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Impressum

These guidelines are effective since 1st May 2023 for worldwide biochar certification outside the European Union and all EFTA countries. The WBC standard was developed by the Ithaka Institute, is linked to the European Biochar Certificate (EBC) and is owned by Carbon Standards International.

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A. Summary of the WBC guidelines to prepare the inspection

Companies that do not produce but process and trade certified biochar should consult Chapter 10 directly.

0. Scope of the WBC guidelines

The WBC guidelines are effective since 1st May 2023 for worldwide biochar certification outside the European Union and all EFTA countries.

1. Inscription

1.1 Producers of biochar or their designated C-Sink Manager register the biochar producing company on the WBC website (https://www.european-biochar.org). The producer will then receive their login to the secured WBC website, where they are requested to provide all necessary information about the company, the production sites, and the pyrolysis technology they use.

1.2 Following a first verification of the technical information and a personal phone contact with the producer or C-sink manager through Carbon Standards International, the company information is transmitted to the accredited inspection and certification body: CERES-CERT AG (https://www.ceres-cert.de).

1.3 The producer will receive an offer and contract for the WBC certification from CERES-CERT AG.

1.4 Once the producer has signed the inspection contract, Carbon Standards International will coordinate an appointment for a technical pre-audit with the biochar producing company, usually done via a video conferencing system.

1.5 During the technical pre-audit, a company-specific quality assurance and sampling plan will be prepared and noted in the technical WBC inspection sheets. In addition, Carbon Standards International will introduce the WBC methodology, the WBC documents, the protocols to be kept, and the procedure for the annual inspection by CERES-CERT AG.

2. Production batch

2.1 A production batch starts with its registration on the WBC website. The production batch receives a unique ID number and QR code.

2.2 A production batch lasts a maximum of 365 calendar days, including all possible interruptions in production.

2.3 The pyrolysis temperature in °C shall not change by more than 20% during production. At a declared pyrolysis temperature of, for example, 600 °C, short-term fluctuations between 480 °C and 720 °C are permitted.

2.4 The composition of the biomass must not change by more than 20%. If, for example, a mixture of 50% grain husks and 50% landscape conservation wood is pyrolyzed, the proportions may vary from 40% to 60% (±(50% x 20%) = ±10%).

2.5 When a production batch is about to expire, a subsequent, new production batch must be registered on the WBC website.

2.6 If the new production batch is produced with the same parameters as the preceding batch, the analysis of the preceding batch is valid until a sample of the new batch is taken and analysed.

2.7 The sampling of a new batch following a production batch produced with the same parameters may be done within a year after the last sampling and analysis.

2.8 The same pyrolysis plant can produce several batches during the reference time of one year if feedstock or production conditions change. However, the interruption of one batch has to be registered before starting or restarting another batch with its own ID.

3. Sampling and sending the sample for analysis

3.1 The representative sample of the first production batch is taken during the initial audit and thereafter at least annually by an accredited sampler in accordance with the sampling plan contractually specified in the initial audit and submitted to CSI.

3.2 The sampler is either the same person as the inspector sent by the certification body CERES-CERT AG or a company internal or external sampler who participated successfully in the official CSI sampling training.

3.3 The sample has to be registered on the WBC website, where the sample ID and the laboratory order for the WBC analysis are generated.

3.4 The sealed and registered sample must be sent with the WBC sample ID and the order for the analysis to the selected CSI-accredited laboratory.

3.5 In addition to the samples taken for analysis, retention samples are required. In accordance with the sampling and quality assurance plan submitted to CSI, the operation shall ensure the sampling and sealed storage (usually daily) of these samples.

4. Permissible biomass for the production of biochar

4.1 All biomasses included in the WBC Positive List may be used individually or in combination as feedstock to produce WBC biochar. Feedstock restrictions apply to each certification class (WBC-Premium, WBC-Agro, WBC-Material), as certain feedstocks require additional rules for quality management, which are set out in the WBC Positive List. Within a batch, the type of biomass may not be changed, and the mixing ratios may not change by more than 20% (cf. 2.5).

4.2 According to the WBC Positive List, mineral additives may add up to 10% of the mass.

5. Specifications for pyrolysis technology

5.1 Excess heat and/or liquid and gaseous pyrolysis products should be used.
5.2 Nationally defined emission limit values must be complied with.

6. Properties of biochar

6.1 The biochar must be analyzed according to the WBC Basic Analysis Package by a CSI-accredited laboratory.
6.2 Limit values and declaration requirements, as listed in Table 1, must be followed.
6.3 Specifications, additional limit values, or more stringent limits that apply only to certain countries are regulated in the respective country annex.
6.4 WBC-biochar must be adjusted to a water content that prevents dust formation and spontaneous combustion (30% is recommended).
6.5 When the biochar is sold exclusively to business customers (B2B) with appropriate and controlled safety precautions, especially with regard to explosion and health protection (dust inhalation), biochar may be sold with a lower water content. A written authorization of Carbon Standard International must be presented.

7. Health and safety

7.1 The workers must sign that they have been informed about possible dangers at the workplace and that they have the necessary personal protective equipment.

Table1 Overview of the most important analytical parameters for WBC biochar

WBC - Certification Class		WBC-Premium	WBC-Agro	WBC-Material
Elemental analysis	Declaration of Ctot, Corg, H, N, O, S, ash			
	H/Corg	< 0.4	< 0.7	
Physical parameters	Water content, dry matter, bulk density (@ < 3mm particle size), WHC, pH, salt content, electrical conductivity of the solid biochar			
TGA	Must be presented for the first production batch of a pyroylsis unit			
Nutrients	Declaration of N, P, K, Mg, Ca, Fe			
Heavy metals	Pb	120 g t^{-1} DM	300 g t^{-1} DM	declaration, no limit values for certification
	Cd	1,5 g t^{-1} DM	5 g t^{-1} DM	
	Cu	140 g t^{-1} DM	200 g t^{-1} DM (*)	
	Ni	50 g t^{-1} DM	100 g t^{-1} DM	
	Hg	1 g t^{-1} DM	2 g t^{-1} DM	
	Zn	420 g t^{-1} DM	1000 g t^{-1} DM (*)	
	Cr	100 g t^{-1} DM	200 g t^{-1} DM	
	As	13 g t^{-1} DM	20 g t^{-1} DM	
Organic contaminents	16 EPA PAH	6 g t^{-1} DM	declaration	declaration
	8 EFSA PAH	1 g t^{-1} DM	1 g t^{-1} DM	4 g t^{-1} DM
	PCB, PCDD/F	Once per pyrolysis unit for the first production batch. For PCB: 0.2 mg kg^{-1} DM, for PCDD/F: 20 ng kg^{-1} (I-TEQ OMS), respectively		

(*) when traded as micronutrient fertilizer, the respective limit value can be overruled.

1. Objective of the guidelines and certification

Since 2010, biochar production has developed rapidly all over the world. Various pyrolysis technologies, biochar production capacities, biochar-based products, and trade evolved into a new industrial sector.

Thanks to wide-ranging multidisciplinary research, the understanding of the thermo-chemical processes involved in the production of biochar and the biogeochemical impacts of its agronomic use have made great progress. A significant increase in biochar application in agriculture has been recorded over the past two decades. The industrial use of biochar as a filler or functional additive in a large spectrum of materials is emerging. With the first certification of biochar-based carbon sinks in 2020, a further acceleration of production and use of biochar occurred. Agricultural applications range from soil conditioners, composting additives, and carriers for fertilizers to manure treatment and stable bedding, silage additives, and feed additives. Industrial applications are particularly relevant to the construction, composite, plastics, paper, and textile industries.

Modern pyrolysis plants as well as certain types of farm-scale production or simple kilns such as flame curtain pyrolysis systems, are ready to produce quality biochar from a large variety of different feedstocks in an energy-efficient way without harming the environment. As biochar properties and the environmental footprint of its production are largely dependent on the technology, pyrolysis parameters, and the careful operation of the pyrolysis units as well as the type of feedstocks to be used, a secure control and assessment system for its production and analysis had to be introduced.

In issuing the present certification guidelines, Carbon Standards International presents an assessment mechanism based on the latest research, practices, and legislation. By requiring the use of this assessment system, the World Biochar Certificate (WBC) will enable and guarantee sustainable production, processing, and sale of biochar. It is introduced to provide customers with a reliable quality standard, while giving producers the opportunity to prove that their products meet well-defined and recognized quality standards. It further aims to provide a firm state-of-the-art knowledge transfer as a sound basis for future legislation.

Biochar technology continues to develop very rapidly. Numerous research projects around the world are investigating the properties of biochar and its interaction with other substances, materials, and the environment. Every year sees new pyrolysis equipment manufacturers enter the market, and the areas in which biochar and biochar products are used are growing rapidly. The WBC-Certificate and its partner, the European Biochar Certificate (EBC) are closely aligned with this research and technical momentum and will accordingly be revised regularly to consider the latest findings and developments. Limit values and test methods will be adapted to reflect the latest findings and amended or updated as necessary.

These guidelines aim to encourage and ensure the control of biochar production and material quality based on well-researched, legally backed-up, economically viable, and practically applicable processes. Users of biochar and biochar-based products will benefit from transparent and verifiable monitoring and quality assurance and third-party controlled analysis data of the biochar. It is our moral obligation, as well as the duty of every biochar user, to make sure that a good idea is not corrupted. The certificate was designed to serve this goal.

The WBC and the EBC certification standards collaborate for the benefit of stringent international biochar quality norms, transparent monitoring, state-of-the-art science and analysis, and fair market development. WBC and EBC recognize each other. However, as certification classes are different between the two standards, biochar that is traded in the EU and EFTA countries must be EBC certified.

WBC or EBC certification is a prerequisite for the certification, registration, and trade of biochar-based carbon sinks (negative emissions from Pyrogenic Carbon Capture and Storage – PyCCS) under the EBC Biochar C-Sink standard.

The WBC guidelines are effective since 15th September 2023 for worldwide biochar certification outside the European Union and all EFTA countries.

2. Definition of biochar

Biochar is a porous, carbonaceous material produced by pyrolysis of biomass and is applied so that the contained carbon remains stored as a carbon sink or replaces fossil carbon in industrial manufacturing. It is not made to be burnt for energy generation.

Biochar is produced by biomass pyrolysis, a thermal conversion whereby organic substances are broken down at temperatures ranging from 350°C to 1000 °C in a low- to no-oxygen atmosphere. Although torrefaction, hydrothermal carbonization, and coke production are carbonization processes, the end products cannot, however, be called biochar under the above definition. Biochars are, therefore, specific pyrolysis chars characterized by their additional environmentally sustainable production, quality, and usage features. Gasification, i.e., the partial thermal oxidation of biomass under a sub-stoichiometric supply of oxygen, is understood as being part of the pyrolysis technology spectrum and can if optimized for biochar production, be equally certified under the WBC.

