Global Biochar C-Sink 3.0 (b.10)

Guidelines for the Certification of Biochar-Based Carbon Sinks

(formerly known as EBC Biochar C-Sink)

Developed by the Ithaka Institute for Carbon Strategies, 2024 - version beta3.0 (26th January 2024)

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Summary

The certification of carbon sinks (C-sinks) is a crucial step in scientifically grounded climate protection strategies. While reducing emissions and phasing out fossil carbon are essential to limit global warming, only active carbon removal from the atmosphere can address the climatic impact of past industrial emissions.

The Global Biochar C-Sink standard represents a significant advancement from the earlier European Biochar Certificate (EBC) C-Sink guideline, which was introduced as the first of its kind in 2021. The EBC C-Sink guideline was the pioneering standard for negative emissions, focusing on biochar-based carbon sinks. The present new standard builds upon and enhances the initial framework, incorporating more comprehensive measures and methodologies for the certification and tracking of biochar-based carbon sinks.

Key updates in the Global Biochar C-Sink standard include rigorous tracking, more holistic GHG accounting, and advanced carbon efficiency requirements. These processes ensure that every carbon unit sequestered through biochar methods is meticulously followed from its extraction from the atmosphere to its final storage. The mandatory tracking system guarantees the integrity and transparent quantification of the carbon sinks.

Furthermore, the Global Biochar C-Sink standard places a strong emphasis on accounting for all direct and indirect greenhouse gas emissions associated with the lifecycle of the biomass, transportation, processing, storage, pyrolytic transformation, application, and monitoring C-sink materials. By requiring these emissions to be fully offset before the C-sink is registered, the standard ensures a more accurate representation of the climate impact of each Global Biochar C Sink.

In summary, this updated standard marks a significant step forward in the field of negative emissions, setting a more robust and comprehensive framework for the creation and certification of material and geological carbon sinks.

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Glossary

C-Sink Matrix	Organic or mineral substrates to which biochar is mixed at a ratio below 1:1 (vol) and which excludes that the biochar may burn unintendedly or might be recovered to be used in a way that the carbon oxidizes to CO_2.
C-Sink Owner	Owner of the land or material where the carbon registered as a C-sink was applied. A C-sink cannot be owned if the land or material where the carbon is applied as C-sink is not also owned.
C-Sink Potential	The pyrogenic carbon of a biochar that was not yet applied to a C-sink matrix but is temporarily stored in packing units, e.g., at the factory gate of a biochar production facility.
C-Sink Trader	An endorsed company or organization that trades the global cooling effects of a C-sink to either compensate the global warming effect of past emissions or to offset a distinct GHG emission.
C-Sink Unit	A C-Sink Unit is the registered amount of a geo-localized biochar C-sinks of the same controlled quality. The minimum size of a C-Sink Unit is 1 t CO_2e.
Certifier	The Certifier is a Carbon Standards endorsed third party inspection and certification body.
Diffuse C-sink	Biochar C-sinks containing less than 1 t CO_2e that was mixed to a C-Sink Matrix preventing the oxidation of biochar.
Endorsing Agent	Carbon Standards AG is in the role of Endorsing Agent. Carbon Standards (1) conducts trainings for the Biochar C-Sink Manager, (2) endorses the Biochar C-Sink Manager, (3) endorses tracking tools and methods used by the Biochar C-Sink Manager, (4) verifies the reporting by the Biochar C-Sink Manager and the Certifier, (5) conducts trainings for the Certifier, (6) accredits the Certifier, (7) endorses the laboratories. Carbon Standards may (8) provide software for on-site control, tracking, certification, and registry of the produced biochar and C-sinks.

Global C-Sink Registry	The Global C-Sink Registry contains the physical location of each C-sink, the year of the carbon removal, the date of application, applied amount of carbon, the carbon persistence, and the C-sink owner.
Methane Compensation	A temporary carbon sink that has the same or higher global cooling effect during 20 years as the absolute global warming effect of the methane emission over 100 years.
Negative Emission Technology (NET)	Negative Emission Technologies (NETs) are techniques that remove more carbon dioxide from the atmosphere than they emit, thereby reducing the overall concentration of CO_2 to mitigate the effects of climate change.
PAC Fraction	The persistent aromatic carbon (PAC) fraction of biochar is defined as the biochar carbon that persists longer than 1000 years in soil, it corresponds to portion of biochar carbon bound in clusters of more than seven aromatic rings as analyzed by the hydro pyrolysis method.
Persistence	Is the time that a defined fraction of biochar is stable in the environment or in the matrix to which the biochar was applied and does not degrade or decay. Sometimes also called: “durability”.
SPC Fraction	The semi persistent carbon (SPC) fraction of biochar is defined as the biochar-carbon fraction that is expected to decay within the first 1000 years.
Standard Developer & Holder	The Global Biochar C-Sink standard was developed and is continuously updated by the Ithaka Institute. The Global Biochar C-Sink standard is owned by Carbon Standards and can only be used under a licensing agreement. Carbon Standards is the Standard Holder managing the entire licensing and endorsement process.
Verified Emission Reduction (VER)	Verified Emission Reduction (VER) is a carbon offset representing a reduction of one metric ton of CO_2 emissions, which is independently verified against a recognized standard but not certified under an international convention like the Kyoto Protocol.

1. Introduction to Biochar C-Sink Certification

When the certification of carbon sinks (C-sinks) was introduced in 2020 by the European Biochar Certificate (EBC), it represented a decisive step towards implementing climate change mitigation. While traditional carbon dioxide (CO_2) credits mostly certified the reduction of emissions compared to a reference scenario, the newly introduced certification of C-sinks guaranteed storage of carbon in the terrestrial system that can be verified at any time and be traced back to the year of the initial carbon removal from the atmosphere.

Carbon sinks are the result of (1) an active removal of CO_2 from the atmosphere, (2) the transformation of the removed carbon into a storable form, and (3) its verifiable storage outside the atmosphere. In the case of biochar, the removal occurs through biomass growth (photosynthesis), transformation through pyrolysis, and storage via application to soil or materials (C-sink matrix). Complete and batch-accurate tracking of each sequestered unit of biochar-carbon ensures the occurred removal of CO_2 from the atmosphere, quantifies the C-sink, and accounts for its persistence. All C-sinks must be registered in the Global C-Sink Registry to allow monitoring, reporting, and verification (MRV) and thus create the transparency and trust needed in the new carbon economy.

Likewise, all greenhouse gas (GHG) emissions that occurred due to the biomass production (carbon removal) and all other activities necessary to establish and maintain the C-sink have to be assessed. For biochar, this includes all emissions of biomass provision, storage, transport, transformation, and biochar application. These emissions must be registered in an emission portfolio in the Global C-Sink Registry. All those emissions caused by the C-sink production must be compensated before the C-sink can be validated in the Global C-Sink Registry and, therefore, used for compensating GHG emissions.

The Global Biochar C-Sink certifies the amount of carbon that is effectively and measurably stored in biochar and thus prevented from returning to the atmosphere but does not issue CO_2 certificates for the avoidance of emissions.

As of 2023, biochar from pyrogenic carbon capture and storage (PyCCS, cf. Schmidt 2019) is the most mature and in terms of delivered C-sinks the most important negative emission technology (NET). However, the portfolio of NETs is steadily growing. Reforestation with single tree tracking, biomass materials, enhanced rock weathering, and marine biomass deposition are equally scaling. Certification standards for the different types of C-sinks allow interlinkages between the standards and follow overarching principles of carbon accounting and registration.

1.1 Global Biochar Carbon Sinks

Plant biomass consists of approximately 50% carbon in its dry matter, which was removed during the plant's lifecycle from the atmosphere in the form of CO_2. Using the energy from sunlight, the plant uses CO_2 and builds it into organic molecules such as glucose, cellulose, or lignin.

When plant biomass is burnt or decomposed, the assimilated carbon is released again in the form of CO_2. However, if the plant biomass is pyrolyzed, about half of the plant carbon is transformed into a mixture of predominantly very persistent carbon compounds that form a solid material known as biochar. While in the environment, any carbon compound is subject to degradation; for most components of biochar, this process is extremely slow, and mostly even so slow, that it is hard to measure for thousands of years. Provided that the biochar is not burned, the biochar carbon remains as a C-sink in the terrestrial system.

If biochar with an H to C_{org} ratio < 0.40 is applied to soil, a major part of its carbon is considered Persistent Aromatic Carbon (PAC) and will constitute a carbon sink for several millennia. A minor though relevant part of the biochar-carbon is less persistent and likely to be microbially degraded within decades to centuries, presenting a mean residence time of 50 years. The biochar carbon that may be decomposed within the first 1000 years after the application to soil is called Semi-Persistent Carbon (SPC) and constitutes a temporary C- sink. For biochars presenting an H to Corg ratio < 0.4, the PAC fraction is conservatively fixed by the standard at 75% and the SPC fraction at 25%. More precise analytical methods to define the portions of PAC and SPC of biochar are expected to be published in 2024. The present standard will be updated accordingly as soon as it becomes possible to draw scientifically reliable conclusions.

If biochar is used as a functional additive in materials such as concrete, asphalt, composites, and plastics, it is assumed that the entire carbon content of the biochar persists and remains a C-sink for as long as the material itself persists. Only when the biochar-containing material is disposed of, destroyed, or decomposed the sequestered carbon could be released back into the atmosphere, causing the C-sink to lose its value. It must be removed then from the Global C-Sink Registry.

1.2 Global C-Sink Registry

The Global C-Sink Registry (https://global-c-registry.org/) is a blockchain-secured digital database for temporary and permanent carbon sinks. All biochar C-sinks certified under the present standard are registered in the Global C-Sink Registry, which is owned and run by the not-for-profit Global Carbon Register Foundation established under Swiss laws. The register contains all relevant information to evaluate certified carbon sinks and to trade their climate cooling effects. The amount and location of biochar application, the biochar quality, the persistence of the C-sink, the year of the original carbon removal, and the owner of the C-sink are the most important information contained in the register. Moreover, all emissions caused by establishing a C-sink are registered in the emission portfolio and must be offset with permanent C-sinks before a registered C-sink can be used for emission compensation. The register allows the conversion of every C-sink and every GHG emission into annual global cooling and annual global warming effects to correctly match C-sinks and CO_2 emissions for annual compensation of climate effects.

1.3 Executive Summary: Global Biochar C-Sink Certification and Registration

To certify the carbon sink and its sustainable establishment, to calculate the global cooling effect of the carbon sink, and to assess all emissions occurred during the carbon sink establishment, the following parameters must be assessed, controlled, and registered:

- The year of the initial biomass CO_2 removal is assessed so that the Annual Global Cooling effect of the C-sink can eventually be calculated.
- All greenhouse gases emitted during the cultivation of the biomass, the pyrolysis process, packing, further product transformation, transport, mixing to a C-sink matrix, and application to the C-sink are tracked and registered in an emission portfolio (c.f., Chapter 4).
- All emissions in the emission portfolio of the biochar production must be offset by retiring a corresponding part of a C-sink in the Global C-Sink Registry.
- The C-sink efficiency of the transformation of biomass into pyrolytic carbon is assessed and must be declared. It is controlled that the biochar C-sink does not replace a more carbon-efficient baseline scenario. The pyrolytic use of biomass must be additional (c.f., Chapter 8.1).
- The energy efficiency of the entire process transforming biomass carbon into pyrolytic carbon sinks, materials, and energy must be higher than 60% (c.f., Chapter 8.2)
- The emission of fossil carbon, i.e. the use of fossil fuels and electricity from non-renewable sources within the entire process from biomass production to biochar packaging at the pyrolysis facility must be reduced to less than 100 kg CO2e per ton

of biochar until 2030 and to less 20 kg CO_2e per ton of biochar until 2035 (c.f., Chapter 8.2).

- Only biochar certified under the European Biochar Certificate (EBC) or the World Biochar Certificate (WBC) is entitled to Global Biochar C-Sink certification. The EBC/WBC certification guarantees the sustainability of the biochar production and use.
- The analytical values to calculate the size and the persistence of the biochar C-sink are provided by the EBC/WBC certificates.
- The C-sink matrix and the GPS location of the final biochar application and, thus, the C-sink are recorded.
- If the persistence of the biochar C-sink does not follow an acknowledged decay function (c.f., Chapter 3, Chapter 11), the monitoring method and controlling period of the C-sink are filed depending on the C-sink matrix.
- The verified C-sinks are registered in the Global C-Sink Registry run by the Global Carbon Register Foundation in Switzerland.

The necessary inspections at the production site must be carried out by a verification and validation body (VVB) endorsed by Carbon Standards. The relevant inspection requirements and calculation templates for certifying biochar carbon sinks are detailed in the following guidelines.

2. Biochar Use and C-Sinks

2.1 Calculation of Biochar C-Sinks

To account for the carbon stored in a biochar C-sink, the organic carbon (Corg) content of the biochar must be determined according to the EBC or WBC method. It is indicated as a mass proportion (in %) based on the biochar's dry weight. The mass of a biochar C-sink at the time of application is thus:

$$\boxed{\text{C\_sink\_initial} = \text{Corg\_content of biochar} * \text{dry mass of biochar applied}}$$

Equation 1: Amount of carbon stored in a biochar C-sink just after applying.

However, every biochar C-sink underlies a time-dependent evolution, and the C-sink is a measure of the mass of carbon that is physically present in the C-sink matrix at any given moment in time since the establishment of the C-sink. The size of a biochar C-sink is, thus, a function of the type of biochar determining its specific persistence in a specific C-sink matrix and the time since the application to the C-sink matrix.

$$\boxed{\text{C\_sink (years)} = \text{Csink\_initial} * \text{specific persistence (years)}}$$

Equation 2: Size of C-sink at a defined time in years after the application. The specific persistence depends on the biochar and the type of C-Sink matrix.

As long as biochar materials are not applied to soil or another long-lasting matrix (c.f., matrix positive list), total or partial losses of biochar-carbon are possible. Fire could destroy biochar, or a customer could buy it for co-firing in a biomass power plant or use it as a reducing agent for steel production. Therefore, biochar must be tracked from the production site to the final C-sink site.

As long as there is a risk that the stored carbon may be released to the atmosphere, the biochar-carbon must be considered a temporal C-sink. Contrary to geological C-sinks, temporal C-sinks have to be monitored and controlled regularly to guarantee their persistence, and the certificates must not be used for CO_2 offsets.

When biochar is stored for more than one year under controlled conditions (i.e., not exposed to rain, wind, and toxins) before being applied to a C-sink matrix, it can be certified as a temporary C-sink for the controlled storage time.

2.2 Geological C-Sink (biochar applied to soil)

Biochar only becomes a geological (long-term) C-sink when its rapid oxidation, e.g., by burning or smoldering, can be excluded. This status is reached when biochar is mixed irrevocably into an inflammable and irrecoverable C-sink matrix that eventually is applied to soil (c.f., Chapter 11). When mixed with animal feed, manure, compost, liquid fertilizer, or anaerobic digestate, it could theoretically be dried and combusted, but when produced and marketed as a soil amendment or feed, it can be excluded that a significant portion of it may burn. Possible partial losses are covered by safety margins, which ensure that in no case more carbon is certified as a C-sink than is present in the C-sink. When biochar eventually reaches the soil after it was used, e.g., as livestock bedding or as part of similar organic substrates for agriculture, or when it becomes an intrinsic component of similar mineral materials, the terrestrial C-sink can be characterized with mathematically defined degradation rates, reflecting the content of PAC/SPC, reaching far into the future (i.e., > 1000 years) which makes it a geological C-sink.

