Digital MRV for distributed Biochar production and Carbon Dioxide removal (CDR) system

Methodology Title	*Digital MRV for distributed Biochar production and Carbon Dioxide removal (CDR) system*
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Approved by

Version History

Version Number	Date of Approval	Author	Key Updates
1.0	13/12/2023	Pr. Lionel Clarke	First Release

Contents

Executive Summary

This distributed biochar production Methodology quantifies the net Carbon Dioxide Removal (CDR) activity through production of biochar for community-based agriculture, livestock and other applications. The CDR activity results from the capture of atmospheric carbon by biomass followed by its conversion to biochar with long-term chemical and biological stability that ensures durable sequestration of GHG emissions over a 100-year time horizon.

This Methodology has been developed to allow Issuance of CDR certificates for sets of distributed biochar production systems. It provides a route to market to biochar kiln designs and operating processes that have a demonstrated net positive carbon sequestration capability, but for which the process of verification is neither practical nor financially viable. It is applicable when the results of multiple separate, yet closely related operations can be checked for consistency and aggregated as a whole. The Methodology applies the aggregation of data captured from multiple distributed kiln operations that fall within a within a defined geographical region and using similar biomass feedstocks, from which well-characterised aggregated data is deemed to be consistent. The associated remote digital Monitoring, Reporting and Verification (MRV) protocols allows for kilns to be located in potentially remote locations, where the need for positive social and environmental impacts associated with Biochar production and use are highest. The process of pooling data allows for the management of inherent batch-to-batch variability and helps share the overhead costs associated with validation and certification across the community of practitioners.

Any pyrolysis kiln design corresponding to these broad criteria, and where confidence exists around the digital MRV protocols, may in principle use this Methodology. The kilns must be compatible with a specified set of sensors and digital data capture mechanisms. The data capture mechanism must be capable of delivering digital localisation, weight and temperature data to the data aggregation and analysis system defined as part of this Methodology.

To ensure the robust certification of CDR activity, this Methodology provides conservative estimates around lifecycle emissions, and durability of the carbon sequestration over a 100-year time horizon. Analysis of data resulting from the use of this Methodology, aggregated from multiple projects globally will provide the necessary confidence to further reduce barriers to entry for the development of small-scale, distributed biochar production. Eligible projects must document and prove the final application of biochar (from sales records, invoices, attestations, and other evidence) prior to issuance of certificates.

Calculation of emissions associated with the biochar production process are based on one or more monitored biochar production variables according to the parameters described or, using default values detailed in the Methodology.

Biochar production activity eligible against this Methodology is guaranteed by the mandatory inclusion of a set of sensors, database and auditing resources. Inclusion of such elements, instrumental for the innovative digital MRV protocols described above, is only achievable through carbon financing.

Terms and Definitions

Term	Definition
Biochar	A carbon-rich solid material formed by the thermochemical processing of biomass in an oxygen limited environment. These processes can be classified as either pyrolysis (in which oxidants are excluded), or gasification (in which oxidant concentrations are low enough to generate syngas). Biochar is considered a carbon sink when its soil applications (e.g., soil amendment in agricultural lands) or non-soil applications (e.g., cement, asphalt, *etc*.) can prove durable Sequestration over time. Biochar is the Removal Output of this Methodology.
Biogenic	Material that is produced or originates from a living organism.
Capacity	The maximum expected Biochar production over a 1-year period.
Capture	The process of capturing GHG directly from the atmosphere, before permanent Sequestration.
Carbon Dioxide Removal (CDR)	Anthropogenic activities removing GHG from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities (IPCC, 2018).
Carbon Stability	Carbon Stability is referenced to the corresponding IPCC guidelines that correlate Biochar stability with ranges of pyrolysis temperatures. Different percentages of the initial carbon content stable over a 100-year horizon (BC_{+100}) are assigned to corresponding ranges of hydrogen to organic carbon content ratio (H/C_{org}) values.
Carbon Performance Predictions Model (CPPM)	A model used by the Data Management System to assess the Carbon Stability and Certifiable Quantity of the Biochar over a 100-year time horizon. Each CPPM must be approved by a Verification Authority. Datasets aggregated over time from multiple operations within a Facility will span a range of measurements reflecting the nature of the process. Typical data ranges consistent with locally verified checks will establish a CPPM.
Centralised Data Analysis system (CDA)	System, gathering and analysing data collected from aggregated Kiln operations, generating statistically-framed determinations of total Biochar quantity and mean Biochar quality from discrete sets of multiple Pyrolysis operations.
Certificate	A tradeable instrument that represents the collection of environmental attributes describing a specific record of CDR at a Facility Issued as set out in the Standard and this Product Code. A single C-Capsule is assigned to one unit (CO_{2eq}) of CDR.
Certifiable Quantity	A Certifiable Quantity of Biochar is determined from the aggregation of digitally captured and stored data from Biochar process. The quantity is determined by analysing load-time data, the quality determined via the temperature-time traces. The quantity determined shall be recorded in a central repository together with the source data for scrutiny upon request.