Biochar is defined by its quality characteristics, by the raw materials used, its sustainable production, and end use.

Biochar is a hyper versatile material with an increasing number of applications in agriculture, environmental engineering, and basic industry. Each application, like the use as a soil amendment, stormwater filter, or additive for building materials, textiles, and plastics, demands specific biochar qualities and characteristics.

3. The Certification Classes WBC-Premium, WBC-Agro and WBC-Material

The WBC certification system is based on three certification classes: WBC-Premium, WBC-Agro, and WBC-Materials. All WBC certification classes are entitled to C-sink certification.

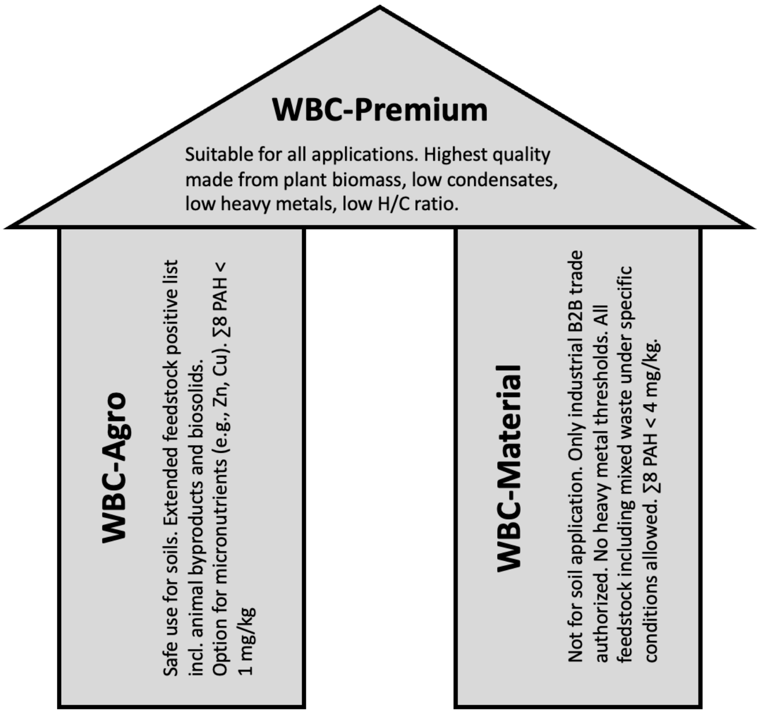

Figure 1: The WBC certification classes.

3.1 WBC-Premium

WBC-Premium is the highest achievable certification class. It provides a strong standard for the safe use of biochar in all sorts of agricultural and industrial applications. It can be used for all known applications of biochar. This includes any type of soil application, water treatment, as an amendment for composting, anaerobic digestion, manure, or potting substrates. It can further be used as an additive for consumer products, including those that may come into direct skin or food contact (e.g., toothbrushes, takeaway coffee cups, toys, carpets, water pipes, etc.), and for industrial devices (e.g., electronics, composites, buildings materials, etc.).

WBC-Premium certification effectively prevents all potential environmental and health risks of biochar application, such as:

1. Toxins entering the food chain,
2. Accumulation of contaminants in the environment,
3. Ground- and surface water pollution,
4. Air pollution due to dust,
5. Hazards to worker and consumer health,

WBC-Premium may be used as feed additives if the producer is additionally certified or licensed as a feed producer. Depending on the country and market, additional analyses may be required. Approval or certification as feed additive takes place independently of the WBC but can be facilitated by data exchange between the WBC and the feed certification body. If it takes place independently of the WBC, the accredited inspection body must be notified, otherwise, marketing of WBC-certified biochar as "feed char"/"biochar for feed" (or similar) is not permitted.

3.2 WBC-Agro

WBC-Agro defines the requirements for safe biochar application in agriculture.

Compared to WBC-Premium, which can equally be used for soil, WBC-Agro presents higher limit values for the H/C_{org} ratio and heavy metals, which allow the use of a wider spectrum of technologies and feedstocks without compromising on soil protection. WBC-Agro has the same ∑8 EFSA PAH threshold as WBC-Premium but no ∑16 EPA PAH threshold, which provides sufficient safety to the agronomic environment, as detailed in chapter 7.12. Under defined conditions, WBC-Agro biochar can be made from nutrient-rich non-plant biomasses such as manure, digestate, or biosolids but not from mixed waste feedstocks. Biochars under WBC-Agro may, therefore, present higher nutrient contents compared to WBC-Premium.

WBC-Agro is considered safe for soil biology, crops, ground- and surface water, and for users.

Under WBC-Agro, micro-nutrient fertilizers can be produced, presenting elevated Zn or Cu values when declared accordingly.

The use of WBC-Agro biochar as a feed additive is not recommended.

Certain countries may have regulations demanding lower threshold values for soil amendments and biochar-based fertilizers than WBC-Agro. In the latter cases, more severe limit values can be regulated in the respective country annex. However, higher country thresholds are not permitted.

3.3 WBC-Material

WBC-Material is the basic and fundamental certification class. It defines the minimum requirements for what can be considered biochar or not according to the WBC.

The WBC-Material certificate guarantees sustainably produced biochar, which can be used in basic industries such as to produce building materials, road construction asphalt, electronics, sewage drains, and composite materials like skis, boats, cars, and rockets without risk to the environment and users. However, precautions in handling, storing, and labeling the materials may be required, as described in the dedicated sections of the WBC certification guidelines (see chapter 11).

WBC-Materials must not be sold to private customers (B2C) or farmers but are traded exclusively to other businesses (B2B) where adequate handling (i.e., avoidance of dust generation, respiratory protection, avoidance of skin contact) can be ensured.

Solid residues obtained from pyrolysis or gasification of biomass that exceed WBC-Material limit values must be considered as (potentially) toxic waste and must be disposed of as waste material according to local, national, or international laws. Pyrolytic products from feedstock that are not listed on the WBC feedstock positive list (e.g., industrial wastes or fossil carbon like lignite) should not be considered biochar and must not be traded under the WBC label.

3.4 General remarks for the application of the certification classes

For all certification classes, the same sustainability criteria regarding the production of biochar (i.e., emissions, feedstock sourcing, and storage, the definition of batches, control of pyrolysis parameters), sampling, and on-site inspection do apply. All certification classes guarantee that the biochar was produced with minimal environmental impact.

All admissible applications of WBC-certified biochar are listed in the WBC-biochar tool that can be accessed via the QR code of the production batch. WBC-Premium biochar is safe to be used for all applications known today, and WBC-Agro for all soil applications. The use of WBC-Material biochar is more restricted and cannot be used, for example, for agricultural purposes, soil applications, and consumer products.

The assignment to a certification class is not necessarily a statement about the excellence of a given biochar (i.e., good, better, or best biochars for a specific purpose/use) – but it does distinguish between biochars that are admissible or inadmissible for a defined form of application (e.g., in agriculture or construction).

Additional analytical specifications for biochars of WBC-Premium and WBC-Agro for individual countries may be regulated in respective country annexes.

Specific industry subclasses defining biochar qualities for use in construction materials, polymers, textiles, and other materials may be developed from 2023 onwards, depending on the demand from the respective industries. If biochar producers desire new certification classes included in the WBC, a formal application should be sent to Carbon Standard International.

4. Biomass feedstock

4.1 Only biomass (i.e., directly or indirectly photosynthesis-derived organic carbon sources) and no fossil carbon such as lignite or hard coal may be used to produce biochar. The WBC positive list indicates which types of biomasses are permissible for each application class.

4.2 The clean separation of non-organic substances, such as metals, construction waste, electronic scrap, etc., must be guaranteed.

4.3 To produce WBC-Premium and WBC-Agro, the biomass used must not contain any paint residues, solvents, or other potentially toxic impurities.

4.4 For WBC-Premium and WBC-Agro, unavoidable biomass contamination by plastic, rubber waste, and/or other fossil carbon-based products/polymers must not exceed 1% (m/m).

4.5 Mixed waste feedstock containing fossil carbon or products made under the use of fossil carbon might be authorized for WBC-Material if proper tracking of organic and fossil carbon is provided. Using such mixed fossil–organic carbon feedstock needs the written approval of Carbon Standards International, including technology-specific processes, monitoring, analysis, and application requirements. If the biochar is subject to C-sink certification, fossil-derived carbon from the C-sink potential of the biochar.

4.6 When using primary agricultural products (e.g., miscanthus or short rotation forestry), it must be guaranteed that these were grown in a sustainable manner and that the land management did not result in a depletion of soil organic carbon.

4.7 Biochar may only be produced from forest wood if sustainable management of the corresponding forest can be proven by PEFC or FSC certificates or by comparable regional standards or laws. If PEFC or FSC certification is unavailable, the producer must submit a dossier on the regional laws and/or certification. A carbon balance of the managed forests may be requested to prove that no clearcutting occurred.

4.8 The pyrolysis of animal by-products, such as livestock manure and manure containing biogas digestates is authorized as feedstock for the certification classes WBC-Agro and WBC-Materials. Pyrolysis conditions must exceed 500 °C for 3 min at minimum to eliminate biological hazards and micropollutants. Its use for industrial materials should be avoided to preserve the valuable plant nutrient from the manures. To avoid health risks for workers during the handling of the animal by-products, a treatment plan for the animal by-products from the arrival at the production site till the pyrolysis must be provided and authorized by Carbon Standards International.

4.9 Biosolids may be used as feedstock to produce WBC-Agro and WBC-Material provided that health risks for workers during the handling of the biosolids are prevented. A treatment plan for the biosolids from the arrival at the production site till the pyrolysis must be provided and authorized by Carbon Standards International. Pyrolysis conditions must exceed 500 °C for 3 min at minimum to eliminate biological hazards and micropollutants.

Unfortunately, the heavy metal contents of most biosolids are too high for WBC-Agro and, thus, for soil application. Some countries adopted fertilizer or waste management ordinances based on nutrient-to-heavy-metal ratios rather than total heavy-metal content (e.g., Denmark). The reason for such a regulation is that mined phosphate contained in most mineral fertilizers is associated with elevated heavy metal contents, especially Cadmium. Using pyrolyzed biosolids could reduce this source of soil contamination.

