -2$ Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in calendar year $y = -3$ Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in the most plausible baseline scenario selected in Section 7.
Equations	(10)
Source of data	For annual values (y=-1,-2, -3) use annual dry weight of biochar output determined using the shortest of the following: 1) historical production 2) the three calendar years immediately preceding the project start date 3) the entire operating history For most plausible baseline scenario determined in Section 7, explain any assumed or observed changes in supply and demand, as well as broader market dynamics that may influence biochar production levels. Broader market dynamics may include factors such as shifts in demand for biochar or its end uses, changes in feedstock availability and competing uses, price signals, policy or regulatory developments, and other relevant economic or operational conditions. Demonstration of these factors must be credible, data-driven, and representative of realistic conditions in the absence of the project. Where records are incomplete or unavailable, the project proponent must use the highest available annual figure or, where no records exist, assume $M_{BAU,b,k,p}$ in Equation (10) equals the design capacity of the facility based on the operating parameters in place at that time (hours of operation per year).
Value applied	As per source data

Justification of choice of data or description of measurement methods and procedures applied	Actual production records are the most accurate. Where data are lacking, it is conservative to assume production is equal to maximum production capacity.
Purpose of data	Calculation of baseline emissions
Comments	For greenfield projects (with no baseline history), these parameters are equal to zero.

10.2 Data and Parameters Monitored

Data/Parameter	$BE_{MM,y}$
Data unit	t CO_2e
Description	Baseline emissions from anaerobic manure management in year *y*
Equations	(1)
Source of data	Documented amounts of manure processed per year
Description of measurement methods and procedures to be applied	Where manure is used as a feedstock, the baseline must include methane emissions from animal manure left to decay anaerobically within the project boundary. Baseline emissions are calculated by using the amount of manure that would decay anaerobically in the absence of the project activity. CH_4 emissions from manure management are quantified using CDM methodology *AMS-III.D. Methane Recovery in Animal Manure Management Systems* following the procedures for baseline emissions. *AMS-III.D.* allows use of either an IPCC Tier 2 approach or direct measurements (paragraphs 17(a) and 17(b) in *AMS-III.D.)*.
Frequency of monitoring/recording	Data aggregated at least monthly
QA/QC procedures to be applied	Records must be provided for verification.
Purpose of data	Determination of baseline emissions
Calculation method	See CDM *AMS-III.D* and the related C&C
Comments	Projects applying *AMS-III.D.* must meet the applicability criteria in Section 3 of *AMS-III.D*.

Data/Parameter	$BE_{SWDS,y}$
Data unit	t CO_2e
Description	Baseline emissions from landfilling in solid waste disposal sites in year *y*
Equations	(1)
Source of data	Documented amounts of solid waste (organic fraction) processed (diverted from landfill) per year
Description of measurement methods and procedures to be applied	CH_4 emissions are quantified using CDM *TOOL04 Emissions from Solid Waste Disposal Sites* following the procedures for Application Type B.
Frequency of monitoring/recording	Data aggregated at least monthly
QA/QC procedures to be applied	Records must be provided for verification.
Purpose of data	Determination of baseline emissions
Calculation method	See CDM *TOOL04.*
Comments	None

Data/Parameter	$BE_{SS,y}$
Data unit	t CO_2e
Description	Baseline emissions at sourcing stage in year *y*
Equations	(1), (13)
Source of data	**For landfilling:** CDM *TOOL4 Emissions from Solid Waste Disposal Sites* (Application B, Equation (1)) Project proponents may obtain values for DOC_f in *TOOL04* from Chapter 3, Volume 5 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.*[30]

[30] Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

	For manure management: CDM *AMS-III.D. Methane Recovery in Animal Manure Management Systems* and the related C&C (Equation (1) or (5))[31]
Description of measurement methods and procedures to be applied	See guidance in *AMS-III.D.* (including related C&C) and CDM *TOOL04*.
Frequency of monitoring/recording	Data monitored continuously and aggregated at least monthly
QA/QC procedures to be applied	N/A
Purpose of data	Calculation of baseline emissions
Calculation method	See guidance in *AMS-III.D.* (including related C&C) and CDM *TOOL04*.
Comments	For woody biomass being landfilled, a DOC_f value of 0.01% must be used, instead of values from CDM guidance or the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. For specific biomass types not listed in the CDM or IPCC guidance, project proponents may use DOC_f values from peer-reviewed sources. Baseline to be reassessed at crediting period renewal.

Data/Parameter	M_{rs}
Data unit	kg/ha
Description	Mass of rice straw available for combustion
Equations	(2)
Source of data	Most recent version of IPCC Guidelines for National Greenhouse Gas Inventories or regional values derived from peer-reviewed publications
Description of measurement methods and procedures to be applied	One of the following from the most recent IPCC Guidelines for National Greenhouse Gas Inventories may be used to obtain aboveground dry rice straw residue ($AG_{DM(t)}$): • Equation 11.6 and Table 11.1a in Chapter 11, Volume 4 • Values in Table 11.2 in Chapter 11, Volume 4
Frequency of monitoring/recording	Source of data for mass of rice straw must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available.