	The Certifiable Quantity can be defined as the quantity of Biochar eligible for Certificate Issuance before application of discounts relative to emissions and Leakage.
C-Go ONE kiln	An open-source design of curtain-flame Biochar Kiln to which this Methodology is applicable. The Methodology is adaptable to many other forms of small-scale distributable Biochar Kiln, but the adoption of this specific design eliminates a key variable in the verification process. Other Kiln designs may be included subject to approval based on validation of the corresponding data capture and analysis process.
Community of Practitioners	The certification of stable carbon from a distributed set of operations involves multiple operators and Data Management Providers, defined as Community of Practitioners. The process of aggregation of data and the accumulation of experience can be applied to provide cross-learnings and collective improvement in performance throughout this community.
Data Export App	A mobile phone app or specialised computer program that extracts date- and time-stamped Kiln datafiles from the DB and uploads the datafile or multiple datafiles to a CDA system for analysis and validation.
Databox (DB)	Databox comprising Sensor data capture, storage and communication components.
Data Management Provider	The entity operating the Data Management System. It could be the Registrant or a third-party service provider.
Data Management System	A system allowing the measurement, extraction, analysis, management, storage and packaging of data to allow for the MRV protocols to be performed according to this Methodology. The Data Management System must result in the reporting of metered data in a format verifiable by the Issuer. The Data Management System and the Data Management Provider must be audited on a yearly basis by an approved Verification Authority to be able to use it for MRV protocols under this Methodology.
Eligible Quantity	The volume of Certificates eligible for Issuance for a given Biochar production activity (taking into account emissions and Leakage).
Event of Carbon Default (EOCD)	An unpredictable Reversal of CDR attributed to a Certificate and dependent on the nature and location of the Biochar produced. An EOCD reflects GHG that has been released back into the atmospheric cycle after the CDR event occurred. The requirements relating to EOCDs are defined in section 6.3 of the C-Capsule *Methodology Requirements*.
Expected Effect	Probability for CDR activity to achieve Durable Sequestration for 100 years without an EOCD.
Facility	A set of multiple distributed Kiln operations, where Biochar production and use as described in this Methodology takes place. Kilns aggregated in a Facility must be located within a defined geographical region and using similar biomass Supply Envelope, from which well-characterised aggregated data lying within a statistically-determined range of Biochar production processes is deemed to be consistent.