The geological C-sink is registered with its persistence curve reaching over at least 1000 years (c.f., Chapter 3).

2.3 Temporary C-Sink (biochar used in materials)

If biochar is used in construction materials, in asphalt, plastics, and composite materials, it can be assumed that the entire carbon content of the biochar persists and remains a C-sink for as long as the material itself persists. Only when the biochar-containing material is disposed of, destroyed, or decomposed may the sequestered carbon be released back into the atmosphere, causing the C-sink to lose its value and must be removed from the C-sink registry.

While biochar in building materials such as concrete may, at the end of the product life, be applied to soil (e.g., when crushed and used in roadbeds) and become by then a geological C-sink, as long as the biochar is not applied yet to soil but contained in a material outside of the soil, it cannot be considered a geological C-sink. Matrixes such as plastics, textiles, paper, or composites cannot fundamentally prevent the oxidation of biochar. The likely end-of-life scenario of such materials is waste incineration, although the deposition in landfills is still common practice in many countries.

Using biochar in materials is often recommended to optimize material properties or replace other materials made from or under the use of fossil fuels. For as long as these biochar materials are in use, the carbon in the biochar remains stored outside the atmosphere and is eligible for global cooling services. There are two distinguished principles for registering biochar materials as temporary C-sinks:

1) For consumer products such as water pipes, skis, or car parts, tracking the actual use is not feasible. However, as they are produced and marketed in large quantities, statistics for specific products can determine an average lifetime. With a statistically validated lifetime before it may end up in waste incineration, the biochar carbon can be certified as a temporary C-sink for the defined product lifetime. While the C-sink would continue in the case of landfill waste disposal, we do not consider it a sustainable practice.
2) When biochar is used in significant amounts in geographically defined infrastructure or buildings (e.g., insulation foam or concrete), a control period must be fixed by Carbon Standards based on the ranges defined for the specific C-sink matrix (c.f., Chapter 11) and the evaluation of specific project parameters. The control of such projects is usually assured remotely, e.g., with satellite imagery. If, for example, a satellite image shows that the building is still present, it can be assumed that the biochar foam insulation between the walls is also present, and thus the temporary C-sink is still in place.

Temporary material C-sinks are registered with their statistically validated lifetime or their controlling period. If the control at the end of the defined controlling period confirms the continued presence of the C-sink, the registry entry of the temporary C-sink is prolonged until the end of the next controlling period. The duration of the new controlling period is updated at the end of each controlling period.

2.4 Temporary Storage of Biochar

Biochar can be stored to preserve it for later years when, e.g., demand and prices increase. For as long as the biochar is stored under controlled conditions and with regular verification, such as in containers, below ground protected from water and biologically active matrices, and in ancient salt or coal mines, it can be considered a temporary C-sink during the controlled storage time. The control is usually assured remotely with continuous temperature and/or CO_2 concentration measurements.

The registered amount of carbon in temporary storage C-sinks must be updated annually.

3. Persistence of Soil Applied Biochar

Once applied to soil, a total loss of a biochar-based C-sink becomes practically impossible. However, despite its persistent nature, even biochar will slowly degrade in the soil matrix. From a chemical perspective, biochar is a mixture of an extensive variety of carbon compounds ranging from aliphatic, simple aromatic to condensed aromatic hydrocarbons, also called aromatic clusters. Thus, observable biochar degradation is the sum of the degradation of theses individual compounds, which can be approximated with an empiric degradation formula. For this purpose, we differential biochar carbon into a Semi Persistent Carbon (SPC) pool that degrades within the first thousand years after soil application and a Persistent Aromatic Carbon (PAC) pool that will persist for more than 1000 years in soil or sediments and can be considered a geological carbon sink (Schmidt et al., 2022). The degradation of SPC can be assessed e.g. by incubation of biochar in soil or controlled lab environments exposed to microbial communities, reasonable incubation times of 1-10 years have been achieved and to provide useful information to this end. However, within such reasonable time frames, only the most labile carbon compounds can be degraded. The persistence of PAC must therefore be derived from observations of the global pyrogenic carbon cycle (see Appendix 1 in (Schmidt et al., 2022)) or from thermodynamic and kinetic conclusions for the chemical and microbial degradation of the polycyclic molecules.

The distinction of these two defined pools changes the key question from "how stable is biochar" to "what is the size of PAC fraction of a given biochar?" and thus, what portion of a biochar can be considered as geological C-sink when applied to soil. The size of the PAC and SPC fractions depends on the severity of the pyrolysis conditions (i.e., temperature, residence time, pressure) but also on the ash content of the feedstock and its particle size (Bowring et al., 2020, 2022; Zimmerman and Gao, 2013). The proportion of PAC and SPC is related but not determined by the H/C_{org} ratio and the electric conductivity of the solid biochar. Today, the most reliable method to determine the size of the PAC fraction of biochar is hydrogen pyrolysis (i.e., Hydro-Pyrolysis (HyPy)).

Hydrogen pyrolysis is an analytical method where the biochar sample is heated to 550 °C in a 150-bar hydrogen atmosphere. All labile organic matter and semi-persistent carbon structures, such as aliphatic compounds and polycyclic aromatic clusters presenting up to seven condensed aromatic rings, react with the hot, high-pressurized hydrogen and are completely removed from the sample. Only the highly stable portion of the carbon compounds, i.e. the PAC, remains. The PAC, as defined by HyPy, consists of condensed aromatic clusters with more than seven aromatic rings which demonstrate extreme stability in the environment, being highly resistant to biological and chemical degradation. Historical biochar samples, dating back centuries, appear to validate the geological persistence of the

PAC fraction, as indicated by Ascough et al. (2012, 2009) and Meredith et al. (2012). However, the number of studies focusing on biochar persistence in relation to HyPy remains limited (Howell et al., 2022; McBeath et al., 2015).

Concurrently, the use of microscopic analysis measuring the total reflectance is suggested to quantify a permanent carbon fraction in biochar, which is referred to as inertinite. The extent to which HyPy measured PAC and inertinite are the same or different has not yet been investigated. Even more than for the above-mentioned case of HyPy, literature on the random reflectance method in relation to biochar persistence is still very limited (Petersen et al., 2023, Sanei et al. 2023) and not yet broadly enough discussed in biochar science. Especially, the significance of the measured inertinite content regarding the stability of biochar in biologically active systems (as opposed to geological storage) is yet missing.

Consequently, there is insufficient confidence to revise the biochar persistence evaluation used in the earlier versions of the present C-sink standard. Several scientific papers on biochar persistence using new analytical methods are announced for the academic year 2024, which will likely lead to an update of the biochar persistence chapter in the Global Biochar C-Sink standard and its recommended analytical methods within the same year.

The semi-persistent carbon (SPC) fraction of biochar is defined as the part of soil-applied biochar that decays within the first 1000 years after soil application. For biochars presenting an H to C_{org} ratio below 0.4, the SPC fraction has a mean residence time of 50 years and constitutes a temporary carbon sink. The mean residence time of 50 years for the SPC fraction is based on the most conservative metanalytical estimate for biochar carbon degradation published to date (Schmidt et al., 2022). Other sources determined significantly lower degradation rates depending on the degree of pyrolysis and the experimental design (IPCC, 2019; Kuzyakov et al., 2014; Lehmann et al., 2015; Zimmerman and Gao, 2013). However, without more reliable methods and long-term experiments, the present Global Biochar C-Sink standard uses conservative projections and calculates the climate-relevant effect of C-sinks with a sufficient safety margin.

EBC and WBC certified biochar with an H/Corg ratio < 0.40 that was applied to soil is therefore registered with a PAC fraction of 75% and SPC fraction of 25% in the Global C-Sing Registry. Soil-applied biochars with an H/Corg ratio ≥ 0.4 that was applied to soil, are registered with an SPC fraction of 100%, and no PAC fraction can be registered.

If the calculation method in the expected update of the standard allows higher PAC proportions for the respective biochar batch, the register entries can be adjusted posteriorly under conditions to be specified.

The remaining carbon of soil-applied biochar with an H/Corg ratio < 0.40 is calculated as a function of time with the following conservative approximation:

$$C_{remain}\text{ (year)} = \frac{M_{BC}*C\_cont}{1000}\ (750 + 45 * e^{-0.5232 * years\_of\_decay} + 205 * e^{-0.009966 * years\_of\_decay})$$

Equation 3. Decay function of biochar presenting an H to C_{org} *ratio < 0.40.* M_{BC} *= mass of biochar;* C_{cont} *= carbon content of biochar;* C_{remain} *= Mass of biochar-carbon remaining in a C-sink after the years of decay since soil application.*

If 1000 tons of biochar with a C-content of 80% and an H to C_{org} ratio of 0.2 is applied to soil, the carbon that remains after 20 years, 100 years, and 1000 years in the soil C-sink, respectively, is calculated as follows:

$$C_{remain}(20y) = \frac{1000\ t*80\%}{1000}\ (750 + 45 * e^{-0.5232*20y} + 205 * e^{-0.009966*20y}) = 734.4\ t$$

$$C_{remain}(100y) = \frac{1000\ t*80\%}{1000}\ (750 + 45 * e^{-0.5232*100y} + 205 * e^{-0.009966*100y}) = 660.5\ t$$

$$C_{remain}(1000y) = \frac{1000\ t*80\%}{1000}\ (750 + 45 * e^{-0.5232*1000y} + 205 * e^{-0.009966*1000y}) = 600.0\ t$$

When C-sinks are sold to offset CO_2 emissions only the PAC fraction must be used. The SPC-fraction of biochar can be used for methane emission offsets (c.f., Chapter 4.3) and global cooling services (c.f., chapter 4)

4. Emission Portfolio and Emission Compensation

The carbon expenditure of a biochar C-sink englobes all GHG emissions caused by biomass production, transport, preparation, pyrolysis, milling, packaging, transportation, mixing, and application to a C-sink matrix. It presents the complete carbon footprint of the biochar from the initial capture of atmospheric carbon till the application to the final C-sink site.

The emissions from biomass production to the packaging of the biochar and its storage at the factory gate are assessed with Carbon Standards' Biochar Tool, and it is the biochar producer that must offset these emissions for every batch and every year of production.

The emissions occurring from the biochar factory gate to the final C-sink site have to be tracked by dMRV providers. Those post-factory-gate emissions are relatively small compared to the C-sink value of the biochar and are commonly offset by retiring part of the biochar C-sink.

All production emissions are registered in the ***Emission Portfolio*** of the production companies for each biochar production batch. Moreover, each packaging unit has its own emission portfolio to ensure that all emissions occurring between the factory gate and the final C-sink are recorded and offset.

All fossil CO_2 emissions from biomass production to C-sink application must be offset by long-term carbon sinks before the registration of a biochar C-sink can be validated in the Global C-Sink Registry. The same must be done for N_2O emissions from biomass cultivation. The global warming effect of CH_4 emissions can be compensated by equally sized global cooling over a 20-year period, which must be validated in the Global C-Sink Registry (c.f., Chapter 4.3)

4.1 Emissions Included in the Emission Portfolio

The emissions of the greenhouse gases CH_4, N_2O and CO_2 from fossil carbon caused by biochar production are recorded. For the EBC and WBC the emissions are related to the production of a batch (same feedstock and pyrolysis temperatures, 365 days maximum production time). It includes:

a) Emissions from the provision of biomass (c.f., Chapter 4.1a), covering biomass production, processing, and transportation.

b) Emissions from the storage of the biomass (cf. Chapter 4.1b)

c) Emissions from the pyrolysis process and other equipment at the production site (c.f., Chapter 4.1c).

d) Emissions from postproduction and transportation to the C-sink site (c.f. Chap. 4.1d).

e) A safety margin in the amount of 20 kg CO_2e per ton of biochar is added to account for all additional emissions not covered under the regular assessment (cf. Chap. 0).

The carbon expenditures are calculated by adding all the above listed emissions as CO_2e using the GWP100 of methane (25 t CO_2e t^{-1}) and N_2O (298 t CO_2e t^{-1}), respectively. It is given as mass proportion based on the dry weight of the biochar (t CO_2e t^{-1}). It is calculated by dividing the total amount of carbon expenditures per batch by the dry weight of the total amount of biochar produced per batch.

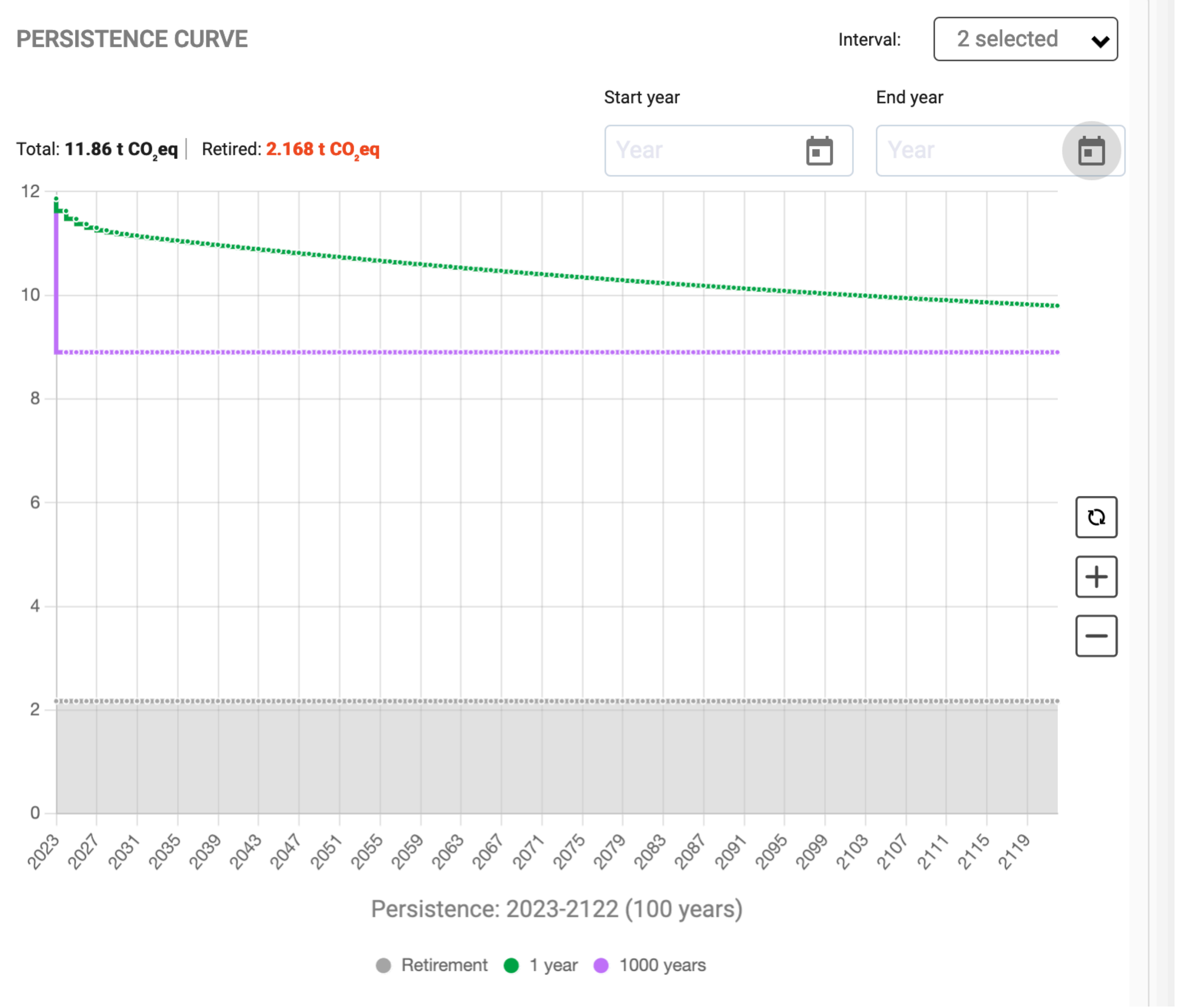
4.2 Offsetting of Production Emissions

CO_2 must only be offset with geological C-sinks, such as the PAC fraction of soil-applied biochar, that are registered in the Global C-Sink Registry (c.f., Figure 1).