[31] Available at: https://verra.org/methodologies/methane-recovery-in-animal-manure-management-systems/

QA/QC procedures to be applied	Guidance provided in Section 5.5 of IPCC (2003) must be applied.
Purpose of data	Calculation of baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	CF_{rs}
Data unit	fraction
Description	Combustion factor for rice straw as proportion of pre-fire fuel biomass consumed
Equations	(2)
Source of data	Most recent version of IPCC Guidelines for National Greenhouse Gas Inventories (Table 2.6 in Chapter 2, Volume 4)
Description of measurement methods and procedures to be applied	IPCC (2019) value: 0.80
Frequency of monitoring/recording	Source of data for combustion factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 must be applied.
Purpose of data	Calculation of baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	EF_{CH4}
Data unit	g CH_4/kg dry matter burned
Description	Methane emission factor for rice straw burning
Equations	(2)
Source of data	Most recent version of IPCC Guidelines for National Greenhouse Gas Inventories (Table 2.5 in Chapter 2, Volume 4)
Description of measurement methods	IPCC (2019) value: 2.7

and procedures to be applied	
Frequency of monitoring/recording	Source of data for the emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 must be applied.
Purpose of data	Calculation of baseline emissions
Calculation method	N/A
Comments	None

Data/Parameter	$F_{Cp,b,p}$
Data unit	percent
Description	Organic carbon content of biochar production lot *b* produced in biochar production facility *p* per tonne of biochar, taken on a dry weight basis
Equations	(4)**Error! Reference source not found.Error! Reference source not found.**
Source of data	**For high-technology biochar production facilities:** For validation, default values from Table 5 or other peer-reviewed data. For verification, laboratory material analysis **For low-technology biochar production facilities:** Default values from Table 5 or other peer-reviewed data
Description of measurement methods and procedures to be applied	**For high-technology biochar production facilities:** Laboratory material analysis must follow IBI Biochar Testing Guidelines, EBC *Guidelines for a Sustainable Production of Biochar*, or other relevant guidelines on the production of biochar. **For low-technology biochar production facilities:** Default values from Table 5 may be used, or alternative peer-reviewed values where these are justified.
Frequency of monitoring/recording	In alignment with the IBI Biochar Testing Guidelines, laboratory testing must be performed at the most frequent of the following intervals: • Annually • After a material change in feedstock • After a material change in thermochemical production parameters

QA/QC procedures to be applied	Laboratories undertaking testing must be accredited or approved by the relevant national agency to conduct required material analysis.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	This parameter must be reported in the “Data and Parameters Available at Validation” section of the project description, and in the “Data and Parameters Monitored” section of the monitoring reports. **For high-technology biochar production facilities:** $F_{Cp,b,p}$ must not exceed 50% in biochar used for non-soil applications. **For low-technology biochar production facilities:** Where more than one feedstock type is used at a facility (i.e., feedstocks are mixed), a weighted mean $F_{Cp,b,p}$ value (using values indicated in Table 5) must be calculated according to the relative dry mass proportions of feedstock types used. Moisture content of each feedstock must be measured monthly. Samples must be taken randomly following the CDM *Standard for Sampling and Surveys for CDM Project Activities and Programmes of Activities*. Feedstock producers must keep logbooks detailing the relative proportions and moisture contents of mixed feedstocks for each biochar production lot, which must be made available during verification.

Data/Parameter	$M_{b,k,p,y}$
Data unit	tonnes
Description	Mass on a dry weight basis of biochar production lot *b* used for application type *k* and produced at biochar production facility *p* in year *y*
Equations	(4), (5),**Error! Reference source not found.Error! Reference source not found.** (9)
Source of data	On-site measurements
Description of measurement methods	Use weighing scales. Adjust the moisture content to determine quantity of dry weight biomass. Use ASTM D1762-84, or for upper middle income, lower middle income, and low-income countries use ISO 589:2008.[32] Laboratories

[32] Following World Bank classifications, available at: https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html

and procedures to be applied	must be WBC or ISO accredited or demonstrate conformance to ISO procedures and rules.
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Calibrate weighing scales as per manufacturer specifications or at least every three years. Amount of biochar applied must be cross-checked with sales receipts, invoices, or other equivalent third-party evidence.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	Moisture content must be monitored for each biochar production lot *b*. The weighted mean must be calculated for each monitoring period.

Data/Parameter	$M_{p,y}$
Data unit	tonnes
Description	Total mass of biochar on a dry weight basis produced in biochar production facility *p* in year *y*
Equations	(5)
Source of data	On-site measurements
Description of measurement methods and procedures to be applied	Use weighing scales. Adjust the moisture content to determine quantity of dry weight biomass. Weighing must occur at the time of transfer of biochar to end-use recipient.
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Calibrate weighing scales as per manufacturer specifications or at least every three years. Amount of biochar applied must be cross-checked with sales receipts, invoices, or other equivalent third-party evidence.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	Parameter must be measured separately for each biochar production lot *b*. Moisture content must be monitored for each biochar production lot *b* and a weighted mean must be calculated for each monitoring period.

Data/Parameter	$P_{EDE,p,y}$
Data unit	t CO_2e
Description	Emissions associated with use of grid-connected electricity for pre-treatment of feedstock at biochar production facility *p* in year *y*
Equations	(6)
Source of data	Electricity meter, on-site measurements
Description of measurement methods and procedures to be applied	As per *VT0010*
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	See *VT0010.*
Purpose of data	Calculation of project emissions
Calculation method	For cumulative electricity meters, use the difference between initial and final readings and record the dates of each reading. Use linear interpolation where meter reading dates do not align with the monitoring period.
Comments	Where direct measurement is required but is temporarily not feasible due to technical or logistical constraints (e.g., lack of access to monitoring equipment, maintenance, remote or hazardous project locations), the project proponent may use estimation methods. This must be accompanied by justification and a demonstration that the constraint is temporary and the chosen estimation method is conservative.