Mineral additives such as rock powder and ashes, as detailed in the WBC positive list, which may be used to control the pyrolysis process and biochar quality, are subject to declaration and require written approval from Carbon Standards International. CSI may request additional quality controls with regard to organic and inorganic contaminants.

4.10 Complete records of the processed biomasses and additives must be kept and archived for at least five years.

4.11 The pyrolysis of bones and slaughterhouse wastes may also produce valuable raw materials that could be used in the interests of the bioeconomy and climate protection. However, it is not yet authorized to use such wastes for the production of WBC-certified biochars due to legal and product safety issues.

If biochar producers are interested in adding new biomass or mineral additive materials on the WBC-feedstock positive list, a formal application should be sent to Carbon Standards International. The CSI Scientific Committee will review the application in detail and either add the feedstock or publish the reasons for the refusal.

5. Definition of biochar batches and their registration

A biochar production batch is defined as:

5.1 Each production batch must be registered in the WBC-biochar tool. The WBC will allocate a unique ID number with a corresponding QR code for the production batch. The ID number and the QR code ensure the traceability of the biomass feedstock, the conditions of production, and the quality of the biochar.

5.2 A production batch lasts a maximum of one calendar year, including all possible interruptions in production.

5.3 The pyrolysis temperature in °C must not change by more than 20 % during production. With a declared pyrolysis temperature of, for example, 600 °C, short-term fluctuations between 480 °C and 720 °C are thus permitted. Documented planned and unplanned production interruptions are permitted, provided that the specified temperature range is maintained after resuming production. Depending on the pyrolysis process, biochar from the plant start-up and shut-down process may need to be carefully separated and documented and must not be marketed as WBC-certified biochar. The precise handling of biochar from the start-up and shut-down process is regulated during the technical audit and documented in the online instruction manual.

5.4 The blend of different types of feedstocks listed in the WBC positive list may not change by more than 20 percentage points. For example, if a mixture of 50% cereal husks and 50% landscape conservation wood is pyrolyzed, the proportions may vary from 40% to 60% [±(50% x 20%) = ±10%].

5.5 If pyrolysis conditions are maintained, and the registered feedstock is not changed, a new production batch must be registered on the WBC website at the latest one day before the expiration of the previous batch.

5.6 Normally, the biochar quantities produced are recorded continuously. On the last production day of a batch, the date and time of the end of the biochar production batch and the total production quantity of the complete biochar batch have to be reported in the WBC-biochar tool.

5.7 If the new production batch is produced with the same parameters as the preceding batch, the analysis of the preceding batch is valid until a sample of the new batch is taken and analysed.

5.8 The same pyrolysis plant can produce several batches during the reference time of one year if feedstock type or production conditions change. However, the interruption of one batch has to be registered before starting or restarting another batch with its own ID.

5.9 The sampling of a new batch following a production batch produced with the same parameters should be done within a year after the last sampling and analysis. Sample taking should be finalized latest during the audit and verified by the auditor.

5.10 Complete production records must be kept, providing detailed descriptions and dates of any production problems or stoppages. Furthermore, the daily taking of the retention sample must be recorded (see chapter 6.3 retention sample).

5.11 The production quantities of biochar must be documented daily.

5.12 All packaging units filled during and after the batch production must be labeled with a unique QR code linking to the batch ID provided by Carbon Standards International and thus to its material properties, including the complete WBC-analysis and dry weight of the packaging unit.

A production batch is considered completed or interrupted as soon as either point 5.3 or point 5.4 are no longer fulfilled. A new production batch with the changed parameters must instantly be registered on the WBC website, and an appointment with an accredited sampler must be arranged. The annual inspection visit takes place once per calendar year, irrespective of the number of batches produced.

6. Biochar sampling

6.1 Representative sample

The biochar samples sent to the accredited laboratory for WBC analysis must be taken by an accredited sampler or by an accredited automatic cross-flow sampling method according to Annex 3. The sampling plan is prepared during the initial audit, has to be approved by Carbon Standard International, and is documented in the online instruction manual (chapter 13.5). The accredited sampler must follow the company-specific sampling plan.

The inspector of the certification body is entitled to take additional samples (random or representative) at any time and send them to the accredited laboratory.

6.2 Sending of the representative biochar sample to the accredited laboratory

Prior to sampling, the representative sample must be registered in the WBC-biochar tool. The accredited sampler must seal the representative samples for analysis. The producer sends the sealed sample to the WBC-accredited laboratory selected by the producing company.

6.2.1 The accredited laboratory shall send the analysis results to the biochar-producing company and a copy to the accredited certification body, Carbon Standard International, and the Ithaka Institute.

6.2.2 The Ithaka Institute has the right to use the results of the analysis in anonymized form for statistical and scientific purposes.

6.3 Retention Sampling

In addition to the WBC analysis sample, the manufacturer is obliged to take regularly (in general daily) retention samples. The exact procedure is determined during the initial audit. If no deviating protocol is determined during the initial audit, the following applies:

Daily, a fresh sample of one liter, either from the crossflow or from the collected daily production, must be taken. The cross-flow sample can be taken both manually and automatically from the daily production [2].

The daily sampling time has to be entered in the production record. The daily samples must be collected for every month in a sample container as a composite 30-liter sample. After one month the composite sample shall be sealed. The next 30 retention samples shall be collected in a new sample container until this container is also sealed and stored.

The monthly retention sample of at least 30 liter must be kept dry and protected for two years. The retained samples serve to protect the producer who will thus be able to prove in the event of any complaints from authorities or customers that the relevant biochar was free of pollutants and that it was of the quality guaranteed by the WBC certificate.

During the initial audit, company-specific regulations for the creation and storage of reserve samples can be defined.

7. Biochar properties

A principle aim of the WBC certificate is to guarantee compliance with all environmental and human health-relevant limit values. It declares all those biochar properties which are relevant to the respective application and certification class. Another aim of the WBC certification is the description of the quality and suitable areas of application in the WBC-biochar tool, based on the specific parameters of the product.

Numerous additional analytical possibilities exist to characterize and classify biochar even more comprehensively. However, many of these would go beyond reasonable cost limits. We do not seek to analyze, regulate, and guarantee all possible parameters but rather those that are necessary to ensure safety and sustainability.

The limit values listed in the following chapter are only valid in conjunction with the permissible test procedures and permissible analytical methods conducted in an accredited lab. These are detailed for the individual parameters in Appendices 1-3.

Additional or more stringent limit values that apply only to certain countries may be regulated in respective country annexes.

7.1 The biochar's organic carbon (C_{org}) content must be declared.

The organic carbon content of biochar varies typically between 25 % and 95 % of dry matter, depending on the feedstock and the pyrolysis temperature. For example, the carbon content of pyrolyzed straw is usually between 40 and 50%, and that of wood and nutshells between 70 and 90%. The WBC does not define a minimum organic carbon content but reserves the right to exclude biochars with properties highly atypical of the specified feedstock (e.g., a biochar made from wood with only 30% C_{org}) after a plausibility check with the manufacturer if, for example, it is a wood gasifier ash rather than a biochar.

7.2 The molar H/C_{org} ratio must be less than 0.7; for WBC-Premium less than 0.4

The molar H/C_{org} ratio indicates the degree of carbonization and, therefore, of the biochar stability. The ratio is one of the most important characterizing features of biochar and is indispensable for determining the C-sink value. Values depend on biomass and pyrolysis process conditions. However, values exceeding 0.7 indicate non-pyrolytic chars or pyrolysis deficiencies, regardless of the feedstock [3]. Values above 0.4 may indicate pyrolysis temperatures below 500 °C, lower aromaticity, and/or precipitation of pyrolytic condensates (aliphatic and small aromatic carbon species) [34]. The stricter limit of 0.4 is applied for WBC-Premium to ensure low condensate contents and the elimination of organic micropollutants (e.g., mycotoxins) as well as plastic contamination in the feedstock.

Feed certifiers should not authorize biochars with H/C_{org} ratios higher than 0.4. A H/C_{org} limit value of 0.4) is imposed by the WBC for certain feedstocks, e.g., animal byproducts, biosolids and mixed waste. Further details are specified in the feedstock positive list.

7.3 The molar O/C_{org} ratio should be below 0.4

In addition to the H/C_{org} ratio, the O/C_{org} ratio is also relevant for characterizing biochar and differentiating it from other carbonization products [3]. Compared to the H/C_{org} ratio, direct measuring of the O content is expensive and not standardized. Therefore, the calculation of the O content from C, H, N, S, and ash content is accepted.

The O/C_{org} ratio can sometimes exceed 0.4 due to post-pyrolytic treatment or by co-pyrolysis with oxidative or catalytically acting additives. In this case, the WBC would conduct a plausibility check and grant an appropriate exemption, provided that product quality and environmental protection are guaranteed.

7.4 Volatile Organic Compounds (VOC) are determined by thermogravimetric analysis (TGA).

During the pyrolysis process, aromatic carbon, carbonates, and a multitude of diverse volatile organic compounds are formed. The latter constitutes a large part of the pyrolysis gas that partially condensates on biochar surfaces and pores. These condensed pyrolysis gas compounds are substantial constituents of biochar materials [4,5], are essential for certain biochar functions and thus necessary for the characterization of biochar.

However, a quantitative determination of VOCs cannot be carried out at a reasonable cost.

For an independent estimation of the true pyrolysis temperature, which can deviate from the temperature measured at the reactor for various reasons, the weight loss of volatile compounds of biochar is determined by gradually increasing the temperature in the absence of air using the thermogravimetric analysis (TGA). The TGA diagram can thus be used to determine both the absolute VOC content and the maximum temperature to which the biochar was exposed during pyrolysis.

The total VOC content and its temperature-dependent degassing are considered as a criterion for the evaluation of the pyrolysis process. For this reason, it is considered sufficient that the TGA analysis need only be carried out in the first control year of a pyrolysis unit.

7.5 The biochar nutrient contents must be declared at least for nitrogen, phosphorus, potassium, magnesium, calcium, and iron.

The nutrient contents of different biochars depends on the feedstock selection and can account for up to a third of the total weight. It should be noted that these nutrients are only partially available to plants due to covalent bonds (especially in the case of nitrogen) and/or the high adsorption capacity of the biochar and may only be reincorporated into the biological cycle over decades. The nutrient availability of the phosphorus found in biochar is, for instance, only about 15% in the first year, while the availability of potassium can reach 50% [6].

For use in agriculture and animal husbandry, nutrient information is legally required. For material uses, the nutrient contents are generally less relevant, but depending on the application, they may influence certain material properties, especially with higher contents of calcium, potassium, and magnesium, which is why the declaration of nutrient contents is mandatory for all certification classes.