The global warming effect of methane (CH_4) emissions can be compensated by an equally sized global cooling effect over 20 years. The total global warming effect of methane is calculated according to their 100-year global warming potential (GWP100) by a factor of 25 tons CO_2e per ton CH_4. However, since non-fossil methane is oxidized to C-neutral CO_2 and H_2O after about 12 years in the atmosphere, compensating of the global warming effect must be done with global cooling over a maximum of 20 years using registered carbon sinks (*c.f., Chapter 4.3)*.

Nitrous oxide (N_2O) has a long residence time in the atmosphere and thus must be offset with geological C-sinks registered in the Global C-Sink Registry. For this purpose, emissions are converted into CO_2e using the GWP100 of 298 tons CO_2 per ton N_2O.

The emission offsets can be realized with the registered biochar C-sink whose production had caused the emission. See the Global Cooling guidelines for a more detailed description of CO_2 emission offsetting.



Total: **11.86 t CO_2eq** | Retired: **2.168 t CO_2eq**

Figure 1: The green line shows the persistence of a biochar C-sink over the next 100 years (slow degradation of the SPC fraction). The lilac line shows the persistence of the PAC fraction on the biochar. The entire area below the lilac line can be traded as geological carbon sink. The grey area at the bottom of the diagram shows the emissions caused for the biochar production and the establishment of the C-sink, which is then retired from the PAC fraction. The C-sink represented by the area below the green curve and above the grey area remains a tradable climate effect of the biochar C-sink. The area between the green and the lila line can only be traded for its global cooling effects (e.g., for methane compensation).

4.3 Methane Emissions and Offsetting

Although the methane concentration in the atmosphere is around 200 times lower than that of CO_2, methane currently contributes between 16 and 30% to global warming, with no consensus between the scientific references. However, the average residence time of methane in the atmosphere is only nine to twelve years as it is oxidized to CO_2 and H_2O in the atmosphere (Prather et al., 2012). During this short period, methane has a climate impact that is over 200 times greater than that of CO_2. To compare these different effects of greenhouse gases and the varying duration of their effectiveness, the global warming potential (GWP) of the gases is calculated for a specified period of time. In recent decades, a period of 100 years has been predominantly used for this purpose (GWP100) (Fuglestvedt et al., 2003). However, in the case of methane emissions, any reference time above 12 years underestimates the global warming effect during the first 12 years and overestimates the climate effect after those 12 years. The longer the reference period exceeds the 12 years during which methane causes a global warming effect, the more the climate forcing is diluted and climate action through compensation with negative emissions delayed (Myrhe et al., 2013).

The decades up to 2050 are the decisive period for limiting anthropogenic global warming. Since methane emissions occurring today and in the upcoming decade have a particularly severe climate impact until 2050, the calculation of methane's climate impact should not be diluted over 100 years. Therefore, the Global Biochar C-Sink standard requires that the compensation of methane emissions must occur during the first 20 years following the emission. This reflects the comparatively short but intense impact of methane and is in line with recommendations from various organizations and scientists (Balcombe et al., 2018).

To compensate methane emissions, the GWP100 of the emitted amount of methane is calculated using the factor 25 kg CO_2e per kg CH_4. We then calculate the absolute global warming potential (AGWP) over 100 years using Jeltsch-Thömmes & Joos (2019). The AGWP must then be compensated by a same-sized absolute global cooling potential (AGCP) over a maximum of 20 years.

Methane emissions could be offset by retiring a PAC portion of the biochar C-sink. However, since the PAC fraction of C-sinks has a negative global warming effect of more than 1000 years while the global warming effect of bio-methane (i.e., methane from carbon-neutral biomass) only lasts a few years, offsetting the short-term global warming of methane with long-term C-sinks is hardly justifiable, it is neither economically nor is it necessary or adequate from a physical point of view.

The comparatively short lifetime of methane in the atmosphere allows it to compensate for its climate impact with temporary C-sinks. The Global C-Sink standards developed the option to compensate for methane emissions with temporary C-sinks such as the SPC fraction of biochar, tree plantations, and biochar-containing materials. However, in the case of industrial biochar production, compensating CH_4 production emissions with the SPC fraction of the produced biochar is the most likely and described below.

Box1: Methane compensation example

If to produce 180 tons biochar with a carbon content of 48%, a total of 300 kg of CH_4 was emitted, the GWP100 of this emission is (0.3 t CH4 * 25 t CO_2e / t CH_4 =) 7.5 t CO_2e. The AGWP over 100 years results in 383.75 tons CO_2e * years (equivalent to a radiative forcing of 3.33×10^{-8} W m^{-2} yr). Those 383.75 t CO_2e yr of global warming must be compensated by at least 383.75 t CO_2e yr of global cooling within 20 years which corresponds to maintaining a carbon sink of 16.7 t CO_2e without decay for 20 years (19.2 t CO_2e * 20 yr = 384 t CO_2e yr), or a carbon sink of 76.75 t CO_2e for five years. It further corresponds to the first seven years of the SPC fraction of those 180 tons of biochar. To encourage afforestation, the global warming effect of the methane emission could be compensated by an exponential growth curve of a newly planted forest over 20 years (exponential increase of tree-based carbon removal over 20 years). The compensating global cooling must start in the first year, provide annual global cooling in every following year, and finalize the compensation latest 20 years after the methane emission.

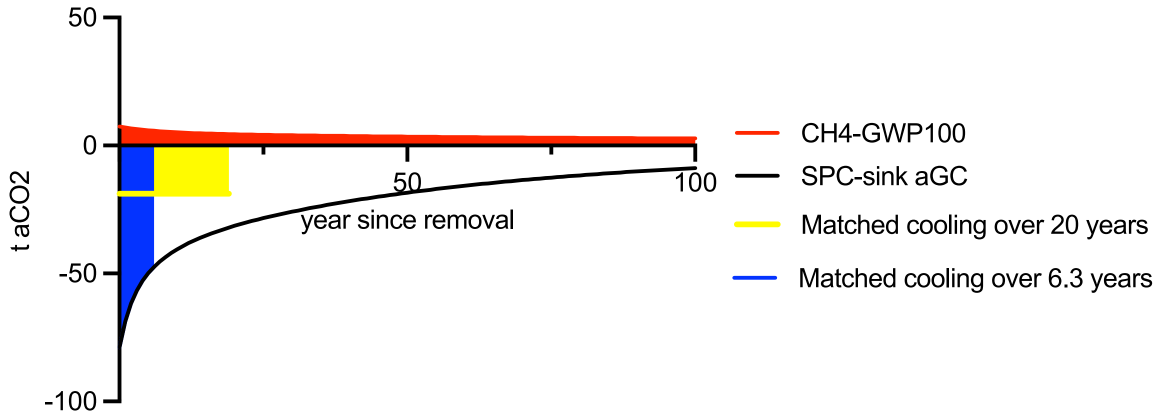


Figure 2: Compensation of the global warming effect of a 300 kg CH_4 emission (area below the red curve) caused by the production of 180 t of biochar with a C content of 48%. As 25% of the biochar carbon is semi-persistent carbon (SPC) with a mean residence time (MRT) of 50 years (black curve), the global cooling effect of the biochar's SPC fraction can be used entirely for 6.3 years (blue area) or partially for 20 years (yellow area).

Methane compensation within Global Biochar C-Sink is defined as creating a carbon sink for 20 years that has a climate cooling effect equal to the climate warming effect of a methane emission over 100 years after the emission occurred. Thus, the total climate forcing of a methane emission must be compensated within 20 years after the initial emission.

4.4 Reduction of Fossil Carbon Emission

Given that global GHG emissions are successfully reduced by 2050 to less than 10% of the emissions recorded for the year 1990, negative emissions of at least 800 Gt CO_2e are still needed until the end of the century to limit global temperature rise to about 2 °C. The remaining 10% of GHG emissions will mainly comprise emissions from agriculture and waste decomposition but must not originate from fossil carbon sources. Consequently, C-sink producers must reduce their fossil carbon emissions, too. It is neither convincing nor acceptable in the long term if C-sink producers consume fossil carbon for the provision of machine fuel and electricity. Therefore, **certified biochar producers must present a plan outlining how to reduce fossil GHG emissions of biochar production to less than 100 kg CO2 per ton of biochar-carbon in 2030 and to less than 20 kg CO2 per ton of biochar-carbon in 2035** (for an example of such a plan, see annex 4).

The following fossil carbon emissions must be included: biomass production, harvest, transport, preparation such as chipping or pelletizing, drying, pyrolysis, and packaging. Methane emissions from storing and pyrolysis should equally be avoided but are not included in the fossil carbon emission reduction plan because of their biogenic origin. Fossil carbon emissions from biochar transportation and external processing do not fall under the responsibility of the biochar producer and will be part of the control of biochar traders, biochar product manufacturers, and users.

$$\text{Biochar\_GHG\_balance} = \frac{\text{Total emission until factory gate} - \text{non fossil CH4 emissions}}{\text{mass of biochar per batch (DM)} * C_{\text{content}} \text{ of biochar}}$$

Equation 4: Calculation of the GHG balance of biochar production from feedstock production until biochar packaging at the biochar production facility.

The fossil emission reduction plan must be updated annually and include a short progress report. The plan can be managed online in the Carbon Standards Biochar Tool or uploaded annually in a new version of the tool.

4.5 Pro Rata Calculation of GHG Footprint

It should be expected that not only the biochar production as such but the entire biomass processing facility with all resulting products (i.e., biochar, electricity, heat, hydrogen, pyrolysis oil, etc.) is climate neutral.

However, in specific industrial setups where biochar is a minor secondary product of the larger pyrolysis or gasification process, it may not be appropriate to attribute the entire carbon footprint of the production to biochar alone. Instead, if the biochar contains less carbon than was used to produce electrical energy and/or other pyrolysis products (e.g., charcoal, hydrogen, pyrolysis oil), the greenhouse gas (GHG) emissions may be distributed proportionally among the different products. The GHG allocation is calculated on the energy base of the products (see Box 6). However, thermic energy is excluded from this allocation since it is considered a byproduct of all processes and should not be factored into the proportional GHG attribution.

To be eligible to use the pro-rata GHG calculation, more than 50% of the energy value contained in the biomass must be used for non-biochar products.

The input energy (E_{input}) is calculated by multiplying the analyzed lower heating value (LHV) of the biomass feedstock ($LHV_{feedstock}$) with the mass of the feedstock on a dry matter base ($m_{feedstock,\ dm}$). The output energy of the non-biochar products ($E_{nonBCoutput}$) is calculated by multiplying the LHV of the **marketable non-biochar solid, liquid, and gaseous products** with the respective mass of the products on a dry matter base and adding the produced electric energy ($E_{electric}$). For electricity production, an efficiency of 40% is assumed. A pyrolysis product is considered as marketed when it is sold to or used in processes not directly linked to the pyrolysis/gasification facility. For example, hydrogen is considered a marketable product when hydrogen is produced, stored in a tank, and sold to another company or used, e.g., in a methanol synthesis at the production site. If the hydrogen is combusted in the combustion chamber of the pyrolysis unit or in a directly linked generator for electricity production, the hydrogen is not considered a marketable product.

(1) $E_{input} = LHV_{feedstock} * m_{feedstock,\ dm}$

(2) $E_{nonBCoutput} = LHV_{nonBCsolid} * m_{nonBCsolid}, dm + LHV_{liquid} * m_{liquid} + LHV_{gas} * m_{gas} + E_{electric} / 40\%$

(3) $E_{biochar} = LHV_{biochar} * m_{biochar\ (DM)}$

Equation 5: Calculations of energy content based on the lower heating value (LHV) of the biochar, the pyrolysis oil, the pyrolysis gas, and the electric energy.

If the energy content of the marketable non-biochar output is higher than 50% of the energy contained in the feedstock input ($E_{nonBCoutput} / E_{input} > 50\%$), the emission portfolio of the biochar C-sink may be established using the pro rata approach.

To calculate the GHG attribution of the biochar product, the total emissions assessed for the entire process from biomass production to biochar output are multiplied by the ratio of $E_{biochar}$ to the total E_{output} ($=E_{nonBCoutput} + E_{biochar}$).

$$(4)\quad BC_{emission} = \text{Production emissions}\ \frac{E_{biochar}}{E_{nonBCoutput} + E_{biochar}}$$

Equation 6: Calculation of the part of total emissions to be accounted for the biochar production on a pro rata base.

All emissions that occur between the biochar output from the pyrolysis unit to the eventual carbon sink must be attributed to the emission portfolio of the biochar.

Box 6: Pro-rata attribution of GHG emissions caused by the biochar facility.

Example for the pro-rata calculation for GHG attribution:

- **Input (feedstock):** Annual feedstock 4000 t of wood with a dry matter content of 65%, carbon content of 48%, and a lower heating value (LHV) of 4 kWh/kg (@ 80% DM) representing (3250 t (@80% DM) * 4 MWh/t =) 13,000 MWh.
- **Output:** The unit produces 260 t biochar (DM) per year with an LHV of 7.9 kWh/kg and a C-content of 85%, representing 2054 MWh; and 3140 MWh electricity, representing 3140 MWh nonBCoutput.
- **Pro-rate eligibility:** Considering a 40% efficiency of the electricity production, (3140 MWh / 40% / 13,000 MWh =) 60% of the biomass LHV. The pro-rate approach is, thus, applicable.
- **GHG attribution:** The biochar to total products ratio is (2054 MWh / (2054 MWh + 3140 MWh / 40%) =) 21%. Thus, 21% of carbon expenditure (excluding the margin of safety, chap. 0) are attributed to the biochar production. To set the biochar production climate neutral, 21% of all CO_2 (+ the margin of safety) and N_2O production emissions must be offset with long-term C-sinks, and 21% of CH_4 emissions compensated with global cooling services. GHG emissions occurring from the packaging station to the factory gate and then to the final C-sink are entirely attributed to the biochar.