Data/Parameter	$P_{EDF,p,y}$
Data unit	t CO_2e
Description	Emissions associated with combustion of fossil fuels used for pre-treatment of feedstock at biochar production facility *p* in year *y*
Equations	(6)
Source of data	In line with the relevant provisions of CDM *TOOL03*.

	Data from on-site measurement devices like tank level sensors/gauges or fuel flow meters must be used, as applicable.
Description of measurement methods and procedures to be applied	Calculated as per CDM *TOOL03*
Frequency of monitoring/recording	Monitored continuously or upon refueling, recorded at least monthly
QA/QC procedures to be applied	Follow *CDM TOOL03.* Fuel consumption must be cross-checked with annual balance from purchased quantities.
Purpose of data	Calculation of project emissions
Calculation method	See CDM *TOOL03.*
Comments	None

Data/Parameter	$P_{ECE,p,y}$
Data unit	t CO_2e
Description	Emissions associated with use of grid-connected electricity to start pyrolysis reactor at biochar production facility *p* in year *y*
Equations	(7)
Source of data	Electricity meter, on-site measurements
Description of measurement methods and procedures to be applied	Must be calculated as per *VT0010.*
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Follow *VT0010.*
Purpose of data	Calculation of project emissions
Calculation method	See *VT0010*.
Comments	None

Data/Parameter	$P_{ECF,p,y}$
Data unit	t CO_2e
Description	Emissions associated with combustion of fossil fuels used to start pyrolysis reactor at biochar production facility *p* in year *y*
Equations	(7)
Source of data	On-site measurements of fuel consumption
Description of measurement methods and procedures to be applied	Must be calculated as per *CDM TOOL03.*
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Follow *CDM TOOL03.*
Purpose of data	Calculation of project emissions
Calculation method	See CDM *TOOL03.*
Comments	None

Data/Parameter	HC_b
Data unit	Dimensionless
Description	Hydrogen to organic carbon ratio of biochar production lot *b*
Equations	(8)
Source of data	Laboratory analysis
Description of measurement methods and procedures to be applied	Laboratory analysis following IBI Biochar Testing Guidelines or EBC *Guidelines for a Sustainable Production of Biochar.* Value must be less than 0.7 for soil applications.
Frequency of monitoring/recording	For each biochar production lot produced at each biochar production facility
QA/QC procedures to be applied	Laboratory must be accredited or approved to conduct the required material analysis by the relevant national agency.

Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	$ET_{b,k,p,y}$ $PE_{FT,p,y}$
Data unit	t CO_2e
Description	GHG emissions from transport of biochar production lot *b* from biochar production facility *p* to end-use location of application type *k* in year *y* GHG emissions at sourcing stage from transportation of feedstock from sourcing to biochar production facility *p* in year *y*
Equations	(11), (14)
Source of data	Transportation records
Description of measurement methods and procedures to be applied	Must be calculated using CDM *TOOL12* where average return trip transportation distance over all feedstocks in a period of 12 months is 200 km or more (considered separately for $ET_{b,k,p,y}$ and $PE_{FT,p,y}$). Either approach in CDM TOOL12 may be used (fuel consumption data or emission factor). Where the emission factor approach is used, the values in the table below must be used in Equation (1) of CDM *TOOL12*. <table><tr><th>Mode</th><th>Default factor</th><th>Source</th></tr><tr><td>Electric train</td><td>0.03 kWh/t × grid emission factor*</td><td>CDM TOOL17 Baseline Emissions for Modal Shift Measures in Inter-Urban Cargo Transport, v01.0, Table 1</td></tr><tr><td>Diesel train</td><td>20 g CO₂/t-km</td><td>CDM TOOL17, Table 1</td></tr><tr><td>Marine transport</td><td>40 g CO₂/t-km</td><td>CDM TOOL17, Table 2</td></tr><tr><td>Light trucks <3.5 t</td><td>245 g CO₂/t-km</td><td>CDM TOOL12, Section 5.3</td></tr><tr><td>Heavy trucks</td><td>129 g CO₂/t-km</td><td>CDM TOOL12, Section 5.3</td></tr></table> * The most recently published national or regional average electricity grid emission factor must be used. Project documents must cite an official ministry or governmental agency. Otherwise, use 1.3 t CO_2/MWh as a default value. Where hydropower and/or nuclear energy provides more than half of the electricity produced, use 0.25 t/MWh (refer to CDM *TOOL05*, paragraph 20 for details).

Frequency of monitoring/recording	Monitored continuously, recorded for every transportation event
QA/QC procedures to be applied	Records must be available for verification.
Purpose of data	Calculation of project emissions
Calculation method	Option A or Equation (1) in CDM *TOOL12*
Comments	Where average return trip transportation distance over all feedstocks in a period of 12 months does not exceed 200 km (considered separately for $ET_{b,k,p,y}$ and $PE_{FT,p,y}$): • $ET_{b,k,p,y}$ is considered de minimis. • $PE_{FT,p,y}$ is omitted from Equation (14) and $CR_{PS,y}$ is multiplied by 0.95.