7.6 The following limit values for heavy metals must not be exceeded

For WBC-Premium and WBC-Agro, the following limit and guide values for heavy metal contents apply. They are based on different national regulations and the corresponding values, especially those in the EBC and IBI, to allow for international standardization. As biochar certified under WBC-Material must be included in material matrices from where the biochar-carbon cannot leach, no limit values for heavy metals apply.

Table 2: Limit values for heavy metals according to the WBC certification classes.

		WBC-Premium	WBC-Agro	WBC-Material
Heavy metals	Pb	120 g t^{-1} DM	300 g t^{-1} DM	no limit value, only declaration required
Potential toxic	Cd	1,5 g t^{-1} DM	5 g t^{-1} DM	
elements (PTE)	Cu	140 g t^{-1} DM	200 g t^{-1} DM (*)	
	Ni	50 g t^{-1} DM	100 g t^{-1} DM	
	Hg	1 g t^{-1} DM	2 g t^{-1} DM	
	Zn	420 g t^{-1} DM	1000 g t^{-1} DM (*)	
	Cr	100 g t^{-1} DM	200 g t^{-1} DM	
	As	13 g t^{-1} DM	20 g t^{-1} DM	
	Ag, Se	no limit value, only declaration required	no limit value, only declaration required	

(*) = guide value

Heavy metals are inevitably a component of all ecosystems. Even in natural soils that are hardly influenced by human activities, every plant absorbs more than 50 geogenic elements of the periodic table, and amidst those, there are all essential heavy metals. The toxicity depends on the specific element, its concentration and bioavailability. Bioavailability of heavy metals in biochar is lower than in its feedstock material or in other soil amendments like compost.

Except for a few heavy metals that are volatile or semi-volatile at the prevailing pyrolysis temperatures (e.g., mercury), the amount of heavy metals originally contained in the biomass is retained in the biochar. While the weight of the original biomass is reduced during pyrolysis by more than 50% due to the loss of carbon, hydrogen, and oxygen, heavy metals remain, which leads to increased concentration, i.e., the heavy metal content in the biochar is higher than in the original biomass.

As long as the biomass was not grown on contaminated soils or has increased heavy metal contents due to plant treatments (e.g., copper spraying in viticulture) or due to contamination with wastes, the concentration effect from pyrolysis is not critical. Heavy metal contents beyond the limit values indicate, above all, biomass contamination and thus represent an additional control of the feedstock quality.

Soils in certain regions are deficient in Zinc and Copper, requiring the replacement of those elements in the form of micronutrient fertilizers. Biochars with Zinc and Copper concentrations exceeding the WBC-Agro thresholds may, therefore, be labeled and traded as Zinc and/or Copper micronutrient fertilizers. However, trading such biochars exceeding Zinc and/or Copper thresholds is not authorized without clearly labeling them as micronutrient fertilizers, labeling the concentration of the micronutrients, and including recommendations for their application.

In industrial applications, including the use of biochar in asphalt, concrete and composite materials, the risk of heavy metals being leached into the environment or harming users of these industrial materials is generally low. For this reason, WBC-Materials only requires the declaration of heavy metal contents but does not define limit values. We expect to set application-specific WBC limit values in the future. However, at the present stage of industrial development, accurate, use-specific limits cannot be determined meaningfully. It is incumbent upon industrial manufacturers that seek to incorporate biochar into their products to comply with the respective limit values pertinent to their industry. In addition, all industrial producers and users are urged to carefully consider the end-of-life handling of their industrial materials to prevent pollutants from entering the environment.

7.7 pH, salt content, bulk density, and water content must be declared.

The pH value of biochar is an important criterion for the targeted use in substrates as well as for the fixation of nutrients in animal husbandry or in industrial products. The salt content, measured via the electrical conductivity of the biochar leachate, may indicate contamination of the feedstock or increased oxidation during the pyrolysis, and should therefore be measured. Bulk density (on dry matter base) and water content are necessary specifications for trading biochar as well as for the production of consistent substrate mixtures and materials requiring consistent carbon contents.

The biochar of the class WBC-Premium must be adjusted to a water content that prevents dust formation and thus also spontaneous combustion (see also chapter 9.3). Appropriate storage must prevent the biochar from drying. WBC recommends a water content of 30% for this purpose. There are no recommendations regarding water content for WBC-Materials, which may only be traded B2B. However, if the biochar is sold with a water content of less than 30% or a water content that cannot effectively prevent dust formation, the manufacturer and trader must indicate the associated hazards following relevant standards and local, national, and international requirements. This includes but may not be limited to spontaneous ignition, dust explosion, and the health hazards of inhaling (fine) dust. Appropriate safety precautions must be indicated.

7.8 The determination of the water holding capacity (WHC)

Water holding capacity (WHC) provides guidance for mixing biochar with liquids, e.g., liquid fertilizer, digestate, or stormwater management. It is also a valuable indication of its effectiveness in increasing a soil's water-holding capacity and for humidity buffering when, e.g., applied to the root zone. WHC may also help to evaluate the moisture absorption and buffering capacity of construction and other biochar-based materials. However, it has to be noted that WHC depends on the particle size of the biochar. To achieve reproducible and comparable values, water holding capacity is quantified after milling to < 3 mm.

7.9 Electrical conductivity of the solid biochar

The electrical conductivity of biochar is a highly important indirect parameter to compare batches and the homogeneity of biochar within a given batch. Moreover, it was shown that certain effects of biochar in soil, in the digestions system, in anaerobic digesters, in composting, and in certain composite and construction materials might be related to the electrical conductivity of the solid biochar. It should not be confounded with the electrical conductivity of the aqueous leachate of biochar, which is used to estimate the salt content.

7.10 Specific surface area and pore size distribution are recommended as additional parameters

The specific surface area according to BET is an important characterization and comparison criterion for the physical structure of biochar. However, it should be noted that no method provides absolute values for the specific surface area, but only relative values which allows for standardized comparisons. The BET surface area is often over- and misinterpreted: The BET does not allow any statement about the colonization potential for microorganisms. A higher BET surface does not necessarily mean a higher potential for contaminant binding. For a more precise evaluation of the pore properties, at least data on pore size distribution would be required. Due to the costs and limited interpretation value, the measurement of specific surface area and pore size distribution are recommended as additional parameters but are not mandatory.

7.11 Limit values for PCB and PCDD/F must be observed

In modern pyrolysis plants, only minimal quantities of PCBs, polychlorinated dibenzo-p-dioxins and furans (PCDD/F) are produced [7]. For this reason, it is considered sufficient that PCB and PCDD/F must only be quantified once in the first control year of a pyrolysis unit.

Formation of PCB and PCDD/F depends on the chlorine content of the pyrolyzed biomass. All biomasses authorized on the positive list have a low chlorine content, and only very low contents of these organic pollutants must be expected for the resulting biochar. If the control bodies of the WBC consider the risk of elevated chlorine content in the biomass to be relevant, additional PCB and PCDD/F analyses may be required. The limit values are based on the soil protection regulations in force in Germany and Switzerland [8,9].

The limit values for PCB are 0.2 mg kg^{-1} (DM), and for PCDD/F they are 20 ng kg-1 (I-TEQ OMS), respectively.

7.12 Limit values for PAH contents must not be exceeded

The pyrolysis of organic materials causes the formation of polycyclic aromatic hydrocarbons (PAH) [10]. The PAH content of biochar depends primarily on the pyrolysis conditions like temperature and the separation of biochar and pyrolysis gases in the reactor and discharge [11,12]. Appropriate production technologies with both classical kilns and modern pyrolysis reactors can avoid undesired PAH-contamination of biochar. The type of biomass feedstock used for biochar production has a negligible influence on the PAH content [13].

Tab. 3: PAH limit values for the WBC certification classes.

WBC -Certification Class		WBC-Premium	WBC-Agro	WBC-Material
Organic contaminents	8 EFSA PAH	1.0 g t^{-1} DM	1.0 g t^{-1} DM	4 g t^{-1} DM
	16 EPA PAH	6.0 g t^{-1} DM	declaration	declaration

During biochar production, PAHs are usually released with the pyrolysis gases and are destroyed when these pyrolysis gases are combusted to produce thermal and electric energy. However, depending on the process conditions, a smaller or larger part of the released PAHs can be adsorbed by the simultaneously produced biochar. Moreover, if biochar is cooled down in the presence of PAH-containing pyrolysis gas, significant amounts of PAHs condensate on the biochar surfaces within the complex porous system. Thus, biochar and pyrolysis gas must be separated at temperatures that do not allow condensation and sorption of PAH on the biochar. Controlled vapor quenching may support avoidance of PAH accumulation.

In principle, biochar with a very low PAH content can be produced even by the simplest of means, as demonstrated by the Kon-Tiki flame curtain kiln [14]. However, some industrial pyrolysis and gasification technologies developed over the past decades resulted in biochars with elevated PAH levels [15], which are an indication of unsatisfactory or unsuitable production conditions [35]. The technical feasibility to produce biochar with very low PAH contents is demonstrated by all EBC-certified biochar companies and their technology suppliers since 2012.

Individual PAHs differ widely in their toxicity [16]. The type and degree of toxicity (e.g., genotoxicity, carcinogenicity, ecotoxicity) depend on the molecular structure, the concentration, the bioavailability, the exposure route, and the temporal course of the exposure. The bioavailability of a PAH molecule is determined by the matrix to which the toxin is bound when exposed to humans, animals, or ecosystems.

As shown by Hilber et al. [17,18], biochar that is amended to soil acts more as sink than a source of PAHs. As PAHs are ubiquitous in agricultural and urban environments such as soil or the atmosphere. Low-PAH-biochars that are used in soil adsorb more PAHs from the soil than they release into the soil. The high adsorption capacity distinguishes biochars from other amendments like compost, digestate, manure, and other fertilizers. The use of identical PAH limit values for low and high PAH-adsorbing materials can thus be questioned.

Biochar is not only a potent adsorber of PAHs [19] but also the bioavailability of biochar-bound PAHs is extremely low [17]. Compared to compost, digestate, fertilizer, atmospheric depositions, or hay, all important entry points of PAHs into agronomic systems [20,21], PAH-bioavailability from biochar is most likely the lowest. The risks of bioavailable PAHs for plants, soil biota, animals, and humans are rather well-known and investigated [16,22–24]; showing very low bioavailability of biochar-PAHs when PAHs are below the present WBC limit values [25]. When applied to soil or feed products, biochar often acts as a net PAH-absorber immobilizing PAHs contained, e.g., in soil or feed.