We hope that by 2035, we can realistically require all bioenergy and biomaterial productions to become climate-neutral. The fact that biochar production as such must reduce fossil GHG emissions of the production to less than 100 kg CO2e per ton of biochar-carbon until 2030 will also chart the way for the entire biomass industry to reach zero fossil carbon status.

4.6 Margin of Safety

In the calculation of carbon footprints, the emissions accounted for are usually divided into Scope 1 (direct emissions at the production site, in this case, combustion of pyrolysis gas, methane emissions during biomass storage, combustion of natural gas for preheating the reactors), Scope 2 (indirect emissions from externally purchased energy, in this case mainly electricity) and Scope 3 (further indirect emissions, in this case, e.g., production emission of the pyrolysis plant, electricity for external server maintenance, emissions of purchased biomasses, fertilizers, transport of biomass). For the Global Biochar C-Sink, the emissions from Scope 1 and 2 are fully recorded. In contrast, from Scope 3, only the emissions from biomass production and its transport are directly quantified. Other indirect emissions from Scope 3 are not recorded individually due to their comparatively low volume but are instead included in the calculation with a flat margin of safety. This includes, for example, the emissions caused by:

- Production and disposal of polypropylene bags,
- Electricity for the operation and cooling of the company's external computer servers,
- Potential methane emissions during the first month of storage of the biomass,
- Fuel consumption by employees for commuting to work and for business trips,
- Marketing and management activities including trade shows and conference attendance,
- Operation of chainsaws or harvesters for felling and peeling trees and for digging up roots,
- Emissions from machine fuels during cultivation of agricultural land and plant protection measures,
- Production, maintenance, repair, and disposal of pyrolysis equipment, transport vehicles, warehouses, and other machinery.
- The loss of small amounts of diffuse C-sinks to waste incineration (e.g., potting soil that is discharged to a waste bin).
- The margin further contains unavoidable imprecisions of the C-sink accounting such as sampling, packaging, volume and dry mater analysis, etc.

There are many small, indirect scope 3 emissions that need to be included when creating a perfect carbon footprint. Compared to the total amount of CO_2e from Scope 1 & 2 as well as from biomass provision within Scope 3, and to the vast amount of carbon accumulated in biomasses, the remaining indirect emissions in Scope 3 play only a minor role. To account for all these GHG emissions that are not directly quantified, a flat margin of safety is defined. The margin of safety generally amounts to 20 kg CO_2e per ton of biochar which corresponds to roughly 0.7 % of the biochar carbon. The margin of safety is applied per ton of biochar and thus not affected by pro-rata accounting. This is an industry-standard margin for the inherent uncertainty of the overall process that allows Carbon Standards to keep the certification process lean and efficient without misappropriating emissions.

If a company produces like in the example above 260 tons of biochar with a C-content of 85%, the GHG margin would be (260 t biochar * 0.02 t CO2e t biochar^{-1}=) 5.2 t CO_2e. Thus, if the biomass provision causes, e.g., 92 kg CO_2e / t biochar and the pyrolysis process 110 kg CO_2e / t biochar), the total GHG emissions would be (92 kg CO_2e for biomass + 110 kg CO_2e for pyrolysis + 20 kg CO_2e for the margin =) 222 kg CO_2e per ton of biochar. The margin would thus be (20 kg / (92 kg +110 kg) =) 10%. This margin of safety covers the indirect emissions not quantified in the system and unavoidable imprecisions in measuring and analyzing the produced biochar.

5. Biomass Feedstock for Biochar C-Sink Production

C-sink certification's overarching goal is to increase the total amount of carbon stored in the terrestrial system and thus reduce the concentration of greenhouse gases in the atmosphere. When certifying C-sinks, it must be ensured that the establishment of the certified C-sink does not reduce the total terrestrial carbon sink. The C-sink must be additional to the total terrestrial carbon sink compared to the moment of CO_2 removal.

The evaluation of a biochar C-sink does not start with the production of the biochar or the transport of the feedstock but precisely at the moment when the growing biomass removes CO_2 from the atmosphere. The climate effect of the carbon sinks is caused by the reduced atmospheric CO_2 concentration while preserving the removed carbon in the carbon sink avoids its re-emission.

The Global Biochar C-Sink certification verifies that (1) the use of biomass does not deplete a long-term natural or otherwise registered carbon sink. It evaluates the climate neutrality of the feedstock production and provision along the criteria for the different feedstock types outlined in chapter 4.3 (*Approved biomass and carbon expenditures for their production*).

5.1 Carbon Neutrality of Biomass Feedstock

Feedstock to be used for biochar production must be carbon neutral under the following definition of of feedstock carbon neutrality:

A feedstock material (biomass) for the generation of a C-sink is considered C-neutral if it is either the residue of a biomass processing operation or if the biomass removal did not, over the reference period, lead to the reduction of the total carbon stock of the system in which the biomass had been grown.

Only C-neutral biomass input materials are permitted for the production of biochar C-sinks. Biochar produced from biomass whose harvesting resulted in the destruction or depletion of a natural C-sink (e.g., clear-cutting of a forest) or has contributed to the disappearance of an existing sink (e.g., inappropriate agricultural practices on bog soil) does not render any positive climate service and must not be certified as C-sink.

Emissions resulting from biomass cultivation (i.e., fuel consumption for land preparation and harvest, fertilizer, irrigation, etc.) do not in themselves challenge feedstock carbon neutrality but are included as carbon expenditures. They are part of the emission portfolio and must be offset with registered long-term C-sinks.

5.2 Biomass Feedstock Additionality

Carbon from biomass shall be preserved as much and for as long as possible. Given the limited surface area of the planet on which plants can grow, natural carbon dioxide removal is limited, and the available biomass must be used responsibly. Biochar C-sinks must be additional to natural C-sinks that could or would have been realized with the same biomass feedstock in the absence of the biochar C-sink solution.

For example, a tree trunk that would normally have been transformed into construction wood or could, economically, be made into construction wood should not be pyrolyzed. Construction wood preserves the entire wood-carbon for as long as the wood is retained in the construction, thus creating a temporary C-sink. Pyrolyzing the same wood would only preserve 30-60% of the wood carbon in the biochar and result in the partial oxidation of the biomass to emitted carbon dioxide. However, if the trunk wood is used to create a C-sink material, the woody residues from processing the tree trunk into construction wood (bark, sawdust, offcuts) could be used as carbon-neutral feedstock for pyrolysis. Also, at the end of the lifecycle of the woody material, pyrolysis could preserve most of its carbon in long-term carbon sinks.

However, the decision about what is the most carbon-efficient use is often not clear. All biomasses can be used in multiple ways, and it is rarely evident which use scenario is more or less sustainable, economical, and carbon-preserving. Straw could be used for animal bedding (good economics, recycling to organic fertilizer replacing synthetic fertilizer, no carbon preservation, additional methane emissions), for biochar production (good economics, renewable energy, 50% of C-preservation), for straw bale housing (small market, 100% C-preservation). It would not make sense to prefer or exclude one of these three scenarios due to additionality considerations.

If wood from a tree trunk is used to make wood chips for energy production by incineration, replacing fossil fuels, those wood chips could also be utilized in gasification, generating a similar amount of energy and producing some biochar as a byproduct. Carbon-preserving materials would be an even more C-efficient option compared to both scenarios. However, despite their clear climate benefits, when used for carbon-preserving purposes, wood materials are not favored by policymakers or the IPCC over bioenergy in today’s context.

In light of the preceding factors, it is reasonable to consider that wood sourced from sustainable forest management and biomass residues collected in accordance with the guidelines outlined in chapter 5.1, should not be dismissed as potential biomass feedstock for biochar C-sink production on the ground of additionality considerations.

5.3 Approved Biomasses and Carbon Expenditures for their Production

Only biochar produced from carbon-neutral biomass is eligible for C-sink certification. Nevertheless, the provision of biomass for pyrolysis results in energy consumption and emissions that must be included in the carbon expenditure of biochar production. Depending on the type of biomass and the way it is produced, specific criteria for carbon expenditures apply.

Global Biochar C-Sink defines ten **general feedstock classes:**

(1) Biomass from annual cropping
(2) Biomass from pluriannual and perennial cropping including short rotation plantations
(3) Forest biomass
(4) Wood from landscape conservation, agro-forestry, forest gardens, field margins, and urban areas
(5) Wood processing waste and waste wood materials
(6) Organic residues from biomass processing
(7) Municipal waste and municipal waste digestate
(8) Manure and agricultural digestate
(9) Biosolids and biosolid digestate
(10) Other biogenic residues

The production of biomass usually causes emissions that need to be accounted for as carbon expenditures of the C-sink:

- If mineral nitrogen fertilization was used to produce the biomass, its carbon footprint, including soil borne N_2O emissions, must be accounted for according to the formula 100 kg N = 1 t CO_2e (Zhang et al., 2013).
- If pesticides were used, a flat value of 94 kg CO_2e per hectare (Audsley et al., 2009) is applied for their production-related emissions.
- The input of fuels for cultivation and harvest must also be added to the emission portfolio with a conversion factor of 3.2 ton CO_2e per ton diesel (Juhrich, 2016).

However, to keep the C-sink certification process lean and appropriate to the developmental stage of the nascent industry, the comparably low emissions for cultivation, harvest, and plant protection are included in the margin of safety (c.f., Chapter 0). Still, fertilization and transportation of the biomass from its origin to the pyrolysis plant needs to be quantified and accounted for as carbon expenditures.

An overview about the accounting of carbon expenditures for the ten general feedstock classes is given in the following chapters 5.3.1 to 5.3.10.

5.3.1 Biomass from annual cropping

If annual crops are grown on agricultural land, it can be assumed that after one year at the latest, the same amount of biomass will have grown again on the same area, which means that approximately the same amount of CO_2 will again be removed from the atmosphere. The harvested biomass can thus be considered C-neutral based on a one-year period (reference period for annuals) so that a C-sink can be created by producing biochar from cropping residues or the entire annual biomass production. Crop rotations may result in differences of annual CO_2 removals, though over the years those differences even out.

Today, material like straw, the stalks of tomatoes, potatoes, cabbages, and other plants, leaves, and pruning wood are considered agricultural residues. The inclusion of carbon (i.e., biomass) as a full-fledged product of agriculture would change this perception and the definition of agricultural residues. They would be considered an essential part of the agricultural (carbon) crop. The dry weight of any of these biomass types also contains 50 % carbon. Using pyrolysis, more than half of this carbon can be converted into long-term C-sinks instead of being lost as CO_2 in a relatively short period through decomposition or combustion, as is still common practice in most parts of the world. The use of biomass from companion plants and crop residues would become a key component of climate farming and critical to mitigating climate change. However, it is not recommended to completely remove all crop residues from the field and thus reduce the important ecological function of soil cover and organic matter recycling. Rather, the aim is to integrate biomass as an agricultural product into the field management plan while preserving its central ecological functions and replenishment of soil organic matter.

All biomass from annual cropping (i.e., the main crop, residues, companion plants) are considered to be C-neutral input material. The time of the CO_2-removal to be submitted to the Global C-Sink Registry is the year of harvest.

However, it must be ensured that the removal of harvest residues does not decrease soil organic carbon stocks (Whitman and Lehmann, 2015).

If biomass was deliberately grown to produce biochar, i.e., when it was the single or main product of this field, carbon expenditures for fertilization need to be accounted for. It must be included in the emission portfolio according to the formula 100 kg N = 1 t CO_2e (Zhang et al., 2013). If pesticides were used, a flat value of 94 kg CO_2e per hectare must be applied. All other cultivation-related related GHG emissions are included in the margin of safety (cf. chapter 6). If the main crop is used for food, animal feed, or biomaterials, no carbon expenditures for the cultivation must be accounted for the C-sink made from its residues.

Box 2: Calculations of the carbon footprint for biomass production

Example for the calculation of the carbon expenditure for the provision of annual biomass

- On one hectare, 10 t biomass were produced using 50 kg N and 25 l diesel, which are processed into 3 t biochar (dry matter = DM) with a carbon content of 75%.
- The emissions amount to (0.05 t N * 100 t CO_2eq * t^{-1} N / 3 t biochar =) 0.167 t CO_2e per ton of biochar for fertilization and (3.2 kg CO_2eq * 25 l / 3 t biochar =) 0.03 t CO_2e per t of biochar for the diesel used.
- The carbon expenditures for N-fertilization must be included into the emission portfolio. The emissions for the tractor diesel consumption are included in the 10% margin that is part of the emission portfolio.

5.3.2 Biomass from pluriannual and permanent cropping, including short rotation plantations

If pluriannual or permanent crops are harvested annually to provide feedstock for biochar production, there is no difference compared to the accounting for biomass from annual crops (i.e., N-fertilizers are accounted annually, the time of CO_2 removal is the year of harvest).

If the biomass harvest is only every second, fifth, or twentieth year, the carbon expenditures for fertilizers and fuels must be accounted for the entire growing period. The time of CO_2 removal must be tracked for every single year of growth and entered accordingly into the Global C-Sink Registry to correctly calculate the global cooling effect of the resulting biochar carbon sink.

The cultivation of mixed and perennial crops, agroforestry and meadows, which, in addition to biomass production, may promote the build-up of soil organic matter, is preferable to the cultivation of monocultures for biomass production. In principle, biomass from crop residues and companion plants should be recognized as a full-fledged tradable agricultural product ("carbon harvest"). The Global Tree C-Sink certification (cf. chap. 5.3.4) may support and facilitate this process. Food and feed production should be synergistic with the production of additional biomass. This would increase farm productivity, enhance biodiversity, soil organic matter, and enable the removal of CO_2 from the atmosphere.

5.3.3 Forest biomass

Unlike agricultural land, a forest is characterized by a high stock of carbon in the above-ground and below-ground biomass. Thus, the living biomass of a forest is a C-sink itself that must be maintained and must not be compromised when biomass is sourced for biochar production.

Under the present standard, an area is considered a forest when presenting a canopy density of at least 50%. The forest area units should not exceed 100 ha for efficient control of sustainable forest growth. The total biomass of an existing commercial forest of max. 100 ha must not decrease when the harvested biomass is used for the development of C-sinks. Therefore, the loss of wood must be balanced by the growth of forest wood in the referenced area unit. Furthermore, only a maximum of 80% of the harvested biomass must be removed from the forest to maintain the nutrient cycle and forest biodiversity. The degree of canopy density within the 100 ha must not fall below 50% because of the timber harvest.

If, for example, the annual regrowth of a 100 ha spruce forest amounts to 650 t (dry matter = DM), only a maximum of 650 t DM per year should be felled, of which a maximum of 520 t DM (80%) should be removed from the forest for wood processing and wood use.