Data/Parameter	$P_{EPE,b,k,y}$
Data unit	t CO_2e
Description	Emissions associated with grid-connected electricity used to process biochar production lot *b* used for application type *k* in year *y*
Equations	(12)
Source of data	Electricity meter, on-site measurements
Description of measurement methods and procedures to be applied	Must be calculated as per *VT0010.*
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Follow *VT0010*.
Purpose of data	Calculation of project emissions
Calculation method	See *VT0010*.
Comments	None

Data/Parameter	$P_{EPF,b,k,y}$
Data unit	t CO_2e
Description	Emissions associated with combustion of fossil fuels used to process biochar production lot *b* used for application type *k* in year *y*

Equations	(12)
Source of data	On-site measurements of fuel consumption
Description of measurement methods and procedures to be applied	Must be calculated per *CDM TOOL03.*
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Follow CDM *TOOL03*.
Purpose of data	Calculation of project emissions
Calculation method	See CDM *TOOL03.*
Comments	None

Data/Parameter	b
Data unit	N/A
Description	Production lot of biochar
Equations	N/A
Source of data	Data records of biochar production
Description of measurement methods and procedures to be applied	Monitored by biochar producers via written or electronic production records
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Type of biochar produced must be cross-checked with sales receipts, invoices, or other equivalent third-party evidence.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	Production lot is defined in Section 3.

Data/Parameter	k
Data unit	N/A
Description	Soil or non-soil biochar application type
Equations	N/A
Source of data	Data records of biochar production
Description of measurement methods and procedures to be applied	Monitored by biochar producers via written or electronic production records
Frequency of monitoring/recording	Monitored continuously, recorded at least monthly
QA/QC procedures to be applied	Type of biochar application must be cross-checked with sales receipts, invoices, or other equivalent third-party evidence, as applicable.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	Any change in how biochar is applied represents a new application type. For soil applications, applying biochar to soils with different temperatures represents different application types. Mixing with a non-biochar substrate (e.g., compost) is a separate application type. For non-soil applications, each of the options listed in Table 2 represents an application type.

Data/Parameter	T_{prod}
Data unit	°C
Description	Average annual production temperature during pyrolysis
Equations	N/A
Source of data	Data records of biochar production
Description of measurement methods and procedures to be applied	Use digital or analog instruments with recordable electronic signal (e.g., thermocouple, thermoresistor, any other instrument prescribed by relevant international or national standards).
Frequency of monitoring/recording	Continuous, aggregated to annual averages

QA/QC procedures to be applied	Periodic calibration against a primary device provided by an independent accredited laboratory is mandatory. Calibration and frequency of calibration is according to manufacturer specifications.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	The average production temperature at which pyrolysis occurs determines the stability of biochar and is used to categorize biochar in accordance with Table 5. Values for organic carbon content in biochar (from Table 2 of Woolf et al. 2021)Table 6 to determine $PR_{de,b,k}$. For low-technology production facilities where measuring temperature is not feasible or sampling of biochar organic carbon content according to the required standards is not possible, use the conservative values indicated in Equation (4) as default values.

10.3 Description of the Monitoring Plan

Project proponents must establish and apply quality management procedures to manage data and information. Written procedures must be established for each measurement stage outlining responsibility and timing requirements.

Project proponents must develop and apply a monitoring plan that allows quantification of GHG emissions at sourcing, production, and application stages. Project proponents must provide a detailed chain of custody report as defined below, including end-use locations.

Due to the complexity and uniqueness of monitoring biochar end-use applications, a list of resources that project proponents may use for monitoring is provided in this section.

Mixed Feedstocks

For mixed feedstocks, project proponents must keep purchasing receipts and logbooks detailing the relative proportions and moisture content of mixed feedstocks for each biochar production lot. Logbooks must show how the material is combined for each production lot to determine an average F_{Cp} when using mixed feedstock. Validation/verification bodies must conduct spot checks during verification.

Training

Biochar producers must provide evidence of adequate training on the use of kon tiki kilns, particularly demonstration of feedstock layering expertise to maintain an undisrupted flame curtain during biochar production.

Procedure to Determine Biochar on Dry Weight Basis

Procedures to determine biochar on a dry weight basis are outlined in the IBI Biochar Testing Guidelines. Where the moisture content of feedstocks is required, ASTM *D4442-20 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials* may be used as a guide. The method involves drying samples to a constant weight in a ventilated oven at 102 to 105 °C.

Geographic Information

To prevent double counting (e.g., accounting for both the soil organic carbon pool and biochar application in soils), the location of the end site where the carbon sink is created must be recorded. This applies to soil and non-soil applications. At least one geodetic coordinate must be provided for each application location.

Application Type

For soil application, project proponents use must specify where the biochar has been applied.

Project proponents must monitor and document all biochar applications to soil throughout the project crediting period to ensure compliance with the following two conditions, as applicable:

- For surface applications, biochar must be applied only when mixed with other substrates (e.g., compost, manure, or digestate from anaerobic digestion), and records must be maintained to demonstrate the composition of the applied mixture.
- For subsurface applications, biochar may be applied either as pure biochar or in combination with other substrates. Where biochar is applied within a matrix structure, the proportion of biochar must not exceed 50% of the total mixture with organic material, and this proportion must be documented for each application event.

Project proponents must maintain verifiable records (e.g., application logs, mixture ratios, and supporting documentation) to demonstrate ongoing compliance with these requirements.

Additionally, biochar used in soil applications does not exceed threshold values for heavy metals and organic contaminants (polychlorinated biphenyls, PCBs; polychlorinated dibenzo-p-dioxins and dibenzofurans, PCDD/Fs; and polycyclic aromatic hydrocarbons, PAHs) specified in Section 7 of the WBC *World Biochar Certificate – Guidelines for a Sustainable Production of Biochar and its Certification* or in relevant jurisdictional regulations.

For non-soil applications such as concrete or asphalt, the proof of application ends when the biochar is mixed into long-lasting material. Appropriate monitoring methods (e.g., statistically validated lifetime averages) must be used to ensure the material containing biochar is still in use and has not been converted to CO_2. Where sufficient statistical data or track records are unavailable, a monitoring plan must be established that is tailored to the expected useful life of the biochar-containing products. This plan must include updating the recycling/reuse statistics or continued use data for the products containing biochar every five years. This may be based on official statistics, where available, or on a statistically significant sample of applications followed up on directly by the facility operator.