Hilber et al. 2019 [26] demonstrated, however, that using low PAH limit values is prudent and reasonable. When biochars with higher contents of PAHs (up to 60 mg Σ16 EPA-PAH per kg biochar) were introduced in the rumen of a fistulated bovine, more than half of the PAHs from the biochar were released in the digestive system of the cow and may thus have impaired the biological system. Therefore, applying the precautionary principle and complying with existing regulations for other substrates and materials in agriculture and industry, the WBC limit values for PAHs were set for the various application classes.

In the past, PAH thresholds of biochar standards such as the EBC and IBI were based on the list of 16 individual PAH compounds compiled by the U.S. Environmental Protection Agency. These 16 compounds were selected from hundreds of PAHs [27] based on environmental relevance, toxicity, and ability to measure them. The reason for using the 16 EPA-PAHs as a reference and the selection of very low limit values was not based on biochar science or biochar-based risk assessments but on limit values that were established for other soil-amendments like compost, digestate, plant substrates, and (contaminated) soil itself in different countries throughout the world. In absence of investigations how PAHs in biochar may pose risks to the environment and health, it was easier and faster to use the lowest known limit values for any type of soil amendment and apply it for biochar, too. The alternative to this pragmatic decision would have been to wait until systematic research provides the evidence to define reference substances and limit values specifically for biochar to protect soils, plants, animals, workers, and consumers - an unacceptable delay for biochar mainstreaming. For this reason, the EBC, IBI, and other standards applied those low PAH limit values in its early standards since 2012.

However, using a limit value for the simple sum of those 16 EPA PAHs attributes equal importance to each of the individual substances in the interpretation of the analysis. Although all 16 PAHs are among EPA's priority environmental pollutants, this list can be divided into eight PAHs with insufficient or no evidence of carcinogenicity and eight carcinogenic PAHs[1]. Therefore, the latter compounds should be given special attention [28] and, consequently, the WBC defines limit values for Σ8 EFSA PAHs as follows.

In 936 biochar analyses using the EBC-accredited methods, we found that the eight non-cancerogenic PAHs accounted for more than 80% of all analysed PAHs. Given the high number of analyses this can be considered a common distribution of PAHs adsorbed by biochar in common pyrolysis and gasification technologies [12]. The current Σ16 EPA-PAH limit values for biochar are thus based on the assumption that this is the general distribution of the individual PAH compounds. It is, however, technically possible to reduce the content of smaller (non-cancerogenic) PAHs in post-pyrolytic treatments, whereas the more complex (cancerogenic) PAHs remain in the biochar because of the higher affinity of biochar for higher molecular weight-PAHs. Hence, the common IBI, EBC, EU, CH threshold of 4 or 6 mg Σ16 EPA PAHs kg^{-1} of such a biochar could mainly consist of cancerogenic substances like Benzo[*a*]pyrene (BaP). Such high contents of cancerogenic substances would pose a considerable health risk when applied to feed and soil. To avoid such risks due to potential post-pyrolytic treatment of highly PAH-contaminated biochars, the WBC sets an additional limit value for the eight cancerogenic compounds that are included in the 16 EPA PAHs.

[1] *The eight cancerogenic compounds within 16 EPA PAH = 8 EFSA PAH* are Benzo[*a*]pyrene, Benzo[*a*]anthracene, Chrysene, Benzo[*b*]fluoranthene, Benzo[*k*]fluoranthene, Dibenzo[*a*,*h*]anthracene, Indeno[1,2,3-*cd*]pyrene, Benzo[*ghi*]perylene

The WBC follows the European Food Safety Authority's (EFSA) suggestion to evaluate food safety by monitoring the total concentrations of these eight cancerogenic PAHs [29]. The WBC limit value of 1 mg Σ8 EFSA PAHs kg^{-1} is safer than the (higher) Σ16 EPA PAHs limit values that could mask elevated amounts of cancerogenic PAHs.

1 mg Σ8 EFSA PAHs kg^{-1} is defined as limit value for WBC-Agro and **WBC-Premium**. For WBC-Material a limit value of 4 mg Σ8 EFSA PAHs kg^{-1} is defined.

The higher limit value for Σ8 EFSA PAHs in **WBC-Materials** (4 mg kg^{-1}) is explained by the fact that applied biochar particles are embedded and firmly bound into mineral or polymeric matrices (e.g., concrete, asphalt, plaster, composites) and direct contact with living organisms can be excluded. This limit is mainly based on what can be regarded as harmless to employees handling the raw materials with adequate safety measures (packaging, storage, and ventilation) and suitable personal protective equipment.

For **WBC-Premium** the additional limit value of 6 mg Σ16 EPA PAHs kg^{-1} applies. The low 16 EPA PAH threshold is a safeguard for other organic contaminants caused by condensation of pyrolysis gases on the aromatic biochar surfaces. In fact, PAHs are signal compounds for all sorts of pyrolytic condensates sticking to the biochar's aromatic backbone. Low PAH contents indicate that the pyrolysis process in place guarantees a satisfactory separation of pyrolytic solids and pyrolysis gases.

Because PAHs are ubiquitous in urban environments (e.g., from car exhaust, tire abrasion, domestic heating, and atmospheric deposition), and because biochar applied to soil is a strong adsorber for PAHs, WBC-certified biochar will act in the urban environment as a net adsorber of those environmental toxins.

The limit values for **WBC-Premium** are stricter than other regulations for consumer products, but the WBC assumes it is consistent with using the same limit value of cancerogenic PAHs for soil, feed, food, water, ecosystem, and consumer product applications. Consumer products do often get into skin contact, and consumer product wastes often enter the environment, which explains this cautious approach.

It should be noted that due to the high adsorption capacity of biochar, most of the analytical methods used for example for soil analysis of PAHs are not suitable for biochar [15]. It is therefore strongly recommended to always use the service of WBC accredited laboratories to perform PAH analyses even outside of the context of WBC certification.

The very low PAH limit values for WBC-Premium only allow an analytical accuracy of 40% for the 6 mg Σ16 EPA PAHs kg^{-1} limit value, which implies an accuracy of ± 2.4 mg kg^{-1} (dm).

8. Pyrolysis

8.1 Biomass pyrolysis must be operated in an energy efficient manner.

Except for the preheating of the pyrolysis reactor, the use of fossil fuels for heating the pyrolysis reactor is prohibited. The use of waste heat from other industrial processes, such as bio-digesters or cement production or the use of solar thermal energy is permitted. If the pyrolysis reactor is electrically heated, the use of renewable energy sources or the use of surplus electricity is recommended.

8.2 The pyrolysis gases produced during pyrolysis must be recovered or burned. They are not allowed to escape into the atmosphere.

A significant portion of the global charcoal and biochar production is still made using obsolete technology [30] where most of the original feedstock carbon is released as toxic emissions to the atmosphere. Although the material quality of biochar produced in such kilns may meet WBC requirements, the environmental impact of such production techniques is highly negative.

However, if pyrolysis gases are trapped and are cleanly burned or used as bio-oil for the chemical industry, the environmental impact is neutral and largely improved compared to biomass burning or natural decomposition. The WBC certificate guarantees that the climate balance of the biochar production is positive and that no unburned pyrolysis gases are released to the atmosphere.

8.3 Syngas combustion must comply with national emission limit values.

With emission limit values and regulations differing from one country and state to the next, any further definition of emission limit values for pyrolysis facilities would exceed the purpose and proportionality of these guidelines. Therefore, manufacturers must provide a guarantee that their facilities comply with national and state emission regulations. An annual, government accredited emission measurement of the production plant is recommended.

For certification of the C sink potential of biochar, the pyrolysis unit must have an WBC certification (see Guidelines for the certification of the C-sink potential). This can be based on an WBC type certificate or at least three independent, accredited emission measurements including the methane or hydrocarbon content in the waste gas stream.

8.4 Biochar production must be carbon efficient and waste heat should be used

Approximately 35 to 60 % of the energy contained in the biomass feedstock is eventually contained in the pyrolysis gas and oil, which is usually burned in the pyrolysis unit. Part of the energy released during the combustion of these gases is often used to heat the biomass for pyrolysis.

Excess heat should be used to at least 70%, e.g., for drying biomass, district heating, generating electricity, or similar sustainable purposes. For a transitional period of a maximum of three years after the installation of the pyrolysis plant, an exemption for missing waste heat recovery can be applied for. In the meantime, a solution for efficient waste heat recovery must be developed. In rare cases, such as mobile pyrolysis units for debris and waste biomass pyrolysis, an exemption for heat recovery can be granted.

Alternatively, the pyrolysis oil and/or gas can also be captured and used for energy storage, e.g., to deliver peak loads in district heating in winter by burning pyrolysis oil that was collected during summer. The material use of the pyro-oil and/or the upgrading of the pyrolysis gas into basic chemicals such as methanol are also conceivable options to eventually reach a carbon efficiency of at least 70%.

9. Work safety and health

9.1 Fire and dust protection regulations are to be complied with local and national regulations throughout the entire production, transportation, and supply chain. An official operating permit must be presented.

9.2 The company must define in which areas of production which protective measures have to be taken by the employees based on possible health risks or dangers within the production.

Based on the risk assessment, the company defines and implements technical, organizational, or personal protective measures.

9.3 All workers must be informed in writing and trained about possible risks and dangers of and around the production facility and sign the document. This concerns, in particular, the self-ignitability of char dust, respiratory protection, contact with bio-oil and tars and possible gas leakage.

9.4 During transportation and bulk transfers, attention must be paid to the biochar being sufficiently moist to prevent dust generation or dust explosions (cf. chapter 7.7).

9.5 Workers must be equipped by the company with suitable protective clothing and breathing masks where necessary. The company ensures that the defined protective measures are kept by the employees.

10. Certification of companies that process biochar and manufacture biochar-based products

In agriculture and animal husbandry, biochar is rarely used in its pure form. More often it is part of a processed product such as a soil amendment, potting soil, compost, fertilizer, bedding material, feed, or as an additive to anaerobic digestion or silage. In addition to the producers specialized in biochar manufacturing, a growing industry has developed, acquiring and processing biochar as a raw material for biochar-based products.

To guarantee and properly label products made with WBC certified biochar, the entire supply chain including production, processing, packaging, and labeling of the products needs to be inspected and certified. The companies use the IT Tools provided or accredited by Carbon Standards International.

Products containing biochar are only allowed to use the WBC logo and the inscription "Manufactured with WBC certified biochar" if the biochar processing company and their biochar-based products have also been certified according to the following guidelines.

10.1 Exclusive use of WBC certified biochar

The risks associated with the use of non-certified biochar in agriculture, livestock farming and in products ultimately destined for agricultural use, such as compost or biogas slurry, are very high, since in this case pollutants such as PAHs, dioxins and heavy metals may enter the human food chain and accumulate permanently in soils and the environment.