However, there is currently no comprehensive forest assessment of area units of 100 ha or less in most countries of the world. The reference area units are considerably larger than 10,000 ha, and the forest regrowth is extrapolated using regional average values.

If, for example, in regional forests such as the Black Forest in Germany or the Arlberg in Austria, the total forest's standing biomass is higher than in the preceding years, the withdrawn biomass is regarded as climate neutral according to the European Regulation [2018/841] (EU-Parliament, 2018). Ecologically, it is at least questionable that, e.g., a densifying mountain forest is allowed to compensate for clear-cutting in a more accessible valley. However, until the expected reform of the EU LULUCF regulation (EU-Parliament, 2018), **all wood from forests whose regrowth demonstrably exceeds the removal, independent of its size and structure, is recognized as C-neutral input for the Global Biochar C-Sink certification. The time of the regrowth is set as time of removal.** If the regrowth of last year is harvested and pyrolyzed, the time of removal is set to the year of harvest. If the regrowth of several years is harvested, the time of removal must be distributed proportionally to the growth years and entered accordingly into the Global C-Sink Registry as described in the Global Tree C-Sink standard (link).

We want to justify here the decision to adhere to European forest legislation and UNFCCC accounting rules despite their imperfections. While it is our intention to set all Global C-Sink standards on scientifically reliable feet, starting with too idealistic restrictions may suffocate the development of the nascent pyrolysis and C-sink economy. If the EU nations promote bioenergy as climate-neutral and allow the regrowth of their forests to be counted as C-sinks in the National Declared Contributions (NDC), it is not up to the Global Biochar C-Sink to classify the same biomass as not climate-neutral. Nevertheless, it is our conviction that forests and forest wood should not be used for energy generation and when generating C-sinks, the process should be more efficient than simply pyrolyzing the extracted biomass for biochar only (Schmidt et al., 2018; Song et al., 2018). Instead, forest wood should first be used as a source for long-lived materials whereas biochar can still be produced from residues, e.g., sawmills or debris. The EBC and WBC standards will be updated in regard to forest wood feedstocks to reflect the technical possibilities and political conditions in the coming years.

If the climate neutrality of a forest is not ensured by the official LULUCF reports of the respective country or by regional legislation, proof can also be provided by *Program for the Endorsement of Forest Certification* (PEFC) or *Forest Stewardship Council* (FSC) certifications and the Global Tree C-sink certification (cf. chap. 5.4). Alternatively, the carbon balance of the forest could be verified by ISO16064-accredited assessment of CO_2 fluxes for the last 20 years. Otherwise, the forest wood is not accepted as biomass input for producing EBC- or WBC-certified biochar. Accordingly, no C-sink of biochar produced from that biomass can be certified.

If, during forest establishment, denser stands are planted and gradually thinned out as they grow, the wood removed in this way is considered a C-neutral input because this measure accelerates the growth of the remaining trees and increases the total accumulation of carbon.

Forest wood damaged by wind, fire, drought, or pests is considered a C-neutral input provided that a climate-change-adapted reforestation plan is provided.

The CO_2e expenditure for forest maintenance and timber harvesting is included in the overall balance via the safety margin for scope 3 emissions (c.f., Chapter 0).

It is assumed that no fertilization occurs in the forest; otherwise, the CO_2e expenditure for N-fertilization would have to be deducted from the C-sink potential.

5.3.4 Biomass from landscape conservation, agro-forestry, forest gardens, field margins, and urban areas

If trees or hedges on agricultural land are pruned or trimmed but not felled and thus grow back from their roots, the biomass is considered C-neutral. Biomass from nature conservation, landscape management, including disaster debris removal and roadside greenery, and urban areas, is also considered C-neutral.

Trees from forest gardens, orchard meadows, tree lines, and hedges for arable farming are often decades old. They have to be managed so that the amount of wood removed per unit area does not exceed the amount of the average annual regrowth. It should be monitored at the farm level (c.f., Chapter. 5.4).

If trees, hedges, reeds, and others have been newly planted on agricultural land for their ecosystem services and biomass production as co-benefit (e.g., landscape conservation, water management, buffer areas around ponds and streams, or agroforestry), the harvested biomass can be considered C-neutral at the time of harvest. However, it must be ensured that biomass production is maintained in the corresponding area either through new planting or rejuvenation.

For pruning and landscaping material, the time of CO_2 removal is assumed to be the year of cutting. Felled trees that are not used at least partly for material purposes but whose wood is entirely pyrolyzed, burnt or decomposed must be registered with their respective growth and thus CO_2 removal curve according to the Global Tree C-Sink standard (link).

5.3.5 Wood processing residues and waste timber

Traceability of wood processing residues is often challenging, especially in larger sawmills, and it is, of course, better if the wood waste is used to build up C-sinks instead of being wasted. However, primary waste wood amounts to more than 50% of the harvested forest biomass and must, when used for C-sink and energy production, be considered a raw material and not a waste. Therefore, when using saw dust, bark, and lumber residues (primary wood waste) from a sawmill or directly from pre-processors in the forest or on the way to a sawmill, the wood must be certified as required under 5.3.3. The more primary waste wood gains prominence as a reliable economic asset, the more it influences secondary wood processors to encourage forestry managers to adopt climate-positive and sustainable management practices.

Secondary wood waste from recycled wood products (e.g., recycled construction and service wood such as lumber, pallets, furniture, etc.), often also referred to as waste timber, are considered C-neutral. The time of CO_2 removal is set to the year of pyrolysis.

5.3.6 Organic residues from the processing of food and other biomass

Pomace, nutshells, fruit stones, coffee grounds, and other organic residues from food processing are considered C-neutral input materials because the CO_2 footprint of food production is credited to the production of primary products (e.g., wine, olive, or any other kind of oil, fruit juice, coffee, etc.). Also, other industrial biomass processing residues such us paper sludge, bio fiber washing, fresh palm fruit bunches are considered C-neutral. The time of removal is set to the year of pyrolysis.

5.3.7 Municipal waste and municipal waste digestate

As municipal waste is pure waste, no emissions for its production must be accounted. Pyrolysis reduces emissions compared to incineration and also to landfill applications. Landfill-applied organic waste is, to a large extent, transformed into methane that is only partly recovered as landfill gas. Overall, the climate balance of soil or material applied biochar from municipal wastes is better than from landfills. Moreover, the contamination of soils at waste dumping sites is clearly reduced thanks to pyrolysis.

Municipal waste contains not only biogenic but also fossil carbon, such as plastic polymers, composites, textiles, etc. Only the proportion of biochar from the organic carbon fraction can be certified as C-sink and must be distinguished from fossil carbon.

To distinguish between organic and fossil carbon, the most reliable analytical method uses radiocarbon analysis (fossil carbon does not present ^{14}C). As radiocarbon analysis is relatively expensive, and mixed waste is highly heterogeneous, biochar from mixed waste should be collected over a longer period (e.g., one month) before taking representative samples and determining the part of organically derived carbon in the well-mixed biochar made from mixed waste. The production, monitoring, homogenization, sampling, and analysis procedures are explained in detail in Annex 2. For organic waste, up to 5% of plastic contamination can be accepted without the need for further measures to subtract the fossil fraction. The fossil carbon content in the biochar is then covered by the safety margin.

5.3.8 Manure and agricultural digestate

Manure and manure digestate are secondary products of animal farming. The storage and application of animal manure and its digestate cause significant quantities of GHG emissions that can be reduced when manure or manure digestate is pyrolyzed (Rathnayake et al., 2023). The feed that animals transform into manure is made from biomass that had removed its carbon from the atmosphere. As animal growth and production is the operation's main objective, the feed production's carbon footprint is not accounted for in the manure. Manure is thus considered as climate-neutral feedstock. Only transport emissions must be accounted for.

Animal feed may contain biochar already registered as a diffuse carbon sink. However, as diffuse carbon sinks are limited to 1 t CO_2e, there is no significant risk of double accounting, given the security margin exceeding this amount by far. All larger amounts of feed-biochar must be tracked to the field and cannot be used as pyrolysis feedstock.

The time of CO_2 removal is set to the year of pyrolysis.

5.3.9 Biosolids and biosolid digestate

In regard to the C-sink accounting, biosolids and their digestate are similar to manure. As food is by large the main original input material for biosolid production and food is by large made from annual crops, the feedstock is considered carbon neutral. Non-organic polymers used in wastewater treatment (flocculation additives) and some industrial waste liquids containing fossil carbon-derived molecules may enter the sludge. For biosolids from municipal wastewater treatment plants, these aspects are largely covered by the margin of safety. Industrial wastewater treatment plants must document the origin of the carbon. The eligibility of industrial wastewater sludge as feedstock for C-sink certification can only be decided individually during the technical audit.

Overall, biosolids are considered as a climate-neutral feedstock for biochar production, and the time of CO_2 removal is set to the year of pyrolysis.

5.3.10 Other biogenic residues

For all other biomass on the EBC and WBC positive list, carbon neutrality can generally be assumed. This must, however, be considered individually during the certification procedure, depending on the feedstock used. The time of removal would generally be the year of pyrolysis, though this is verified during the certification procedure.

New feedstock categories will be added for C-sink certification as required or requested.

5.4 Monitoring Perennial Biomass Production Systems

Until general monitoring of growth, storage, and use of biomass carbon is established on a broad scale, this standard relies on self-declaration by biomass producers regarding carbon neutrality, with the exception of forest wood (chap. 5.3.3), unless there is an urgent suspicion of carbon overexploitation. We encourage forestry biomass producers to become certified under the Global Tree C-Sink standard, which generates remuneration opportunities for C storage in living biomass and guarantees the carbon neutrality of the biomass produced.

6. Storage of biomass feedstock

If moist biomasses are stored for too long in too large piles, uncontrolled self-heating occurs. In this process, the biomass is microbially degraded, similar to composting, which results in the loss of carbon as CO_2. Depending on the biomass and storage conditions, emissions of CH_4 and N_2O may also occur.

Biomass power plants often use the self-heating of wood chips to dry them. A review of 14 scientific studies on the decomposition of woodchips during storage has shown that depending on storage conditions, wood species, and wood moisture, between 0.6 to 4.3% of biomass carbon is degraded per month (Whittaker et al., 2016). For wood chip piles larger than 1 m^3, biodegradation of the wood leads to oxygen consumption inside the pile, eventually leading to anaerobic degradation and methane emissions. How high the actual methane emissions are depends on factors such as temperature, humidity, pile volume, type and age of the wood, and its C to N ratio. Measurements have shown that up to 20% of the gaseous carbon produced during storage inside the pile is transformed into methane (Pier and Kelly, 1997). However, Jaeckel et al. (2005) found that methanotrophic microorganisms in the heap's better-aerated near-surface layers degrade between 46% and 98% of the methane produced in the core before it can escape as an emission to the atmosphere. In summary, scientific studies of actual methane emissions from wood chip storage are sparsely available and often incomplete, so generalizations regarding storage emissions must be made cautiously (Ferrero et al., 2011).

However, storage emissions can be effectively avoided. If this involves additional effort and possibly also costs, the avoidance of emission losses has the beneficial side effect of losing less of the biomass's energy content. The following measures are generally recommended for biomass storage and, if implemented correctly, would avoid any storage emissions to be added to the emission portfolio of the batch and production unit.

- Wood and other biomass should be chipped only a few days and at a maximum of four weeks before pyrolysis. Log storage is considered unproblematic regarding methane emissions; coarse wood (thinner logs, branches, cuttings, etc.) should be stored as airy as possible and not mixed with green waste.
- If just-in-time chipping is not possible, the wood chips or biomass should be dried as soon as possible, e.g., with the excess heat from pyrolysis and stored dry with a maximum of 20% residual moisture. If the biomass is sufficiently dry, biodegradation does not take place or is slowed down considerably.
- Pelleting of biomasses and dry storage of pellets avoids rapid biomass decomposition.

- Alternatively, the wood chips or the biomasses can be stored in small, well-ventilated containers such as lattice boxes (max. 2 m^3). Due to sufficient ventilation, anaerobic degradation and thus methane emissions can be prevented.
- Other practical methods will certainly also prove efficient.

If none of these recommendations can be implemented, it must be assumed that substantial methane emissions occur, that they are not covered by the margin of safety, and therefore must be calculated as follows:

For the storage of moist wood chips and sawdust, we assume that 2.5% of the biomass carbon is degraded per month, of which 20% is transformed into methane. 75% of this methane gets microbially degraded in the storage pile and is not released into the atmosphere. We thus calculate for moist storage of woody biomass that (2.5% * 20% * 25%=) 0.13% of the biomass C is emitted as methane-C per month.

For storing moist, non-woody biomasses such as straw, crop residues, pomace, etc., but also for wood waste with a high content of green plant material, data on methane emissions during uncontrolled composting are applied. According to the IPCC methodology, 10 g of CH_4 emissions are generated per kilogram of biomass (DM) during complete composting (Pipatti et al., 2006). This corresponds to about 1.5% of the carbon contained in the biomass. Assuming that a conventional windrow composting process takes an average of 6 months (Pier and Kelly, 1997), the composting storage results in an emission rate for methane-C of (1.5% / 6 =) 0.25% per month.

For the storage of wood chips and sawdust with more than 25% moisture for more than one month, CH_4 emissions of 0.13% of the original C-content are imputed per month. For all other biomasses with more than 25% moisture and storage time over one month, 0.25% of the original biomass C-content are accounted for CH_4 emissions. One kilogram of methane-C equals (1 kg / 12.011 kg $kmol^{-1}$ * 16.04 kg $kmol^{-1}$ =) 1.335 kg methane. Methane emissions that may already occur during the first month of biomass storage are sufficiently covered by the general margin of safety (c.f., Chap. 4.6).

$$\text{CH}_4\text{\_wood\_storage} = \text{Mass of feedstock (DM)} * \text{C\_content of feedstock} * (\text{\#months of storage} - 1\ \text{month}) * 0.13\ \% * 16\ \text{kg mol}^{-1} / 12\ \text{kg mol}^{-1}$$

Equation 5: Calculation of CH_4 emissions during the storage of moist woody biomass (> 25% water content) if storage exceeds 1 month.

$$\text{CH}_4\text{\_non-wood\_storage} = \text{Mass of feedstock (DM)} * \text{C\_content of feedstock} * (\text{\#months of storage} - 1\text{ month}) * 0.25\,\% * 16\text{ kg mol}^{-1} / 12\text{ kg mol}^{-1}$$

Equation 6: Calculation of CH_4 emissions during the storage of moist non-woody biomass (> 25% water content) if storage exceeds 1 month.

For example, if wood chips that are used as feedstock for pyrolysis have a water content above 25% and are stored in a large pile for an average of two and a half months prior to pyrolytic processing, a C loss of ((2.5-1) months * 0.13% =) 0.195% of the total C of the pyrolyzed biomass is assumed. For an annual processing of 4000t (DM) of wood chips with a C-content of 48%, the methane emissions to be estimated for 2.5-month storage without preceded drying would correspond to (4000 t * 48% * 0.195% =) 3.74 t CH_4-C, which equals 5.0 t CH_4 . The calculation is carried out using the values given above and rounded to 0.1 t.