Chain of Custody

The chain of custody must be transparently described to document material flows from feedstock sourcing through biochar production to the final biochar end-use application. This must include at least feedstock type, amounts delivered, dates, names, addresses, and contact information of the responsible persons or organizations. Project proponents must monitor and demonstrate continuous chain of custody and geolocation data for pure, unblended biochar through to the final point of application. Retail sales of pure, unblended biochar are only eligible where such monitoring and documentation are maintained and verified.

1) Where biochar is directly used and not incorporated into a mixture or matrix (e.g., applied directly into subterranean storage locations or applied to soils as biochar pellets), the physical location where biochar is applied is considered the end-use location. In such cases, detailed chain of custody documentation, including the geolocation and type of soil or non-soil application, must be provided.
2) Where biochar is incorporated into a mixture or matrix from which it cannot be separated, the mixing facility is considered the end-use location. This applies to mixing at retail facilities, blending sites, or intermediary processing locations, and includes both soil and non-soil applications. In such cases, the following conditions must be met:
    a) Biochar is distributed as part of a blended product and is mixed with a non-combustible matrix (e.g., soil, compost, sand, fertilizer) at a ratio of no more than 50% biochar by volume prior to distribution.
    b) Eligible retail products carry clear, on-package labeling, instructing the consumer on eligible soil application methods and explicitly prohibiting use as a fuel.

Project proponents provide objective supporting evidence of the intended end use of biochar within such mixtures, which may include marketing materials, product specifications, sales documents, technical sheets, buyer declarations, or other commercially verifiable information. Chain-of-custody documentation is required up to the mixing facility.

Monitoring Tools

Project proponents must verify that soil or non-soil application takes place (e.g., using tracking records, mobile or desktop applications, QR codes, blockchain technology, non-fungible tokens (NFTs), GPS use-location coordinates, or any other tracking software that allows for chain of custody record generation from the sourcing stage (i.e., biomass origin) to the end-use application of biochar.

Where measurement and monitoring equipment is used during biochar production (e.g., to measure temperature), the project proponent must ensure that the equipment is calibrated according to current best practice (e.g., relevant industry standards, manufacturer specifications, or device supplier). Material laboratory analysis of biochar must follow international standards such as the most recent version of the IBI Biochar Testing Guidelines or EBC *Guidelines for a Sustainable Production of Biochar*.

Where suitable laboratory facilities capable of performing the required biochar analyses (as specified in this methodology) are not available within the project's host country, the project proponent may send biochar samples to accredited laboratories located outside the host country. In such cases, the project proponent must:

1) demonstrate the lack of appropriate in-country laboratory options.
2) ensure that the selected foreign laboratory meets the accreditation, quality assurance, and analytical requirements specified in this methodology.

Chain of custody documentation must be maintained for all samples tested, regardless of whether tested inside or outside the host country.

Data Management

Quantitative sources of information and recordkeeping practices on biochar sourcing, production, and application must be chosen. Project proponents must have an offsite electronic back-up of all logged data. For example, monitoring data must provide information on biochar production lot number, quantity, type of application, geographic location, and proof that the biochar will not be burned or pyrolyzed. Project proponents must provide access to all platforms and make all evidence available to the VVB.

The monitoring plan must contain at least the following information:

1) A description of each monitoring task to be undertaken, and the technical requirements therein
2) Type of technology used to produce biochar
3) Written logs of operation and maintenance of the project system
4) Roles, responsibilities, and capacity of the monitoring and management teams

Quality Assurance and Quality Control (QA/QC)

Project proponents must develop a QA/QC plan to ensure measurements are made properly. Some examples of QA/QC measures are:

1) protecting monitoring equipment (sealed meters and data loggers)
2) protecting records of monitored data (hard copy and electronic storage)
3) checking data integrity on a regular and periodic basis
4) comparing current estimates with previous estimates to check data integrity
5) providing sufficient training to personnel to perform activities related to the sourcing, production, and application of biochar
6) maintenance of all calibration records for all instruments used, which must be made available for VVB review

All necessary documents must be collected and centrally stored by project proponents and be available for verification. Documents and records must be stored in a secure and retrievable manner for at least two years after the end of the project crediting period.

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APPENDIX 1: DEMONSTRATION OF FEEDSTOCK AS WASTE BIOMASS

This appendix provides procedures to demonstrate that the feedstock is waste biomass in the baseline scenario (i.e., in the absence of the project activity). This must be demonstrated at project validation.

Assessment of feedstock use must cover the five years preceding the initial crediting period start date or initiation of validation (defined as the start date of desk review by the VVB), whichever is earlier. All qualitative and quantitative information on biomass use in the baseline scenario must be determined via consultation with the manager or landowner from whom the biomass is sourced or the contracted supplier (e.g., biomass broker or intermediary).

Acceptable sources of information on biomass use in the baseline scenario are listed below. The principle of conservativeness must be applied in all cases.

1) Where the source of biomass (entity and geographic location) is known, and the biomass is not used in the baseline scenario, either of the following:

    a) Historical management plans, receipts, or other records from the areas where the biomass is sourced from showing that the biomass was not used for alternative purposes in the five years preceding the initial crediting period start date or initiation of validation, whichever is earlier. These may be supplemented with other forms of evidence such as remote sensing (e.g., satellite imagery) or documentation from comparable sourcing areas.

    b) Substantiation via a signed attestation from the manager, landowner, or supplier stating that the biomass was not used for alternative purposes in the five years preceding the initial crediting period start date or initiation of validation, whichever is earlier. This may also be used for new sources of biomass that did not exist before the initial crediting period start date (e.g., residues from a new food processing mill). The attestation must not deviate from other available evidence such as remote sensing (e.g., satellite imagery) or documentation from comparable sourcing areas.