Therefore, products made with biochar can only become WBC certified if the processing company uses exclusively WBC certified biochar for their biochar-based products. The certified company may not use, store, or trade any biochar for agronomic purposes that is not WBC certified.

Without WBC exemption, no non-WBC certified biochar may be used, stored, or traded by the certified company. An exception here is EBC certified biochar registered in the Carbon Standards International IT-tools.

10.2. Incoming goods verification

All incoming biochar or biochar-based products must have the corresponding WBC certificate (WBC-Premium, WBC-Agro, WBC-Materials) marked on the delivery documentation and labels. The incoming goods verification must be documented and is usually done in the Carbon

Standard IT tools. Unlabeled biochar and biochar-based products without a WBC exemption permit must not be processed.

10.3 Storage

Biochar and biochar-based products must be stored in such a way that no contamination can occur. Particular attention should be paid to gaseous pollutants (for example engine exhaust gases) as these can be absorbed by the biochar. Biochar processors must ensure that neither different WBC certification classes nor different batches from different or the same manufacturers are mixed without documentation. The quality and origin of stored biochar as well as a traceable identification number and product name must be marked clearly visible on the storage or packaging material.

10.4 Processing journal

Each processing step of biochar and biochar-based products must be documented in a processing journal. The quantity and quality of all processed biochar and the amount of biochar contained in the final products must be documented.

If the biochar or biochar-based products are merely repackaged or relabeled, the quantity and quality of the original and final products must still be listed in the processing journal.

The control of the flow of goods (balance between incoming biochar and biochar products, specific processing, and the outgoing biochar and biochar products) must be tracked and always documented.

11. Labeling and advertising with the WBC trademark

11.1 Trademarks

Carbon Standards International owns the following trademark:

11.2 Right to use the WBC trademark

Carbon Standard International grants:

(1) Manufacturers of WBC certified biochar, as well as of products containing WBC certified biochar,

(2) Processors and traders of WBC certified biochar and products containing WBC certified biochar and

(3) Users of WBC certified biochar (e.g., farmers, operators of composting plants, operators of biogas plants) as well as of products containing WBC certified biochar (e.g., farmers, gardeners, animal keepers).

the right to use the WBC trademark for the aforementioned goods and services. The WBC trademark may only be used as shown in chapter 11.1. Additions or modifications are not permitted.

The trademark "WBC" (word mark) may only be used alone or with the following additions:
(1) "Certificate", "Certification", or "certified"
(2) "Premium", “Agro”, “Materials”

11.3 Advertising with laboratory analysis according to WBC standard

If an analysis of the biochar has been carried out by an accredited laboratory (see list at www.european-biochar.org/en/ct/10) in accordance with the WBC standard, but no WBC certification was obtained, the lack of certification must be pointed out in a suitable form when advertising the analysis result. Misleading statements in this regard should be avoided in any case. Permissible are for example formulations like "laboratory analysis after WBC standard*", footnote *: "not certified".

11.4 Mandatory information on biochar

The shipping label for unprocessed WBC biochar must indicate at least the following information about the biochar:

- Certification Class
- Organic carbon content (C_{org})
- H / C_{org} – ratio
- pH
- Dry weight
- Volume

All other relevant analytical information such as feedstock, pyrolysis temperature, elemental analysis, nutrient content, heavy metals, WHC, electric conductivity of the solid biochar, and ∑8 EFSA PAHs can be found via the QR-code of the certified batch. **The QR-code of the WBC-certified batch must be printed on the packaging and the delivery note.** The analytical parameters of the biochar uploaded by the accredited laboratory can thus be accessed via this QR code.

If the packaging units are produced before the QR code is created - such as packaging for the end consumer - a company's own QR code on the packaging unit can link the product to the company's website, from where a permanent redirection to the WBC-biochar tool of the certified batch must be set up before the packaging units are sold.

11.5 Production date and QR code

In addition to the QR code of the biochar batch, the production date must be noted on each packaging unit. For large packaging or storing units whose contents are produced over several days, the production period must be marked.

11.6 Mandatory information about biochar-containing products

The shipping label and the biochar product packaging label shall include the following information:

- The application class of the biochar (WBC-Premium, WBC-Agro, WBC-Material)

- Organic carbon content of the biochar used in the product

- Biochar content in dry matter contained in the packaging unit

- Status of C-Sink (if the carbon contained in the biochar was already registered as a carbon sink)

If biochars of different WBC application classes are used in one product, the end product may only bear the WBC application class(es) whose requirements have been met by each individual biochar.

If several WBC certified biochars are mixed in the product, a corresponding averaged values for the organic carbon and nutrient content based on the mass (dm) of the blended biochar portions must be reported. H / C_{org} – ratio, the highest temperature reached in the pyrolysis process, electric conductivity, WHC, and pH must be provided as the range of the lowest and highest value of the individual biochars used.

Certified resellers of biochar or biochar products do not need to name and identify the original company or production site of the biochar.

12. Control, quality management and certification

12.1 Principles of certification

The inspection of the World Biochar Certificate is coordinated by the independent accredited Swiss inspection and certification body CERES-CERT AG. The inspection is carried out on site at each production facility. It takes place once a year. Producers are obliged to keep their production records up to date in accordance with their respective WBC instruction manual (see 12.5).

If a biochar producer desires to become WBC certified, their entire biochar production site must be inspected and certified, regardless of whether only one batch, several or all batches qualify for one of the WBC certificates.

Should an WBC certified producer produce a batch that cannot be certified to WBC Materials due to non-compliance with limit values, the producer must prove proper disposal of this waste according to local or national regulations. Otherwise, the certification of the plant may be permanently withdrawn.

Biochar processing companies may be exempted from the annual inspection visit to the production site if they can prove that they process less than 100 t of biochar per year. In such cases, compliance with the production and quality guidelines is evaluated by the accredited certification body by means of self-declaration and production protocols.

12.2 WBC-certified companies

For production, processing and trade of WBC biochar, a distinction is made between four company types:

a) Biochar producer (on-site inspection)

Biochar producers operate pyrolysis plants and manufacture WBC-certified biochar from biomass. Additionally, they may grind, screen, and/or package biochar. Only biochar produced by the company itself may be stored on the premises, otherwise, additional certification as a processing company and trader is required.

If the biochar is further processed by other, non-pyrolytic process steps (e.g., by charging it with nutrients, mixing it into compost, fermentation, activation or blending with other products), an additional WBC certification as a processing company and trader is required.

A technical pre-audit by Carbon Standard International and an annual inspection visit by the accredited certification body is mandatory. The representative sampling must be carried out by an accredited sampler.

(b) Processing companies and traders (on-site inspection if > 10 t p.a.)

Processing companies that purchase WBC-certified biochar and use it to manufacture new, biochar-based products, must be WBC certified. Common processes are the blending of biochar with additives, activation by thermal processes (production of activated carbon), enhancement by biological and/or chemical treatment or mechanical processing. Furthermore, the mixing of different WBC-certified production batches, which may also be purchased from different WBC-certified manufacturers, also falls under the category of processing (cf. chapter 10).

The trade of unpackaged, loose goods (e.g., containers) or repackaging of purchased biochar is also subject to the inspection and certification obligation for biochar processing plants.

The initial audit is carried out by the accredited certification body, which also determines the processing protocols and the protocols for documenting the flow of goods with the processing companies.

(c) Trader of packaged goods – no certification needed.

The mere trade by third parties of pre-packaged biochar and biochar-based products labelled by the certified manufacturer according to WBC regulations is not subject to any further inspection and certification obligation.

Therefore, if a non-certified company or person sells WBC-certified biochar or biochar-based products, both the certified manufacturer and the unique ID number and QR code of the biochar batch must be clearly traceable. The certified manufacturer must therefore be named on the label and delivery note. Consequently, the label affixed by an WBC certified company must not be altered, pasted over or removed. If the original label is removed or covered over, the goods are no longer considered WBC certified. Additional labels, however, may be applied alongside the original labels.

If the original manufacturer is not named on the packaging or the delivery note and the goods are thus relabelled, the company placing the goods on the market must then be WBC certified, otherwise it may not label the goods as WBC certified.

The relabelling of closed packaging of certified biochar and biochar-based products or the sale under own trade name without mentioning the actual manufacturer is subject to the certification obligation as a private label trader.

(d) Private Label Traders (remote inspection)

If the biochar and biochar-based products are manufactured, packaged, and labelled by the manufacturer for another company, and the name and contact information of the manufacturing company do not appear on the packaging, the retailer marketing the goods under its brand name must be WBC certified as private label trader. Otherwise, the own brand retailer may not label the goods as WBC certified.

This also applies if closed-packaged biochar goods are purchased from other manufacturers or distributors and then relabelled in such a way that the manufacturing company and its contact data are no longer recognizable as such. The company placing the goods under its own brand must necessarily be WBC certified. Otherwise, he may not label the goods as WBC-certified.

Provided there is no repackaging of the goods, WBC certification of private label traders does not require on-site inspection; it can be done via online declaration and remote assessment.

12.3 Registration for certification

To register for certification, please register your company on the WBC website (www.european-biochar.org) and provide all necessary information about your company and production. You will then be contacted by the team of the Carbon Standards International who will assist you throughout the entire certification process.

New biochar producers are highly recommended to contact Carbon Standards International before commencing operations to ensure all required recording procedures are initiated and incorporated into the production processes.

Carbon Standards International AG
Ackerstrasse 117
5070 Frick
Switzerland
Tel. +41 (0) 62 552 10 90
info@carbon-standards.com

12.4 Technical pre-audit of biochar producers

Carbon Standard International commissions the Ithaka Institute to carry out the technical pre-audit of biochar producers. The aim of the initial audit is to understand the technical production process to identify potential problems for certification and quality management. During the technical pre-audit, the standard method and frequency of accredited sampling, the type of retained samples, the determination of dry weights, and the plant's own quality control program may be adapted if necessary. All adaptations and precessions of the usual certification and quality management procedures are documented in a specific online instruction manual prepared by Carbon Standard International.

The initial technical audit of biochar producers includes the following steps:

1) The company uploads the detailed technical description and flow charts of the production process in the WBC-biochar tool.
2) In a video conference between the company to be certified and Carbon Standards International, open questions are addressed, the technical production details are discussed, and the scope of the on-site visit clarified.

All detailed technical information shared between the production company, the Ithaka Institute, Carbon Standards International, and CERES-CERT are subject to strict confidentiality and are protected by data protection law. Non-disclosure agreements (NDA) between the companies and CSI can be signed before the technical audit. In addition, the cooperation agreements regulate confidentiality.