If 4000 t (DM) of grape marc with a C-content of 48% were processed, the methane emissions to be estimated for 2.5 months of storage without prior drying would correspond to (4000 t * 48% C * 0.25% CH_4 * 1.5 months =) 7.2 t CH_4-C and 9.6 t CH_4.

For the storage period, not only the storage on the premises of the pyrolysis plant is considered, but the entire storage period of the biomass, be it at the harvest site or the site of any biomass processor or trader. For example, for the processing of pomace, the storage start time is considered to be the emptying of the wine press. For wood chips, the moment of chipping applies. During control, the logistics of biomass processing and its transport must be fully traceable.

During the on-site control visit, the core temperature of the biomass has to be measured for all sites where biomass is stored for more than one month. In case of temperatures of more than 5°C above ambient temperature, which cannot be plausibly explained, e.g., by diurnal fluctuations, the above formula is applied to calculate the accruing GHG emissions. The EBC and WBC certification monitoring may also specify an in-house temperature monitoring of the stored biomasses (e.g., daily measurement of the core temperature of one or more biomass storage facilities).

7. The Biochar Production Facility

7.1 Energy and Fuel Consumption for Transportation, Preparation of the biomass, the Pyrolysis Process and Post-Treatment of the Biochar

Biochar production usually produces an energy surplus. Still, some external energy is usually required to operate pyrolysis facilities. For example, electrical power is necessary for control systems as well as for conveying biomass and biochar. Depending on the type of pyrolyzer, (fossil) fuel gas or electricity is also required for preheating the reactors and/or burning chambers. Certain plant types produce pyrolysis oil and pyrolysis gas in addition to biochar but use electrical energy to heat the biomass. Consequently, to calculate the pyrolysis plant's carbon footprint, each plant must be equipped with meters for electricity and if applicable for natural gas and fuel.

The energy and fuel-related carbon expenditure for the entire process chain, from the provision of biomass to the packaging of the biochar, is calculated in CO_2e and included in the emission portfolio of the batch and the respective production unit (i.e., the pyrolysis unit that is used to produce the batch). This concerns in particular:

(1) Transportation of the biomass to the pyrolysis plant.

(2) Chipping, homogenization, pelletizing, and drying of the biomass.

(3) GHG emissions of the pyrolysis plant (i.e., electricity, heat, and fuel consumption).

(4) Post-pyrolysis treatment of the biochar (e.g., drying, mixing, liquid loading, grinding, pelletizing, etc.) and other products (e.g., purification of H_2, CO_2, and/or other gases, refining of pyrolysis oil, etc.).

(5) Transport of the biochar to the collection depot (factory gate).

Emissions due to post-pyrolytic treatment of non-biochar products need to be considered to allow accurate pro-rata calculation of carbon expenditures, even though these products are not certified under the present standard. Accounting for electricity and fuel consumption for all these individual steps is necessary for the certification. The conversion of electricity consumption into CO_2e is based on the specific information provided by the contractual energy provider or the average CO_2e value of the regional electricity mix used. If renewable energy is used, the CO_2e footprint can be close to zero. However, some greenhouse gas emissions occur also for solar, wind, biomass, and hydropower and must thus be declared and included in the emission portfolio. In the case that the energy provider cannot provide a reliable footprint assessment, average literature values will be used by the certifier (IPCC, 2022; Kadiyala et al., 2016; Nugent and Sovacool, 2014). If the pyrolysis plant itself generates at least as much electricity on an annual average as is consumed in the production facility and the entire production facility offsets its emission with biochar C-sinks, a CO_2e of zero may be assumed for electricity consumption.

The amount of fuel used to heat the pyrolysis reactors are to be reported per batch (invoices for purchasing fossil fuels) and are converted to CO_2e by fuel type (usually 65 t CO_2e per TJ (Juhrich, 2016))

For the consumption of diesel or benzine fuel for transportation, chipping, drying, etc., the conversion factor of 3.2 ton CO_2eq per ton diesel fuel is applied (Juhrich, 2016).

7.2 Energy Surpluses

If the energy balance of a biochar production facility is positive, i.e., measurably more electrical and/or thermal energy is produced than consumed, the positive energy balance can be credited as an emissions reduction with the appropriate agencies, but not within the Global C-Sink. The positive energy balance can neither increase the C-sink nor offset emissions from biomass supply.

If all GHG emissions of the biochar production are offset and compensated for covering also the CO_2 footprint of the production of the other pyrolysis products (e.g., electricity, hydrogen, pyrolysis oil, etc.) those secondary pyrolysis products can be certified as carbon neutral. However, if the pro rata approach (chapter 4.5) is employed, carbon neutrality of the non-biochar pyrolysis products cannot be certified.

7.3 Methane Emissions during the Pyrolysis Process

During pyrolysis, the pyrolysis gases are usually oxidized in a suitably designed combustion chamber. Usually, the gaseous combustion products pass a filtration step and are then emitted mostly as CO_2. If the pyrolysis process is well-adjusted and the combustion chamber correctly designed, non-CO_2 GHGs and other pollutants can be kept at very low levels in the exhaust. However, CH_4, NOx, CO, and particulate matter (PM) are, as in all combustion processes, never completely absent and must be controlled. Concerning the net climate impact, methane emission is particularly important to measure. CO, NOx, SOx, and PM are also harmful to the environment, but according to the IPCC, they do not have a clear greenhouse gas effect (IPCC, 2013) and are therefore not accounted for the emission portfolio, while CH_4 is included.

As detailed in Chapter 4.3, for the conversion of the global warming effect of methane, the GWP100 is accounted for with a factor of 25, but it must be compensated within the first 20 years after the emission. Due to the high GWP100 of methane and the short compensation period, even very small methane emissions during the pyrolysis process have a major impact on the carbon footprint of biochar production. In pyrolysis plants without controlled combustion of the pyrolysis gases (e.g., Kon-Tiki or traditional charcoal kilns), the global warming effect of methane emissions can even exceed the climate-positive effect of biochar for the first 20 years.

Measuring methane emissions below 5 ppm is technically complex. Continuous measurement over an entire production year is not possible with currently available technology. Therefore, either at least two CH_4-emission tests per pyrolysis unit with the same feedstock representing the typical operation of the unit are required, or the pyrolysis unit must have a type certification according to EBC or WBC.

For CH_4 emission tests, a detailed measurement strategy with precise details of the measurement technology, measurement intervals, and measurement accuracy must be submitted in advance to the Carbon Standards for review. Once the procedures are accepted, the methane emissions factor of the pyrolysis unit is calculated as the mean of the two measurements plus one standard deviation as the margin of security.

Box 4: Calculation of pyrolytic carbon expenditures.

Example for the calculation of the carbon expenditure of pyrolysis (continued)

- With an annual production of 500 t of biochar (DM) having a carbon content of 75.0%, **50,000 kWh of electricity** is used to operate the pyrolysis plant (measured with a dedicated electricity meter at the pyrolysis unit). The local electricity mix emits 450 g CO_2eq per kWh. Thus, the carbon expenditure for electricity consumption is 50,000 kWh * 0.45 kg CO_2e $(kWh)^{-1}$ = 22.5 t CO_2e per year.
- Emission measurement of pyrolysis exhaust gases resulted in a **methane content of 10 ppm** (6.6 mg CH_4 m^{-3}) in the exhaust gas for 7000 operating hours per year at a gas volume flow of 1500 m^3 per hour. This results in methane emissions per annual batch of (1500 m^3/h * 7000 h * 6,6 mg CH_4 m^{-3} =) 69,3 kg CH_4.
- To preheat the pyrolysis reactors, **5 t of liquefied petroleum gas (LPG;** 3 t CO_2e t^{-1}) are consumed per year. This results in a carbon expenditure of 15 t CO_2e per year.
- The above results in an emission portfolio entry of 22.5 t CO_2e electricity + 15 t CO_2e LPG + 69.3 kg CH_4 pyrolysis emissions per batch.

For the EBC and WBC pyrolysis type certification, at least three installations of the same type from the same manufacturer must be in commercial operation at different sites. For each of these three plants, at least two independent, state-accredited emission measurements including CH_4 or C_xH_x must be available. From these measurements, a statistical mean value with standard deviation is calculated. The average methane emission of this type of plant is then set to be the mean value plus one standard deviation. If an emission measurement for methane or C_xH_x is below the measuring accuracy of the instruments, the limit of quantification (LOQ) is used. The assessed methane emissions are thus higher than the calculated average and provide a sufficiently high safety margin to cover any potential emission peaks, e.g., during start-up and shutdown of operation. The measured values for methane emissions are given in ppm of the flue gas (i.e., combusted pyrolysis gas) and converted into g CH_4 per ton of biochar via the flue gas flow per mass unit of biomass input or biochar output. This resulting value is then registered as the methane emission factor for all pyrolysis units of the same type, utilizing a consistent standard feedstock.

8. C-Sink and Energy Use Efficiency

Biomass is a valuable resource that must be utilized responsibly. In the Global Biochar C-Sink, this is assessed using the carbon and energy use efficiency. While there is minimum limit value for the energy use efficiency that all certified pyrolysis units must comply with, the carbon use efficiency is only indicative and displayed on the product label.

8.1 C-Sink Efficiency of Pyrolysis Operations

C-sink efficiency refers to the ratio of carbon transformed into a storable form (i.e., amount of carbon in a batch of biochar) to the input of carbon (i.e., amount of carbon in the biomass used to produce the biochar). To reach at least 15 Gt CO_2e of global long-term carbon sink establishment per year, the C-sink efficiency of biomass-based negative emission technologies must be increased. Plants are extremely efficient in concentrating highly diluted atmospheric carbon into dense carbon molecules. The removed carbon is preserved and acts as a C-sink for as long as a plant lives. Every transformation step of biomass leads to carbon losses, i.e., emissions of (biogenic) CO_2. The harvest induces the decomposition of roots and harvest residues, GHG emissions occur during the manufacturing of food, feed, and biomaterials, and finally, waste management, i.e., composting, anaerobic digestion, waste incineration, or landfills also result in biomass decomposition in one way or the other. Typically, the carbon balance is zero as all carbon that is emitted from biomass use was initially removed by plants from the atmosphere. However, considering that plants provide a natural carbon service (removing carbon from the atmosphere), humanity could use this carbon pump to tweak the biomass-use systems to remove as much carbon as possible from the atmosphere. The area on earth where plants can grow is limited. Even the ocean area that we can use wisely to grow brown algae or other biomasses is limited. Using finite resources makes mankind responsible for using them wise and efficient.

Compared to composting, mulching, incineration, or waste dumping, pyrolysis significantly increases C-sink efficiency. However, when using primary biomass such as wood, pyrolysis is less C-efficient than its material use in buildings, infrastructure, furniture, composites, or textiles. Also, storage of compressed, dry biomass in controlled geological storage, such as salt domes or oil wells, would be by far more C-efficient, preserving close to 100 % of the biomass carbon.

Depending on production parameters and feedstock, pyrolysis preserves about 30 to 60% of the biomass carbon in the biochar. When pyrolysis oil can also be sequestered, C-efficiencies of around 80% can be reached (Schmidt et al., 2018); with CO_2-CCS of the combusted pyrolysis gas, even higher C-efficiencies are possible.

If, in a pyrolysis process, only the biochar-C is preserved, the C-sink efficiency is too low to aspire for large-scale negative emissions. To develop the pyrolysis technology in the next decade, this might still be acceptable, but as long as biomass carbon is the principal source for carbon sinks, no carbon must be squandered.

The C-sink efficiency of a pyrolysis facility is a measure of the part of biomass-carbon that is preserved by a technical transformation process as a potential C-sink.

At the current stage of pyrolysis and other CDR technology development, imposing specific thresholds for C-sink efficiency would be overly restrictive. This is further emphasized by the increasing role that pyrolysis energy plays in providing process heat for industry and district heating while reducing reliance on fossil fuels. However, it is essential to have a clear objective of transforming a growing proportion of biomass carbon into carbon sinks. This also may comprise temporary C-sinks in rather short-lived products, e.g., from pyrolysis oil; and replacing crude oil products in everyday lives is also part of climate change mitigation. To achieve this, C-sink efficiency must be evaluated and disclosed on the Carbon Sink Certificate, utilizing the C-sink efficiency Label outlined below (Figure 3).

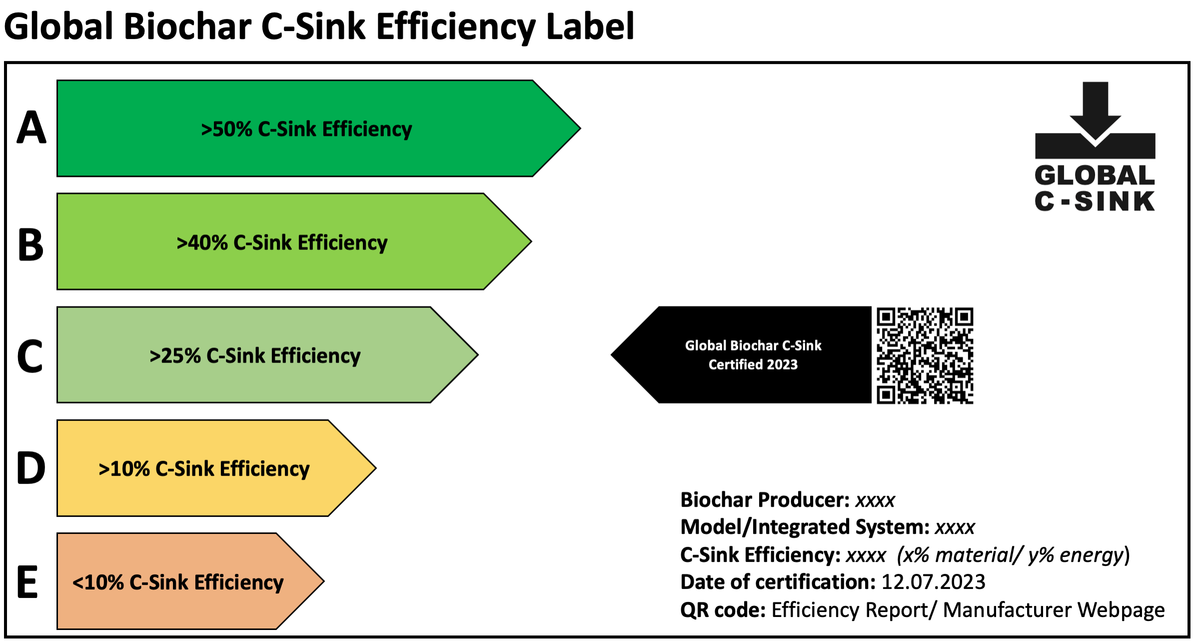


Figure 3: C-sink efficiency label showing how much biomass carbon is transformed into storable carbon by a pyrolysis facility.

The C-sink efficiency of a biochar batch is calculated by dividing the total sequestrable pyrogenic carbon (biochar, pyrolysis oil, purified CO_2, and derived products) by the total biomass carbon used as feedstock for the entire batch. Only biochar, pyrolysis oil, and CO_2 that is or will be registered as C-sink are included. Biochar that is or will be sold as charcoal for barbecue, for the metal industry or other applications where the carbon is oxidized and reemitted to the atmosphere must not be included. The value is given as a percentage of initial biomass carbon.