2) Where the source of biomass is known and some or all of the biomass is used in the baseline scenario, either of the following:

    a) Historical management plans, receipts, or other records from the areas where the biomass is sourced from showing that the biomass supply is sufficient to satisfy project demand without compromising future non-project biomass delivery commitments. These must be used to compare historical biomass volumes delivered annually in the five years preceding the initial crediting period start date or initiation of validation, whichever is earlier, with expected project- and non-project-related volumes for the duration of the project crediting period.

b) Substantiation via a signed attestation from the manager, landowner, or supplier stating that the available biomass supply is sufficient to satisfy project-related demand without compromising future biomass delivery commitments. This must be supplemented by an analysis of historical biomass volumes delivered annually in the five years preceding the initial crediting period start date or initiation of validation, whichever is earlier, combined with expected project- and non-project-related volumes for the duration of the project crediting period. The attestation must not deviate from other available evidence such as remote sensing (e.g., satellite imagery) or documentation from comparable sourcing areas.

3) Where the source of biomass is unknown (e.g., the biomass is sourced from a biomass residue market with unknown producers):

   a) Demonstration that there is an abundant, unused surplus of the same or similar type of biomass in the project region through an analysis showing that the total biomass quantity available is at least 25% larger than the total biomass quantity used (including by the project facility) for that type of biomass. The analysis must be based on an assessment of biomass availability and use in the five years preceding the initial crediting period start date or initiation of validation, whichever is earlier. Where five years of historical data are not available, at least one year of data must be used as evidence and must be complemented with additional evidence demonstrating that the available data is representative of the five years preceding the initial crediting period start date or initiation of validation, whichever is earlier. The analysis should reflect characteristics specific to the biomass type and markets (e.g., wood residues for bioenergy production) where the project is located.

APPENDIX 2: BIOCHAR BACKGROUND INFORMATION

Given the diversity and complexity of biochar GHG accounting, this methodology limits eligible feedstock types, biochar production technologies, and end uses.

Biochar is made from a diverse array of feedstocks and can be produced with a wide variety of technologies. Life cycle assessments of biochar indicate that the climate benefits of biochar are highly variable and dependent on many factors. For example, if fossil fuel energy is used to chip, grind, transport, and dry feedstocks, then the climate benefits of biochar used for soil and non-soil applications can be reduced or eliminated (Hedley et al. 2020; Puettmann et al. 2017; Sahoo et al. 2021).

Biochar production systems vary substantially by technology type. During production, there are a mix of emissions including carbon dioxide, methane, and soot. Carbon in biomass is biogenic and a part of the active natural carbon cycle. Because the CO_2 released during biochar production had been recently captured from the atmosphere and stored in plant tissues through photosynthesis, biomass is generally considered carbon-neutral. However, CH_4 and soot emissions have a more powerful global warming potential than CO_2 (Amonette et al. 2021).

Eligible high-technology biochar production facilities involve some form of post-pyrolysis combustion such as funneling gases through an afterburner (to control CO_2 and CH_4 production), re-injection of gases into the pyrolysis system to increase efficiency of production, or using the excess heat produced to generate electricity or for other useful purposes.

Project proponents are encouraged to recover any unused energy portions from pyrolysis oils and/or gases by adding power generation, additional heat, or other uses on-site or by third parties to further optimize energy efficiency. Biochar climate benefits may increase if the syngas or bio-oil produced is used to replace fossil fuel-based (mainly coal) energy sources.

Low-technology biochar production facilities lack the same controls as high-technology facilities. However, project proponents must demonstrate that low-technology facilities minimize CH_4 and soot production. Systems that minimize CH_4 and soot include those that harness natural convection processes to create a combustion zone above the pyrolysis zone to reduce the impact of excess methane production, particularly at start-up and shut-down.

Use of technologies and feedstocks that lead to health and safety issues and unwanted environmental emissions, and pose a contamination risk to soils, are not eligible under this methodology.

APPENDIX 3: PERMANENCE OF BIOCHAR CARBON REMOVALS

This appendix provides a brief overview of current science related to the permanence of biochar carbon as a background for the carbon sequestration calculations in Section 9. Biochar is considered a carbon sink where its soil applications (e.g., soil amendment on agricultural lands) or non-soil applications (e.g., cement, asphalt) are carbon-persistent over time. Although this appendix discusses longer timeframes, permanence is estimated over 100 years in this methodology.

Permanence refers to the continued existence of sequestered biochar carbon over time, as opposed to its conversion to CO_2 (mineralization) that is released back to the atmosphere. Permanence depends on environmental conditions such as whether the biochar is exposed to or protected from degradation pathways. Decomposition of biochar carbon includes conversion into other organic compounds.

Summary of current research

- Biochar is much more permanent in soils than fresh biomass is. Biochar's slower mineralization makes a large fraction of biochar carbon durable over at least centennial timescales. Accordingly, biochar produced and used following best practice is an effective carbon sequestration method.

- The sequestration characteristic of biochar is due to the formation of aromatic rings (i.e., six carbon atoms bonded into a ring) and the fusing together of these rings into larger aromatic structures during biomass pyrolysis. A high proportion of large fused aromatic structures makes biochar much less prone to microbial decomposition than fresh biomass.