Fundamental changes in operational procedures must be reported to Carbon Standards International and may lead to a repetition of the technical audit and an adaptation of the WBC online instruction manual. The accredited certification body may also order a new technical audit due to operational changes that prevent the inspection visit from being carried out in a meaningful way.

Processors and traders of biochar are subject to an initial audit by the certification body CERES-CERT AG, but do not need a separate technical audit by Carbon Standards International or the Ithaka Institute.

12.5 WBC instruction manual

The present WBC guidelines describe the basic requirements for WBC certification. For biochar producers, an WBC instruction manual based on these guidelines may describe the exact implementation of these rules where necessary. This includes:

- Organization of the operating documentation,
- Procedure for the annual inspection visits
- Responsibilities of the WBC quality manager
- Requirements for occupational health and safety
- Flow charts for representative sampling
- Flow chart and documentation for taking and storing the retention samples
- Additional analyses of critical or strongly varying parameters (e.g., PAH, heavy metals, contamination or impurities of biomasses, etc.).
- Determination of the dry matter content for each individual packaging unit, if the C-sink potential is to be determined for the individual batches

The WBC instruction manual is a contract between the WBC-certified company and Carbon Standards International. The instruction manual is treated confidentially by the certification body and Carbon Standard International.

Processing companies and biochar traders do not receive a separate instruction manual.

12.6 WBC quality manager

The management of the certified company must appoint a quality manager who is familiar with the effects of the various production processes on the quality of the biochar. The quality manager must be authorised within the company to implement measures to ensure and control the quality of the biochar and to document them.

The quality manager is the contact person for the accredited certification body and Carbon Standards International as WBC label holder. If there is a change of personnel in the position of quality manager, the certification body and Carbon Standards International must be informed.

In the first year and later at least once per certification period, the quality manager is obliged to participate in external trainings of CSI on the production, quality assurance, and application of biochar.

The quality manager must ensure the proper documentation and evaluation of the operational processes that influence the quality of the biochar. The documentation must be continuously updated and should be regularly submitted to the management of the company. Information about detected defects must be immediately forwarded to the responsible employees and the defects must be corrected.

The quality manager is the contact person for his colleagues in case of disturbances in the production process. He may delegate individual control and documentation tasks to other employees. In this case, he must instruct the responsible employees and monitor the proper execution of the assigned tasks.

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Annex 1
Analytical Methods for WBC-biochar
Basic Package

The current issue date of the respective standard applies in each case. Further descriptions in this annex may contain deviations and/or concretizations with regard to the mentioned standard. The explanations in italics are only intended to provide the reader with basic information; the implementation is based exclusively and precisely on the standard referred to. Whenever possible, ISO methods are used. If those are not available, the DIN or other methods are described in more detail. Once new ISO methods suitable for biochar analysis are published, the following lists (annexes 1 and 2) will be complemented.

Sample preparation (DIN 51701-3):
After homogenization, the sample is divided representatively into portions. This subsampling is done by quartering (quarter method) of the homogenized sample. Approximately 100 g of the original sample are used for the determination of the conductivity, the salt content and pH. A portion of the sample is dried at 40 ° C and is divided into some subsamples after drying and homogenization. Approximately 250 g of the 40 ° C dried and uncrushed sample is used to determine the true density and the BET surface of the material. Approximately 50 g of the 40 ° C dried sample is finely ground in a vibratory mill. After homogenization the fine material is subsampled for further analysis (i.e., PAH, TGA, ash, CHN, S, trace and major elements). Unless otherwise specified, the particle size of the analytical samples is specified by the respective methods and standards.

Bulk density (analogue VDLUFA-Method A 13.2.1):
To calculate bulk density a dried, water free sample of at least 300 ml is poured into a graduated cylinder and the mass is determined by weighting. The volume of the sample is read after 10 times compression by means of falling. The bulk density (on dry matter base) in kg / m³ is calculated from the mass and the volume of the sample.

Electrical conductivity (salt content) - Method of the BGK (Federal Quality Association Compost), volume 1, method III. C2 – in analogy to DIN ISO 11265:
Adding 20 g of the sample to 200 ml desalinated water and shaking it for 1 hour, followed by filtration of the solution. The conductivity is then measured using the filtrated water. The correction of temperature is automatically done in the measuring device. The electrical conductivity is given for a solution at 25°C. The salt content is calculated using the factor 52.8 [mg KCl/l]/[10^{-4}/cm] and is given in mg KCl/l. This is based on the conductivity (14.12 * 10^{-4} S/cm) of a 0.01 molar KCl solution.

pH-value DIN ISO 10390 ($CaCl_2$):
A minimum of 5 ml of the air-dried sample is placed in a glass vessel. Five times the volume (25 ml) of a 0.01 M $CaCl_2$ solution is added. The suspension is overhead rotated for 1 h. The suspension obtained is directly measured with a pH meter.

Water content according to DIN 51718:
Method A / two-step method (Reference method for coal)

Raw moisture
The sample (100 to 1000 g) is spread evenly in a drying bowl crucible, weighed with 0,1 g accuracy and dried in an oven at (40 ± 2) ° C until the mass is constant. If necessary, the sample is divided and dried in more than one crucible.
Analysis: raw moisture (FG) in%

$$FG = \frac{m_E - m_R}{m_E} * 100$$

FG	=	raw moisture in %
m_E	=	mass of the sample before drying in g
m_R	=	mass of the sample after drying in g

Hygroscopic moisture
Hygroscopic moisture is the moisture held firmly within the pore structure of biochar. Measuring hygroscopic moisture will lead to an understanding of a particular biochar's ability to hold and release moisture.
A subsample of the air-dried and crushed (grain size < 1 mm) sample is weighed immediately after the subsampling into a TGA crucible and is dried in a nitrogen atmosphere at (106 ± 2) ° C to constant mass.
Evaluation: hygroscopic moisture (FH) in %

$$FH = \frac{m_E - m_R}{m_E} * 100$$

FH	=	hygroscopic moisture in %
m_E	=	mass of the sample before drying in g
m_R	=	mass of the sample after drying in g

Water content
Evaluation: water content (Wt) in %

$$W_t = FG + FH * \frac{100 - FG}{100}$$

W_t	=	water content in %
FG	=	raw moisture in %
FH	=	hygroscopic moisture in %

Ash content (550 °C) analogue DIN 51719:
To determine the ash content in biochar two programs of the TGA (30 or 60 min) could be used. The weight determination of the crucible is carried out automatically. Enter the sample number for corresponding crucible position. Add 1,0 g of the sample to the ceramic crucible and spread the substance evenly in the crucible. Weighing is done automatically relative to the crucible position.
Runs the following heating program in the oven:

heating with a rate of 5 K / min to 106 ° C under a nitrogen atmosphere to constant mass (Δm <0,05%).

- temperature increase with 5 K / min to 550 ° C under oxygen atmosphere,
- hold this temperature for 30 or 60 min to constant mass (m <0,05%).

The ash content is automatically determined and calculated for the sample used.

Carbonate CO_2 according to DIN 51726

1 g of pre-dried and ground sample is weighed to 0.2 mg and placed in the decomposition flask. The device consists of an absorption tower, which purges the air of carbon dioxide, the decomposition flask with an attachment to add the decomposition acid and three connected washing bottles. The carbon dioxide freed air is sucked through the system. After the system is purged and the washing bottles are filled with an absorbing solution of $BaCl_2$ and NaOH solution, 30 ml decomposition acid (hydrochloric acid with $HgCl_2$ as a catalyst and a wetting agent) are added to the decomposition flask. The content of the decomposition flask is boiled for about 10 minutes. The inert gas flow transports the carbon dioxide produced through the acidic solution in the first wash bottle in the other two wash bottles. In the second wash bottle, the carbon dioxide dissolves under consumption of base and is precipitated as barium carbonate. If something precipitates in the third wash bottle, the measurement must be repeated with a lower initial mass. The consumption of base in the second wash bottle is determined by a pH-titration using hydrochloric acid. The carbonate content of the sample is calculated from the base consumption and is calculated as CO_2.

CHN according to DIN 51732:

The use of TruSpec Micro or comparable devices is recommended. The sample is combusted in a stream of pure oxygen. Resulting CO_2, H_2O and nitrogen oxides are quantified to calculate the elemental composition.

Sulphur according to DIN 51724-3

The pre-dried and crushed sample is weighed in a ceramic crucible. With the aid of a catalyst layer of V_2O_5 and at high temperatures (> 1300 ° C) the sulphur is oxidized in an oxygen stream. The resulting SO_2 is detected in an Infrared cell and is calculated with the sample mass as total sulphur content.

Oxygen (calculation) according to DIN 51733

The oxygen content is a parameter derived from calculations. It is assumed that the biochar sample consists essentially of ash, carbon, hydrogen, nitrogen, sulphur and oxygen. If one subtracts the ash, carbon, hydrogen, nitrogen and sulphur content in percent from 100 %, the result will be the oxygen content in percent.

C_{org}, H/C und O/C (calculation):

Other quantities and ratios can be calculated from the determined data.
C_{org} is derived from the total carbon content minus the inorganic carbon content (CO_2) in the sample. The H content is analysed through CHN-analysis (see above).

PAH according to DIN EN 17503 (extraction method 10.2.3 using toluol)

The toluol extraction time of the PAHs contained in biochar must be six hours.

Trace metals after microwave-assisted digestion according to DIN 22022-2, DIN 22022-7, DIN EN ISO 17294-2 / DIN EN 1483:
(Pb, Cd, Cu, Ni, Hg, Zn, Cr, B, Mn, As, Ag)
The pre-dried and crushed sample is weighed and placed into the reaction vessel of the microwave. 6 ml of nitric acid, 2,0 ml of hydrogen peroxide and 0,4 ml of hydrofluoric acid are added. The reaction vessel is sealed and is placed in the microwave.
Program flow of the microwave pressure digestion:
heating (room temperature to 190 ° C) in 15 min
holding time at 190 ° C for 20 minutes
free cooling

additional only for ICP-OES:
Program flow of the fluoride masking (Boric acid, adding 5 ml of saturated solution):
heating (room temperature to 160 ° C) in 8 minutes
holding time at 160 ° C for 7 minutes
free cooling
After complete cooling, the reaction vessels are opened, and the digestion solution is transferred to in a 50 mL plastic volumetric flask and filled with deionized water.
The diluted solution is measured by ICP-MS (DIN EN ISO 17294-2).
To determine the levels of mercury DIN EN ISO 12846, DIN 22022-4; DIN EN ISO 17294-2, and DIN 22022-7 can be used.