To estimate the carbon efficiency, the pyrolysis company is requested to declare for what markets their products are intended. The carbon efficiency is calculated at the factory gate.

8.2 Energy Use Efficiency of Pyrolysis

The limited availability of biomass necessitates its efficient utilization. To address this, the standard incorporates two complementary strategies. While the C-sink efficiency discussed in the previous chapter is introduced for transparency purposes (customer information), there is a threshold value for energy efficiency that must be met in the production of each biochar batch for Global Biochar C-Sink certification.

The energy use efficiency provides the rate of how much of the energy contained in the biomass feedstock was transformed into usable energy and other beneficial products with a market value. The energy use efficiency does not express how beneficial and meaningful the different products are but provides a measure of how energy efficient the biomass carbon is used within the process. This may include the following uses on top of biochar production:

- Thermal and electric energy production to replace fossil fuel-derived energy, it avoids GHG emissions. Thermal energy can be used, e.g., in district heating or industrial processes.
- Thermal energy from combusting pyrolysis gas can be used to dry biomass feedstock for the pyrolysis plant itself, which would be accepted as a meaningful energy use.
- Charcoal is used for metallurgy to replace fossil carbon and thus reduces GHG indirectly. If it is used for barbecue or for other applications where it is oxidized and the carbon is reemitted as GHG to the atmosphere, it can still be seen as financially reasonable and climate-neutral carbon use.
- Pyrolysis oil can be used for the chemical industry or as fuel. Its carbon will, thus, be oxidized and returned as CO_2 back to the atmosphere within a relatively short time. Still, it will not cause more emissions than the biomass had removed from the atmosphere during its growth.
- Pyrolysis gas contains hydrogen and methane, that can be extracted.

- CO_2 can be extracted in pure form from the combustion of pyrolysis gas and pyrolysis oil for further use (i.e., carbon capture and use – CCU) or storage.

Therefore, if the non-biochar fraction of the pyrolysis products is used for energy production or as raw material for chemical or other industries, the biomass-carbon is considered as having been used meaningfully.

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The carbon use efficiency is calculated as follows (in kWh):

- The energy content of the feedstock is quantified as the lower heating value (LHV). If the feedstock is clearly defined, the LHV can be taken from. Mixed and not clearly defined biomass and feedstock known for its high energy content variability (e.g., sieving residues from composting) must be analyzed in a laboratory endorsed by Carbon Standards. A list of endorsed laboratories is available on the Carbon Standard webpage.
- The energy content of the biomass processed for production of the batch is calculated by multiplying dry mass and lower heating value providing the parameter $E_{feedstock}$.
- The energy needed to produce the batch is quantified according to Chapter 7.1 ($E_{Expenditures}$)
- The energy content of the solid pyrolysis products (biochar, charcoal) is quantified as the LHV and multiplied by the total dry mass of biochar produced (E_{solid}). The LHV of the biochar and charcoal must be analyzed from the EBC/WBC certification sample.
- If pyro-oil is separated for storage or use, its LHV is quantified and multiplied by the total amount of pyro-oil co-produced with the biochar batch ($E_{pyrooil}$). The LHV of the pyro-oil must be analyzed in a laboratory endorsed by Carbon Standards. If different fractions of the pyro-oil are produced, the LHV of each fraction has to be analyzed.
- If thermal energy is used for drying biomass, 810 kWh per ton of evaporated water (2.44 kJ per gram of water + 20% margin) can be accounted for. The amount of evaporated water can be calculated based on the mass and moisture content of the biomass received and the achieved moisture content (e.g., 15% as required by most pyrolysis units) (E_{drying}).
- If thermal energy is supplied to district heating or industry, the actual amount used must be metered ($E_{thermal}$)
- If the pyrolysis gas is used to produce hydrogen, methanol, or other marketable fuels or chemicals, their energy content is to be provided as $E_{fuel\_products}$. If CO_2 is separated after oxidation of the pyro-gas, this can be accounted for with a maximum of 1000 kWh t^{-1} CO_2 which provides the parameter (E_{CO2pur}).

The total amount of used electrical and thermic energy, and the heating value of the marketed pyrolysis products is divided by the sum of the energy content of the biomass feedstock and the external energy used to produce the entire batch. The value is given as a percentage.

$$E_{eff} = \frac{E_{solid} + E_{pyrooil} + E_{fuelproducts} + E_{thermal} + E_{drying} + E_{electric} + E_{co2pur}}{E_{feedstock} + E_{expenditures}}$$

Equation 7: Calculation of the energy efficiency (E_{eff}) using the energy content of the biochar (E_{solid}), the pyrolysis oil ($E_{pyrooil}$), the fuels produced by the pyrolysis proces ($E_{fuelproducts}$), the produced thermal energy ($E_{thermal}$), the energy used for feedstock drying (E_{drying}), the electricity produced ($E_{electric}$), the energy value of separated CO2 from the flue gas (E_{CO2pur}), the higher heating value of the feedstock ($E_{feedstock}$), and the energy expenditures for the entire pyrolysis facility ($E_{expenditures}$).

In most cases of today's pyrolysis facilities, the calculation looks a lot simpler:

$$E_{eff} = \frac{E_{solid} + E_{thermal} + E_{drying} + E_{electric}}{E_{feedstock} + E_{expenditures}}$$

Equation 8: Simplified calculation of the energy efficiency to be used for most biochar production facilities.

For every batch of a certified pyrolysis unit, at least 60% of the sum of the energy contained in the biomass and all energy expenditures of the process must be used.

Box 5: Exemplary calculation of the energy use efficiency

Example for the calculation of the energy use efficiency of a wood gasification plant for one annual batch:

- **Input (feedstock):** Annual feedstock 4000 t of wood with a dry matter content of 65%, a carbon content of 48%, and a lower heating value (LHV) of 4 kWh/kg (@ 80% DM) representing (3250 t (@80% DM) * 4 MWh/t =) 13,000 MWh.
- **External energy input (consumption)**: Electricity consumption of the facility during the batch 375 MWh, 3 t LPG starter gas with 13 kWh/kg, 13 t diesel for feedstock preparation and transport with 11.8 kWh/kg representing (375 MWh + 3 t * 13 MWh/t + 13 t * 11.8 MWh/t =) 567.4 MWh
- **Output:** The unit produces per year 260 t biochar with LHV of 7.9 kWh/kg representing 2054 MWh, 5000 MWh of used heat, 2340 MWh electricity, and uses 800 MWh of the heat for feedstock drying representing (2054 MWh biochar + 5000 MWh used heat + 800 MWh drying + 2340 MWh electric =) 10,194 MWh.
- **Energy efficiency of batch**: 10,194 MWh / (13,000 MWh + 567.4 MWh) = 75.1%.

The 75,1 % energy efficiency is higher than the threshold of 60%, the facility an be certified.

9. Biochar Properties for C-Sink Certification and Labeling

9.1 Labeling of Global Biochar C-Sink Certified Biochar

If a pyrolysis plant is certified according to the EBC or WBC standard, the following information must be provided on each packaging and on delivery bills:

1. EBC or WBC certification is a prerequisite to Global Biochar C-Sink certification, so the QR code of the respective EBC or WBC batch and the delivery note must be printed on each packaging unit. This QR code refers to the Carbon Standards Biochar Tool, which documents the corresponding biochar batch's analytical data and production conditions.
2. Since the C-sink potential refers to water-free biochar, the dry weight of the biochar must be indicated for each packaging unit. The dry weight is the mass of the dry substance and is stated in tons or kilograms, rounded to 1% of the total weight. If the analysis of the dry weight results, for example, in 455.57 kg of 1000 kg fresh weight, the dry weight is rounded to 1% of the 1000 kg, i.e. to 10 kg. The dry weight would, therefore, be 460 kg.

The specifications for the labeling of products can be found in the Design Manual of Carbon Standards.

This QR code must also serve the MRV system to track the biochar prior to its final use.

9.2 Dry Matter Content of Biochar: on-site measurement

The size of a C-sink is defined by its mass and carbon content. Mass here refers to dry mass, and it is a true challenge to measure it regularly onsite. The dry matter content of biochar cannot be measured directly but must be calculated from the fresh weight and the measured water content.

The water content of biochar can be subject to considerable fluctuations at the time of sale or even directly at the discharge of the pyrolysis plant. Reasons for this can be a fluctuating intensity of the quenching at the discharge, the absorption of air humidity, or air drying. Therefore, it is impossible to determine the C-sink using the dry matter content analyzed once per batch during the annual EBC/WBC-accredited laboratory analysis.

Also, the bulk density, which is needed to calculate mass from a given volume, can vary significantly within a batch, mainly due to variations in the particle size distribution of the pyrolyzed biomasses and abrasion during the transfer and transport of the biochar. Thus, a volumetric determination of the dry weight of the produced biochar is also not appropriate.

Therefore, the reliable and regular determination of the dry matter (DM) content is a prerequisite to indicate the dry weight and, thus, the C-sink potential of a packaging unit of biochar. This is a considerable effort for biochar producers, which is, however, unavoidable to maintain verifiability and, thus, confidence in the Global Biochar C-Sink method.

For each sub-quantity of max. 10 m^3 of biochar, at least 20 individual sub-samples must be taken using a sampling drill stick. Combining a minimum of 20 sub-samples must yield at least a total sample volume of 10 liters of biochar. The individual sub-samples can be taken either from a collected pile or container of max. 10 m^3 of biochar or from each of several big bags presenting a total amount of max. 10 m^3. The combined sample is weighed using a balance with a precision of at least 1 gram. The biochar is then dried at 110 °C for at least 16 hours and weighed again. Weighing must be done immediately (max. 1 minute) after removal from the 110 °C drying oven. Otherwise, moisture may condense on the biochar and falsify the result. This method simplifies the usual DIN 51718 and ISO 589, which may equally be followed.

$$\text{DM [\%]} = \frac{net\ weight\ after\ drying}{net\ weight\ before\ drying}$$

Equation 9: The dry matter content (DM) is calculated by dividing the net weight after drying by the net weight before drying.

If, for example, big bags of 1.3 m^3 are used for storing biochar, a maximum of seven big bags may be combined for one representative sample. At least three sub-samples from each of the seven big bags must be taken with a standard sampling drill stick. All 7x3 subsamples are then combined and weighed as described above, dried, and weighed again. If the 10-liter sample weighs 3.057 kg before drying and 2.139 kg after drying, the dry matter content is (2.139 kg / 3.057 kg =) 69.970%. This value is rounded to full percentages for further calculations (here: 70%). The DM content determined in this way must then be multiplied by each big bag's individually determined (fresh) weight (see example in Table 1). This results in each big bag's respective dry weight, with which each big bag must then be labeled. For instance, if a big bag weighs 200 kg (fresh weight, net weight) and has a determined DM content of 70%, the dry weight is (200 kg * 70% =) 140 kg. It is rounded to whole kilograms.

For the described DM determination via drying of a representative sample, a relatively large drying oven and correspondingly accurate balances are required. Still, the effort for 10 m^3 or seven big bags is manageable. Weighing of the big bags should be done on the same day as the sampling.

Deviations from the procedure described here can be regulated during the technical EBC/WBC audit, if, e.g., the dry weight is determined via a deviating method. If a producer can prove that the dry matter content does not change by more than ±2% over extended periods and production quantities, larger intervals between measurements can be authorized. If biochar with a particle size of more than 30 mm is produced, the subsamples' volume must be increased accordingly.

Table 1: Example of calculation of dry weight of a series of seven big bags.

Serial number of big bag	Volume	Weighed weight	Dry matter content	Dry weight
Big bag 2020-490	1,3 m3	195 kg	70%	137 kg
Big bag 2020-491		200 kg		140 kg
Big bag 2020-492		200 kg		140 kg
Big bag 2020-493		210 kg		147 kg
Big bag 2020-494		195 kg		137 kg
Big bag 2020-495		200 kg		140 kg
Big bag 2020-496		200 kg		140 kg

10. Post-Production dMRV: transport, processing, and tracking of biochar

10.1 Biochar dMRV System

From the moment a packaging unit filled with biochar (e.g., a big bag = super sack or a container) leaves the EBC or WBC certified factory site, many things can happen that may reduce or eliminate the potential C-sink of the traded biochar. The biochar may be burned, for example, as charcoal, processed into activated carbon, or used as a reducing agent in steel production, a significant amount of carbon would be lost to the atmosphere. Also, fossil fuels may be burned for the transport of biochar, and/or electricity may be consumed during pelleting or any other post-pyrolytic treatment. All resulting emissions must be compensated for.

Thus, biochar must be tracked by a digital Monitoring, Reporting and Verification (dMRV) system. The dMRV systems track the transport of each packaging unit from the factory gate to the final use and calculates the related emissions. Alike, all other carbon expenditures that are not covered by the security margin must be recorded. This data is either added to the emission portfolio of the respective biochar batch and must be compensated by the biochar producer or becomes part of the emission portfolio of the processor, trader, or C-sink owner.

The dMRV system is usually provided by an external MRV system provider. External MRV systems and tools must be endorsed by Carbon Standards annually.

For as long as the packaging unit is stored closed on the factory premises and is protected from wind, rain, gases, and unauthorized diminution of stock, the C-sink potential remains unchanged. If the biochar is stored for more than one year, it can be registered as a temporary C-sink for the time of storage (cf., Chapter 2.4).

Once the biochar leaves the premises of the producers, further emissions must be tracked. For this purpose, every packaging unit containing more than 1 m^3 of biochar must be labeled with a scannable identification code (i.e., usually a QR code, cf. Carbon Standards design manual). The label accompanies the product on all transports. When scanning the ID, the following information must be provided by the MRV system for customers, traders, and certification bodies:

- Biochar producer
- Batch ID
- Biochar analyses
- Date of production
- Year of CO_2 removal

- Owner of C-sink material
- Point of departure (GPS) for all kind of transports > 1 km.
- Biochar C-content
- Link to the emission portfolio

Packaging units smaller than 1 m^3 biochar may be grouped into a larger unit (e.g., 20 bags of 50 l packed on a palette) where the larger unit is labeled with the scannable ID / QR code, given that all smaller units have the same destination.

The tracking tool accompanies the cargo on its way. At the destination where the packaging unit is discharged, the packaging unit must be scanned and the new location registered to calculate the traveling distance and the CO_2e footprint of the transportation means. If the product changes ownership, it must be technically transferred to the new product owner. The new product owner confirms the request of the transfer online, and with this step the seller and the buyer confirm the transfer of ownership.

To ensure that the MRV system works without leakage and that only high-quality, verifiable C-sinks are sold as a climate service, Carbon Standards introduced an endorsement protocol for external MRV software tools (REF/LINK). Endorsed C-Sink Managers may use their own Carbon Standard endorsed MRV Tool to track biochar along the supply chain on behalf of the C-Sink Owner.