- Biochar has variable properties that influence its permanence. Higher production temperatures and longer reaction times generate a greater proportion of larger fused aromatic structures, thus increasing permanence.

- The extent to which biochar is comprised of fused aromatic rings can be measured indirectly using the biochar's hydrogen to organic carbon ratio. Other indirect metrics have also been proposed. The oxygen to carbon ratio is considered less reliable because it can be biased by oxygen present within biochar ash. Hydrogen pyrolysis requires specialist equipment that is not widely available and has a high per-sample cost for analysis. Random reflectance has also been proposed more recently but has not yet been well calibrated against decomposition rates, particularly for different biochar production lots.

- Biochar mineralization in soil is primarily due to biological activity. Biological decomposition may also be augmented by physical and chemical weathering processes (including photo-oxidation) that can oxidize biochar surfaces and reduce particle sizes, making the biochar more accessible to biological activity.

- The high energetic cost of breaking down fused aromatic molecules means that microbes typically do not target them preferentially as a food source. Nonetheless, biochar decomposition can occur as a side-effect of microbes excreting enzymes and other metabolites into the soil to digest other nearby food sources (referred to as co-metabolism).

- The most robust method for measuring biochar mineralization in soil involves controlled laboratory incubation experiments, in which isotopic signatures distinguish how much CO_2 comes from biochar as opposed to from soil organic matter. Field experiments better represent actual conditions, but usually suffer from methodological difficulties that make accurate quantification challenging.

- To predict how much biochar carbon will remain after longer periods (e.g., 100 years or more), experimental data must be extrapolated using a mathematical model. Multi-pool exponential decay is the most often used model in the scientific literature, and forms the basis for the IPCC Guidelines for National Greenhouse Gas Inventories. It assumes that biochar is a mixture of materials that can be grouped into a finite number of distinguishable "pools" (i.e., fractions), each with a characteristic mineralization rate. The model provides a conservative estimate of permanence, because the experimental data to which it is fitted may be too short in duration to reliably indicate the decay rate that would be approached after many decades or centuries. The power model is sometimes proposed as an alternative but is inherently less conservative because it assumes that no matter how much biochar is mineralized, the remaining material will always be more permanent than what has been removed. Although the power model has been found to fit observed mineralization rates over a few years as adequately as a two-pool exponential model, there are currently no empirical data to show that biochar mineralization will continue to slow indefinitely.

- Where protected from biological activity (e.g., buried in marine sediments or embedded within sedimentary rocks), biochar can persist for millions of years. The occurrence of extremely old charcoal-derived fragments (inertinite) within sedimentary rocks (e.g., coal) may indicate that fused aromatic molecules in biochar should be considered essentially inert over at least millennial timeframes. However, the long-term persistence of biochar when it is protected from biological decomposition within sedimentary rocks does not necessarily imply that it will be equally persistent in a biologically active soil environment:

    - Biochar that has been artificially aged by chemically or biologically removing the most easily decomposed fractions continue to decompose at rates similar to the remaining fraction observed in laboratory incubations of un-aged biochar.

    - There are known biological pathways for decomposition of poly-aromatic compounds, and the soil microbes that express enzymes for breaking down aromatic bonds become more abundant after biochar addition.

    - Even the most stable form of fused aromatic carbon – graphite – can be decomposed by microbes in soil, albeit very slowly.

  - Global and regional budgets indicate that a substantial fraction of naturally occurring biochar must decompose, or it would be found in larger concentrations in both soils and sediments.

- Accurately quantifying the permanence of biochar over longer timeframes remains an active area of scientific research. Uncertainty becomes greater as data are extrapolated over longer timescales. The assumption that fused aromatic molecules in biochar are completely inert over many centuries or more, even when incorporated into biologically active soils, is not currently well-supported by empirical evidence. Therefore, the assumption that biochar decomposition can be modeled by extrapolating experimental data using a multi-pool exponential decay model is considered both conservative and aligned with available observational data. If more robust quantification of biochar permanence over longer time frames becomes available, it may then become feasible to update this guidance with more accurate values. However, applying conservative values that are empirically well supported is currently the most reasonable approach.

APPENDIX 4: NON-EXHAUSTIVE LIST OF INVASIVE SPECIES DATABASES

Database and Website	Description
Global Invasive Species Database (GISD) of the Invasive Species Specialist Group (ISSG) https://www.gbif.org/ or https://www.iucngisd.org/gisd/	Coverage: Worldwide Publication date: 2015 A query using a genus, species, or common name can be made using the basic search function. The search will return any invasive species with a name, or part of a name, that matches the search term, whether it is an accepted scientific name, a synonym, or a common name. Results returned include common names, higher taxonomy, and environmental system in which the species occurs.
National Invasive Species Information Center, USA https://www.invasivespeciesinfo.gov/	The site serves as a portal for information on invasive species and an educational gateway to information, organizations, and services related to invasive species.
European Food Safety Authority (ESFA) https://www.efsa.europa.eu/en/topics/topic/invasive-alien-species	Coverage: European Union EFSA's Panel on Animal Health and Welfare (AHAW Panel) and Panel on Plant Health (PLH Panel) assess the risks posed by invasive animal and plant species.
Invasive Species Centre, Canada https://www.invasivespeciescentre.ca/invasive-species/meet-the-species/invasive-plants/	Lists invasive plant species and refers to provincial organizations related to invasive species.