Main elements after melting digestion DIN 51729-11, DIN EN ISO 11885 / DIN EN ISO 17294-2: (P, Mg, Ca, K, Na, Fe, Si, S)
The melting process is performed on the ashes of the biochar. 200 mg of the fine ash are weighed into a platinum crucible and thoroughly mixed with 2 g of lithium metaborate.
The platinum crucible is placed in a digestion oven. The digestion remains at least 15 minutes at 1050 ° C in the oven. The melt is dissolved in hydrochloric acid and filled to 500 ml.
The samples are measured with ICP-OES (DIN EN ISO 11885) or ICP-MS (DIN EN ISO 17294-2).

Declaration of the nutrient content
The content of nitrogen, phosphorous, magnesium, calcium and potassium must be stated in g kg^{-1} of nitrogen, P_2O_5, MgO, CaO and K_2O, respectively, referring to dry matter of biochar. It is recommended to provide all main elements (for P, Mg, Ca, K additionally) as g kg^{-1} (element, not oxide) and the results of elemental analysis and calculation (CHNSO, C_{org}, carbonate) in % of dry matter of biochar.

Water holding capacity (WHC) according to DIN EN ISO 14238, annex A
Water-holding capacity. This can be measured using the method E DIN ISO 14238, annex A. The test consists of soaking the 2mm fraction of the material in water for a period of 24 hours.

After this, the material should be placed on a dry sand bed for 2 hours for removing free water. The saturated material should then be weighed and then dried at 40°C in a compartment dryer. After drying the material should be weighed again to estimate the water holding capacity.

Electrical conductivity of the pyrogenic solid

To determine the conductivity of the solid biochar, it is first necessary to compress the finely ground biochar under standardized pressure. During this compression process, the electrical resistance is then measured vertically through the test specimen. Based on the measured resistance of the biochar and the geometry of the compacted matter, the specific conductivity can be determined using the following formulas:

$$\Omega specific = \Omega electric * \frac{A}{h}$$

$$LF = \frac{1}{\Omega specific * 1000}$$

$\Omega\text{specific} = \text{specific resistance in Ohm} * \text{cm}$
$\Omega\text{electric} = \text{electric resistance in Ohm}$
A = Area of the compressed biochar = contact area of the electrode in cm2
H = Height of the compressed biochar in cm
LF = Conductivity in mS/cm

For the determination of the conductivity, a device for compressing the biochar, a multimeter with the capability of 4-wire measurement and a measuring construction in which the biochar can be compressed and the electrical resistance can be measured at the same time are required. The measuring construction consists of a pressure flask whose bottom and lid each consist of corresponding copper electrodes. The electrodes used are to be connected to an external multimeter.
In an exemplary setup, for example, a sample chamber volume of 10 cm³ results in a relevant weighing range of 1-2 g of a sample dried at 40 °C and finely ground for analysis. A pressure in the range of 10 - 50 kN must be applied to this test setup using a hydraulic press (e.g., toggle press). When the specified target pressure is reached, the resistance is immediately read on the multimeter and converted using the above formulas. The average conductivity is obtained from the mean value of the solid conductivities under 10, 20, 30, 40 and 50 kN pressure.

This method was developed by the Ithaka Institute and Eurofins. The necessary measuring equipment can be obtained from Eurofins. The establishment of an ISO standard for this measurement method is currently being attempted.

Annex 2
Additional Parameters

The current issue date of the respective standard applies in each case. Further descriptions in this annex may contain deviations and/or concretizations with regard to the mentioned standard. The explanations in italics are only intended to provide the reader with basic information; the implementation is based exclusively and precisely on the standard referred to.

Gross calorific value / net calorific value according to DIN 51900:
To determine the calorific value a bomb calorimeter which fulfills the requirement of the stated standard is used. 0,3 to 0,8 g of pre-dried and ground sample is weighed into a combustion bag, capsule, or crucible. The sample is mounted in the combustion bomb with an ignition wire and 10-20 ml of eluent in bottom part of the bomb. The bomb is placed into the calorimeter. The oxygen filling, the ignition and the measurement are done automatically. After combustion the bomb must be checked for signs of incomplete combustion. The gross calorific value is calculated using the calibration and measurement data. With further corrections, the net calorific value is calculated.

Ash content (815 °C) DIN 51719:
The ash content at 815 ° C is determined after determining the ash content at 550 ° C by rising the temperature from 550 ° C with 5 K / min to 815 ° C and holding until constant weight (mass difference ± 0,05%) is reached.

Volatile matter according to DIN 51720:
1,0 g of the pre-dried and ground sample is placed into a crucible (with lid). The sample must form a uniformly thick layer on the bottom of the crucible. The crucible is placed in the oven preheated at 900 ± 5 ° C. After 7 minutes (± 5 sec), the crucible is removed from the oven and reweighed after cooling to room temperature. The volatile matter content is calculated from the mass loss of the sample.

Thermogravimetric analysis (TGA):
The TGA curve is determined, similar to how the ash content is measured, with the TGA. For this purpose, 1,0 g of pre-dried and ground sample is weighed in the TGA crucible. During the temperature rise from 30 ° C to 950 ° C with 10 K / min, the crucible is weighed at frequent intervals in the TGA furnace. The result is shown graphically.

PCB
VDLUFA VII 3.3.2.2 (DIN-PCB; hot extraction, GC-MS) DIN EN 16167 (use extraction method 2 with Toluol and not with light petroleum), DIN 38414-20 and DIN EN 16215
The sample is crushed into powder (<1 mm) and dried at a maximum of 35 ° C. Alternatively, it can be dried chemically or by freeze-drying. 5-10 g of sample are extracted by Soxhlet extraction with toluene for 6 h with the addition of suitable internal standards. Alternatively, an ASE extraction can be used. The extract is concentrated and purified

according to VDLUFA VII 3.3.2.2 with silica gel column chromatography. The quantification of the purified extract is done with GC-MS or GC-ECD.

PCDD/PCDF/coplanar PCB according to DIN EN 16190:2019-10, DIN EN 16215, Commission Regulation (EC) No 152/2009 (modified by No 2017/771) HRGC/HRMS method
The sample is crushed into powder (<1 mm) and dried at a maximum of 35 ° C. Alternatively, freeze-drying can be used. After the addition of isotope-labeled standards, 2 g of sample material are extracted with toluene in a Soxhlet for 20 h. Alternatively, special hot extractors such as an ASE can be used. After concentration, the extract is purified by multiple column chromatography and can be divided into different fractions. At this point it is also possible to obtain the DIN-PCB fraction. Finally, the components are measured with GC-HRMS.

Specific surface area according to DIN ISO 9277 (BET) and DIN 66137 (density)
The samples should be dried at 40°C and milled to a particle size < 3.15 mm. Nitrogen is used as the adsorption gas. Degassing temperature and time are set to 150°C and 2 hours. The degassing has to be done under vacuum. The multipoint BET method should be applied.

Chrom(VI)
DIN according to EN 16318: 2016-07
Chromium cannot be oxidized during pyrolysis and is instead reduced during pyrolysis, i.e., Cr(VI) is converted into less mobile and dramatically less toxic Cr(III), which is already regulated as the total Cr content of biochar. Nevertheless, this method is offered to provide analytical evidence of compliance with the requirements of the EU Fertilizer Product Regulation, if required.

<u>Particle size distribution</u>
Particle size distribution is determined by sieving according to DIN 66165 or ASTM D2862, based on local preferences and equipment availability. *For this purpose, suitable sieves with ascending mesh sizes are stacked on top of each other. The sample is placed on the uppermost, widest-meshed sieve, and then the apparatus is operated for a defined time so that the biochar is sieved dry by shaking or shaking and tapping. After that, the oversize on each sieve is weighed.*
Biochar that has been pre-sieved to less than 2 mm or ground appropriately can also be analyzed for particle size distribution using laser diffraction according to ISO 13320. The specifications of the instrument must be adhered to so that the technically largest possible biochar particles can also still be measured.

Annex 3

A4.1 Representative sampling

In order to obtain a biochar sample as representative as possible (in terms of accuracy and precision), a batch must be sampled within the first seven days of production according to the following exact methodology. An incremental cross-stream sampling guarantees the most representative sampling of the product.

A. Pyrolysis systems with continuous production

1. On three consecutive days, 8 samples of 3 liters each are taken at intervals of at least one hour directly at the discharge of the freshly produced material. This sampling can also be done by an appropriately adjusted automated cross-stream sampler.
2. The 24 subsamples are combined to form a composite sub-sample.
3. The taking of each of the 24 samples (= 3 x 8 daily samples) as well as the homogenization and sample division, must be documented with the exact sampling times in the sampling protocol delivered to the certification body (CERES-CERT).

B. Systems with non-continuous production processes

1. The quantity of biochar from which a representative sample is to be taken from must be at least equal to the production volume of one day.
2. The biochar pile to be sampled must first be thoroughly mixed by moving it from one pile to another three times with a front loader or shovel.
3. At 24 different spots of the pile, samples of 3 liters each are taken.
4. The 24 subsamples are combined to form a composite sub-sample.
5. The sampling has to be documented in the sampling protocol delivered by the certification body (CERES-CERT).

C. Homogenizing and dividing of the sample

The mixed sample of 24 x 3 liters = 72 liters can either be sent directly to the accredited laboratory, where it shall be homogenized and divided into a representative analytical sample, or the company proceeds as follows to produce a small representative analytical sample on its own.

1. If the particle size of the composite sub-sample is larger than 3 mm, it should be milled to < 3 mm, otherwise no representative sample division is possible.
2. The milled composite sub-sample is either divided by a mechanical sample divider to 2 to 2,5 l or homogenized according to the following instructions:
3. The milled composite sub-sample (total 72 liters) is poured onto a clean surface and then shoveled three times from one pile to another.
4. A sub-sample of 1,5 l is then taken at 15 spots in the mixed pile.
5. The 15 subsamples are again poured together.
6. The new 22,5 l subsample has than to be homogenized thoroughly by turning and piling it 3 times upside-down.
7. From the mixed pile of the 22.5 l subsample, 15 subsamples of 150 ml each shall now be taken at 15 different spots of the pile and united.

The samples to be sent to the accredited laboratory have to be labeled with the QR code generated in the WBC-biochar tool.

The expected uncertainties regarding accuracy and precision were described in detail by Bucheli et al. [33] and will be considered by the WBC when evaluating the results. The aim of the prescribed sampling method is to achieve a well-characterized cross-sectional sample.