10.2 Biochar Processor

If the biochar is delivered to a processing company who makes new biochar-based products from the biochar, the receiving company must be EBC or WBC certified as a processing company and/or trader. All processing steps must be recorded with their CO_2e footprint. The annual EBC/WBC audit controls that the processing company supplies the data into the MRV-system regularly for each batch that was handled. Once the products are repackaged, they must be registered as new product and C-sink unit providing the following information:

- Product processor
- Biochar production batch ID and/or QR code to access EBC/WBC biochar analysis.
- Date of biochar production
- Year of CO_2 removal
- Owner of C-sink material
- Point of new departure (GPS)
- Biochar C-content of product
- C-sink matrix, if mixed to one

- Emission that occurred during processing
- Link to the emission portfolio of the C-sink unit and/or company

If the biochar was mixed into a C-sink matrix, the packing unit may be smaller than 1 m^3. Packaging units of biochar-based products smaller than 1 m^3 become either a diffuse C-sink or several packaging units are grouped under one new C-sink ID and are delivered to and applied at one C-sink location.

10.3 Biochar Trader

All biochar traders must be registered at Carbon Standards and receive their company ID and access to the MRV tool for trader.

Biochar traders who do not repack the packaging units only need to scan the ID and add the storage location and date of arrival to the registered data. Once it leaves the premises again, the date of departure must be registered.

If the biochar is repacked, the new packaging units must be registered and linked to the former registered packaging unit and all material and transportation data.

If the size of the new packaging units is smaller than 1 m^3, the new packaging units cannot be registered anymore except when grouped to a new unit (e.g., a palette) of > 1m^3.

If the biochar were mixed into a C-sink matrix, the trader would have to register as biochar processor with Carbon Standards.

11. Geo-Localized and Diffuse C-Sinks

Biochar carbon sinks must be registered with the geo-localized area where the biochar or its derived products have been applied. This encompasses scenarios where biochar serves as a soil amendment or finds application in various contexts, such as construction for residential, infrastructural, or road-related purposes. Upon registration, the individual, company, or organization that holds jurisdiction over the geographically marked land becomes the C-sink owner and is required to undergo registration. This registration entails furnishing comprehensive personal or organizational details, including the full company dataset and for individuals the name, date of birth, birthplace, and current residence.

Recording the location and landowner of the C-sink is essential both for subsequent monitoring and for compensating the C-sink owner for climate services when maintaining and preserving the C-sink.

In certain specific instances where marginal quantities of biochar are applied or utilized in products, the registration of so-called diffuse carbon sinks (i.e., non-geo-localized) is permitted.

Biochar that was mixed at a volume ratio of at least 1 to 1 with compost, litter, admitted types of feed, liquid fertilizer, cement, sand, clay, ash, or lime can be considered a carbon sink (one volume part biochar for at least one volume part of organic or mineral matrixes). From the moment of the blending with those organic or mineral matrixes, the combustion of the biochar and, thus, the loss of carbon can be practically excluded. The C-sink matrix positive list (annex 3) classifies and specifies all permissible C-sink materials and applications.

The geo-localization of the biochar must be provided if a biochar-based product containing more than 1 $tCO2_e$ of biochar is applied at one C-sink location. For packaging units containing biochar-based products representing less than 1 $tCO2_e$ of biochar and which are not grouped into deliveries with a total amount exceeding 1 $tCO2_e$ of biochar, the following conditions for diffuse C-sinks apply.

If the registration of the geographical location and the site owner of the C-sink is not possible or practicable, but the biochar is nevertheless shown to have been introduced into a permissible C-sink matrix that precludes combustion (e.g., compost, biogas slurry, cement, etc., see above), the C-sink is considered as a diffuse C-sink. If the size of packaging units becomes too small (e.g., 30 l bags sold in a garden market), it may not be possible to verify the fate of the C-sink physically. Nevertheless, it can safely be assumed that the carbon used in this way remains a terrestrial C-sink as the biochar cannot be separated from the matrix anymore, and the product will be combusted (i.e., in waste incineration). The later may happen in rare cases and is then considered to be included in the security margin.

Diffuse C-sinks may only be accepted when processors produce biochar-products for the consumer market in small packaging units. Usually, those packaging units for consumers can be carried without machines and have a volume of less than 50 liters. The maximum amount for diffuse C-sinks is 1 tCO2$_e$.

However, there would be risk of double counting if, e.g., the biochar-based product (e.g., a 30-l biochar-compost bag) was certified as a diffuse C-sink by the processor while the client thinks to compensate for some of its own global warming effects when using the biochar product in his garden. To avoid such misunderstandings, diffuse C-sinks must be labeled as a C-sink product informing the buyer that the C-sink of the product is already registered and cannot be claimed for other emission compensations (see below).

If a biochar-based product is used in a garden or agricultural soil as a diffuse sink and the farmer or gardener applies for soil organic carbon certification ("humus certificates"), double accounting could occur because the usual measurements used to quantify soil carbon will account for biochar as soil organic carbon. However, as diffuse C-sinks are limited to 1 t CO$_2$e of biochar, and as such small amounts are hardly measurable using usual methods for measuring soil carbon, the risk of double certification is considered low (Rathnayake et al., 2023a). As recommended by Rathnayake et al. (2023), certification of soil organic carbon (SOC) requires declaring any application of biochar and deducing it from certified SOC. The Global Biochar C-Sink certification does not authorize the certification of SOC for the same fields that are registered as biochar C-sink locations.

When selling biochar base products to professional clients at total annual volumes of > 1 t CO$_2$e biochar, geographic localization of the application must be provided. If the biochar-based product contains, e.g., 20 m^3 compost and 1 tCO2$_e$ biochar for a total volume of 22 m^3 biochar-compost, it must be registered with geographic localization. The owner of the land where the biochar was applied will be the C-sink owner. If the total volume of the biochar-compost is, e.g., 6 m^3 containing only 0.4 tCO2$_e$ biochar, the biochar-compost can be considered a diffuse C-sink. The C-sink owner would be the company that processed the biochar to the biochar-compost or the trader of the product.

If a packaging unit of a biochar product (mixed to a matrix included in the C-sink matrix positive list) is traded, and its C-sink value was already registered as a diffuse C-sink through the processor or trader, it must be clearly indicated on the packaging unit and the delivery documents that the C-sink value of the biochar has already been registered and declared. The product must then not be declared or traded as a C-sink anymore and must not compensate GHG emissions. This reference must at least be made by printing the following Carbon Standards registered seal: "Global C-Sink Registered" and a QR-Code with the web link to more detailed information about the C-sink registration and use. Further details can be found in Carbon Standard's Design Manual (link).

12. Approved Biochar Uses for C-sinks

Biochar that is mixed to a C-sink matrix listed in the C-sink matrix positive list (annex 3), can be registered a C-sink, given the conditions marked in the C-sink matrix positive list are met. The following subchapters provide a complementary orientation for general categories of biochar C-sinks.

When biochar or biochar-based products arrive eventually at the site where the C-sink will be established (e.g., a farm, a construction site, a composite factory), the location and date of arrival must be registered in the MRV tool. Any further onsite transformation, such as mixing to a C-sink matrix such as compost, animal feed, or concrete must be documented. When the biochar or biochar-based product is applied to a defined field or site, the geo-location must be registered using KML (Keyhole Markup Language, e.g., from Google Earth) or similar file types. A photo showing bulk applications with date and geolocation must be uploaded to the MRV system. In the transition period until January 2025, a GPS point within the field or plot of application can be accepted instead of KML file data. Further documentation may be required depending on the site and application type, as further detailed in the following subchapters.

The owner of the land where the biochar is applied or the owner of the biochar-containing material will be registered as C-Sink Owner and must agree to take responsibility for the C-sink maintenance (c.f., Chapter 11).

12.1 Soil Application

Mixing with soil or another eligible C-sink matrix (c.f., annex 3) at a portion of at least 50:50 (vol/vol) must be guaranteed, which is fulfilled in most cases of agricultural biochar application. Biochar depositions at a lesser mixing proportion are considered temporary biochar storages (c.f., Chapters 2.4 & 11.5)

12.2 Application in Animal Farming

If the biochar is first applied as feed, bedding, or manure additive, the biochar becomes blended with a C-sink matrix and is thus eligible as C-sink. However, the location of the eventual C-sink must still be registered. If the biochar containing animal manure or compost is spread or incorporated on-farm, the entire farm can be considered as C-sink location and entered as KML file into the MRV tool.

If the biochar containing manure or compost with a C-sink unit size above 1 m3 of biochar is sold or provided to another farm or company, the farm must be registered as a biochar processor. However, in most cases the biochar containing manure or compost will not be transported in packaging units to adjacent farms but rather as bulk material, and it may become impractical to create new packaging unit IDs. Depending on the individual systems in place, appropriate tracking of the biochar containing manures, composts, or digestates to other farms and thus C-sink sites will be developed during the technical audit of the biochar manure processor. For C-sink units below 1 m^3 of biochar, the biochar-manure substrate may be considered a diffuse C-sink (c.f., chapter 10.7).

11.3 Application in Construction Materials

Biochar that is applied in construction materials, be it buildings, urban constructions, infrastructure, or roads, is usually pre-mixed at a processors site. In most cases, the pre-mixed materials are not transported in packaging units, but rather as bulk material measured in weight or volume. Depending on the individual systems in place, an appropriate tracking of the materials to the construction and thus C-sink site must be developed and submitted to Carbon Standards for approval. The tracking system has to be described in detail and linked to the Global C-Sink Registry entry of the respective C-sink.

For incorporating biochar into building materials such as concrete, mineral plasters, gypsum, or clay, a permanent sink might be assumed in most cases. Most demolished building materials are used as fillers, e.g., in road construction, and make incineration by then unlikely. However, concrete can be ground and reactivated under oxidative thermal treatment, where the embedded biochar could be oxidized (Bogas et al., 2021; Carriço et al., 2020; Mostazid and Sakai, 2023). Given the high environmental costs of concrete production, the recycling of cement and aggregates from demolished constructions is the most likely scenario to evolve in the next several decades. It is impossible to predict today how biochar-containing construction materials will be treated in about 80 years when they reach the average end of the building lifecycle. In view of the likelihood of oxidative thermal treatment of demolished concrete, permanent storage of biochar in concrete constructions cannot be guaranteed. Therefore, the existence of the construction and the fate of the construction material must be monitored, and only global cooling services can be traded but no geological carbon sinks (CO_2-offsets). However, as long as the biochar is incorporated in the building material, it is protected against biological and chemical degradation far better than in soil, and no degradation rate must be considered for the lifetime of the building material.

After the biochar-enriched concrete or lime and clay plaster is crushed and used, for example, as a road bedding material, its status in the Global C-sink registry can be updated. It would change from a temporary to a geological C-sink, adopting the same persistence curve as that of biochar applied directly to soil.

11.4 Application in Composite Materials

Biochar can be used as an additive or filler to a multitude of composites, thermoplastics, textiles, organic or mineral fibers, paper, filters, metal, electronic, and other materials. Most of these materials are of small size, have a relatively small lifetime of a few years, but exist in thousands to millions if not billion replicates. It is impossible to register each individual product (e.g., the handle of a hammer, the housing of a watch, a T-shirt, or a sewage pipe).

To register the carbon of such products, the average lifetime of the product must be assessed. A monitoring plan to verify and, where necessary, correct the average product lifetime must be submitted to Carbon Standards. Depending on the size of production, the monthly (> 1000 t CO_2e per month), quarterly (> 1000 t CO_2e per quarter) or annual (≤ 1000 t CO2e per quarter) production of one product type at one production site must be registered as a C-Sink Unit in the Global C-Sink Registry. Annual global cooling services can be traded for periods given by the average lifetime of the product.

11.5 Biochar Storage

It is possible to store carbon in geological sites such as salt domes, crud oil wells, coal mines, or even in silos. For as long as the biochar is stored under controlled conditions and with regular verification, protected from water and from biologically active matrices, it can be considered a temporary C-sink during the controlled storage time. The control is usually assured remotely with continuous measurements of temperature, humidity, and CO_2 concentration. The monitoring plan must be approved by Carbon Standards.

The biochar carbon can be registered as total stored carbon, and the amount of stored carbon must be updated annually in the Global C-Sink Registry. Annual global cooling services of stored carbon can be traded only one year in advance. This means that the Global Cooling Services compensate the global warming effect of past emissions for the coming year.

11.6 Other Forms of C-Sink Establishments

Other application and storage methods not mentioned or covered in the C-sink matrix positive list may be approved by Carbon Standards. The new C-sink method must be submitted to Carbon Standards. If approved, the method will be included in the C-sink matrix positive list and published with the respective monitoring and control stipulations on the Carbon Standard website following the link to the Global Biochar C-Sink certification.

13. Registration of the C-Sink

The Global Biochar C-Sink certification is the prerequisite for generating marketable C-sink certificates. However, before the climate effect of C-sinks can be traded and used to achieve climate change mitigation targets of individuals, companies, organizations, regions, or nations, they must be registered in the Global C-Sink Registry.

The following information are registered for biochar carbon sink:

1. C-Sink Owner (owner of the land where the C-sink is established, or owner of the material that contains the biochar, or producer of biochar containing products).
2. KLM-file of land or area where the C-sink was established.
3. Date of C-sink establishment.
4. Year of CO_2-removal (date of carbon uptake of biomass that was pyrolyzed).
5. EBC/WBC batch number.
6. Biochar analysis - can be linked with the Carbon Standard Biochar Tool
7. Type of C-sink (geo-localized or diffuse).
8. C-sink matrix.
9. Amount of biochar in dry tons.
10. Amount of carbon in CO_2e.
11. Persistence curve of C-sink (depending on C-sink matrix).
12. Controlling period (depending on C-sink matrix).
13. C-sink project documentation (as link to the Carbon Standards Biochar Tool.)
14. Report of the verification and validation body
15. Confirmation of the compensation of the emission portfolio of the biochar

This information is collected by the Biochar C-Sink Manager at the various stages of the biochar and C-sink life cycle using dMRV. The C-Sink Owner must ensure the completeness and correctness of the data, which is controlled by the verification and validation body.

The right to use the "Registered Carbon Sink" seal, owned by the Global Carbon Register Foundation, is acquired by registration of the corresponding C-sink in the Global C-Sink Registry.

to be replaced with the new Global C-Sink label !

Manufacturers of biochar are advised to sell the registered C-sink effects only through Carbon Standards' endorsed C-sink traders. This is the only way to guarantee that exactly the amount of carbon actually removed from the atmosphere in the form of CO_2 and the respective global warming effects are certified and sold.

Biochar producers may equally become accredited as C-sink traders and thus sell C-sink effects (global cooling services or CO_2e offsets) to third parties or offset their own emissions.

For more detailed information, please refer to the Global C-Sink Registry guidelines and the website of the Global Carbon Register Foundation (www.global-c-registry.org). Today, the Carbon Standards and its Global Carbon Sink standards collaborate with the Global Carbon Register Foundation. Carbon Standards C-sink tools provide direct data exchange with the register and support its methodology. However, Carbon Standards and its standards are free to collaborate also with other registries given they provide the same data security and science-based calculations of annual cooling and warming effects.

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