APPENDIX 5: RISK OF REVERSALS

There is a risk that sequestered carbon in biochar that has previously been verified may be lost. For example, prior to use in soil or non-soil applications, produced biochar may be intentionally combusted for use as a fuel source. This risk is avoided by requiring that biochar is used only in eligible soil or non-soil applications and that end-use application is monitored. Various other natural and non-natural reversal risks must be mitigated during and after use in soil or non-soil applications.

Natural Risks

Where biochar is used in soil applications, natural risks are associated with climatic and geological factors (e.g., fires, floods, wind, and precipitation). Fire represents the most significant risk since it can result in the immediate loss of sequestered carbon due to the combustion of biochar. Erosion by wind or water (flooding) poses the risk that biochar is transported outside of the project boundary and beyond the control of the project proponent.

These natural risks are substantially mitigated through the incorporation of biochar into the soil subsurface, ideally to at least 10 cm depth. However, project proponents may also apply biochar on the soil surface. In this case, the risk of loss due to fire or erosion is heightened since the biochar remains exposed on the soil surface. Risks are mitigated by requiring biochar to be mixed with other amendments (e.g., manure, compost) prior to surface application, which reduces biochar's combustibility and erodibility (IBI 2010).

- Loss due to combustion: The nature of changes in soil during and after fires depends on both the temperatures reached at different soil depths and the degree of heating that different soil components can withstand before being altered (González-Pérez et al. 2004). Temperatures during fires decrease dramatically with soil depth (Enninful and Torvi 2008) and most loss of soil organic matter during wildfires is limited to the very top layer of soil (Boerner et al. 2009; Majder-Łopatka et al. 2019). Except for high-intensity wildfires in forest settings, the heat generated during a fire does not typically combust the organic matter in soils, particularly in agricultural settings. Studies have shown that subsoil application of biochar increases soil's resilience to different abiotic and biotic stressors. For example, application of biochar increases soil water retention (Głąb et al. 2016), thus mitigating risks of loss due to combustion. When biochar is applied to the soil subsurface its risk of combustion decreases significantly, and when applied to the soil surface in combination with amendments its combustibility is further reduced (IBI 2010).

- **Loss due to transport outside the project boundary:** Studies have shown that when biochar is applied on soils, it may reduce water runoff and overall soil erosion (Gholami et al. 2019; Lee et al. 2015) and thus the risk of it being transported outside the project boundary is reduced. Similarly, risk of wind erosion is greatly reduced by incorporating biochar into the soil subsurface. Some biochar could still be transported outside the project boundary due to erosion, but this does not directly imply that the sequestered carbon in the biochar would be lost to the atmosphere. Rather, biochar may be transported via overland flow or wind into waterways and eventually deposited into sediments where it is likely to persist for as long as or longer than in the soil where it was originally applied.

Where biochar is used for non-soil applications, natural risks are considered minimal. Lee et al. (2019) have shown that when biochar is used in bio-composites such as those with inorganic clay, it reduces thermal conductivity, thus increasing the material's thermal resistance to combustion. When biochar is incorporated into building materials such as mineral plasters, gypsum, or clay, the material is not prone to incineration; rather the biochar is protected against biological and chemical decay (Gupta and Kua 2018). The European Biochar Certificate (EBC) considers that when biochar is incorporated into building materials such as concrete, lime plaster, gypsum, or clay, combustion is nearly impossible (EBC 2021).

Non-Natural Risks

Non-natural risks are those associated with project management, financial viability (e.g., insufficient funds to complete the project cycle), government policies, or community and stakeholder resistance, among others.

- **Social risks** (e.g., community resistance or non-acceptability) are considered minimal since only biomass that would have been combusted or left to decay is eligible as a feedstock for biochar production. Therefore, competing uses for feedstock will not exist. Instead, communities might have access to new livelihood and revenue stream opportunities from the introduction of project activities.

- **Project management and financial risks** are considered minimal due to the independence of annual removals achieved from project activities. If a project proponent becomes bankrupt after verification and issuance of Verified Carbon Units or terminates their project before the end of the crediting period, it would be considered to have a minimal impact on project claims from previous years because once used in soil or non-soil applications, biochar will remain as a sequestered material. For example, biochar applied to agricultural soils will continue to act as a carbon sink irrespective of the fate of the project. The carbon sink function of biochar used in a non-soil application (e.g., biochar infused in cement) will continue irrespective of activities in subsequent years (Akinyemi and Adesina 2020). Climate benefits associated with biochar applied in one year of the project are not dependent on continuation of application of biochar in subsequent years.

DOCUMENT HISTORY

Version	Date	Changes
v1.0	12 Aug 2022	Initial version released.
v1.1	05 Jul 2023	• Clarifications to eligible feedstocks in Section 4 • Clarifications to eligible land types for soil application in Section 4 • Corrections and clarifications to GHG sources included in the project boundary in Table 2 • Corrections to equations in Section 8 • Clarifications to parameters available at validation in Section 9 • Clarifications to standardized activity method reassessment procedures in Appendix 1 • Clarifications to the procedures to demonstrate that feedstocks are waste biomass in Appendix 2 • General improvements, corrections and clarifications
Draft v2.0	15 July 2026	• Expansion of eligibility to existing biochar production facilities • Inclusion of detailed criteria for high-technology biochar production facilities • Replacement of standardized approach (positive list) with the project method approach for demonstration of additionality • Expansion of eligibility of feedstocks, including invasive species and other new (not purpose-grown) feedstocks • Introduction of monitoring approaches for measuring key parameters, including hydrogen to organic carbon ratio of biochar and moisture content • Inclusion of procedures for calculating feedstock transport emissions • Consideration of safe storage and transport of biochar • Inclusion of requirements for uncertainty analysis and assessment • General editorial improvements