Facility Audit	The systematic, independent, and documented assessment of a Facility verified by the Issuer against the selected Methodology.
Feedstock	The material undergoing thermochemical processes to produce Biochar.
Flame-curtain “Kon-Tiki” Kiln	Flame-curtain (‘Kon-Tiki’) Biochar kilns are simple, self-fuelling, batch-operated, open-top kilns designed to minimise the emissions of Pyrolysis-derived GHGs without the incorporation of expensive gas recirculation systems by combusting Pyrolysis gases being generated within the body of the kiln within a flame-front located at the upper surface effected via the successive manual addition of fresh combustible materials.
Foundation	The governance body for the International Attribute Tracking Standard (Standard). A not-for-profit foundation that is independent of the various entities that may be Accredited. The I-REC Standard Foundation owns the Standard and is staffed and supported by a secretariat. Legally known as “Stichting I-REC” and founded in the Netherlands under Chamber of Commerce number 59458844.
GHG	Greenhouse gases as covered by the Kyoto Protocol. In this Product Code, quantities of GHG are expressed in tonnes of CO_{2eq}.
Issuance or Issue	The act of creating a record of one or more Product Certificates in an Account on a Registry.
Issuer	An Issuer is an entity Accredited by the Foundation responsible for: • Processing and approving Facility Registrations on the registry after verification of the relevant elements by a Verification Authority; and • Verifying the production data to Issue Certificates in relation to a CDR activity compliant with this Methodology.
Kiln	A Biochar production system, in line with the eligibility criteria set in this Methodology.
Leakage	Predictable Reversal which re-enters the atmospheric cycle after the Biochar production at a Facility over a 100-year period.
Leakage Buffer	A mandatory buffer applied to Certificate Issued, commensurate to the amount of Leakage evidenced in this Methodology.
Methodology	The detailed requirements for an eligible CDR technology or process to be registered under the C-Capsule Code on the Registry. A Methodology shall be approved by the Foundation before use at Facility Audit.
Operating Supervisor	Larger teams of Operators may assign an individual with access to a suitable mobile phone and connectivity to be the Operating Supervisor charged with downloading and transmitting digital data from each Kiln for central aggregation. A local Kiln supervisor with the necessary technology and access to training materials may otherwise be allocated to carry out this task.
Operator	A person physically operating an individual of a set of Kiln. Kiln operators must be trained in its operation and in associated safety procedures, as defined in this Methodology, in order to achieve Competent Operator Status. A local list of trained operators should be maintained by the local representative for reference.

Organic Carbon Content	Amount of organic carbon stored in the Biochar as a mass proportion (in %) based on Biochar's dry weight.
Pyrolysis	The thermochemical decomposition of a material or compound into a carbon rich residue, non-condensable combustible gases, and condensable vapours, by heating in the absence or lack of oxygen.
Registry	A register of Certificates which includes records of the full lifecycle of ownership and use from Issuing to end use (redemption). A Registry must be Accredited to the Standard by the Foundation.
Registrant	The entity that registers a Facility on the Registry, being by virtue considered as the project developer owning the attributes of the Facility.
Sensor	Temperature and weight sensors as described by this Methodology (in section 8.4.1 and Appendix 11.11.4).
Situation Analysis	Situation analysis comprises the assessment of a proposed set of Kiln of operations within a given biomass supply envelope to establish the expected quantity and consistency of Biochar production that may be achieved. This provides an initial criterion for validating the maximum quantity of Certificates that may be generated from within a Facility.
Sequestration	The durable utilisation or storage of Captured GHG in a stable form.
Supply Envelope	The specific type of Feedstock defined at the Facility Audit as to be used for Biochar production at the Facility and eligible for Certificate Issuance. All types of Feedstocks listed in the Supply Envelope must be considered eligible by this Methodology.
Verification Authority	An Entity independent of the Registrant, Operator, Facility owner, Data Management Provider and the carbon market. Its role is to verify some of the Facility characteristics and Biochar production data and audit the Data Management System against this Methodology. Verification Authorities shall be approved by the Foundation.

1. Process Description

1.1 Summary Description

To be eligible for Issuance of Certificate under this Methodology, the activity performed at the Facility must result in the production a determined quantity of stable Biochar. CDR results from organic biomass being heated with no or limited supply of oxygen, such as pyrolysis or gasification processes. In such processes, the biomass undergoes a carbonisation reaction forming Biochar, at a quality able to evidence durable sequestration of GHG over a 100-year time horizon. Biochar needs to be produced from Feedstock defined as biomass waste and further utilised for a defined set of eligible use-cases.

The Methodology applies the data captured from an aggregation of multiple distributed Kiln operations within a Facility, defined as a mean to manage inherent batch-to-batch variability. Analysis of data resulting from the use of this Methodology, aggregated from multiple projects globally will provide the necessary confidence to further increase the list of eligible Feedstocks, and reduce the barriers to entry to the development of small-scale distributed Biochar production.

1.2 Process Flow

The Capture of CO_2 from the atmosphere is performed at photosynthesis, which results in the production of a form of Biogenic carbon defined as the Feedstock used by the Facility to produce Biochar.

The point of Issuance of Certificates for this Methodology will be the utilisation of the Biochar produced at the Facility. This means Certificates can only be issued after the Biochar has been evidenced to be utilised in a form compliant with section 2.5.

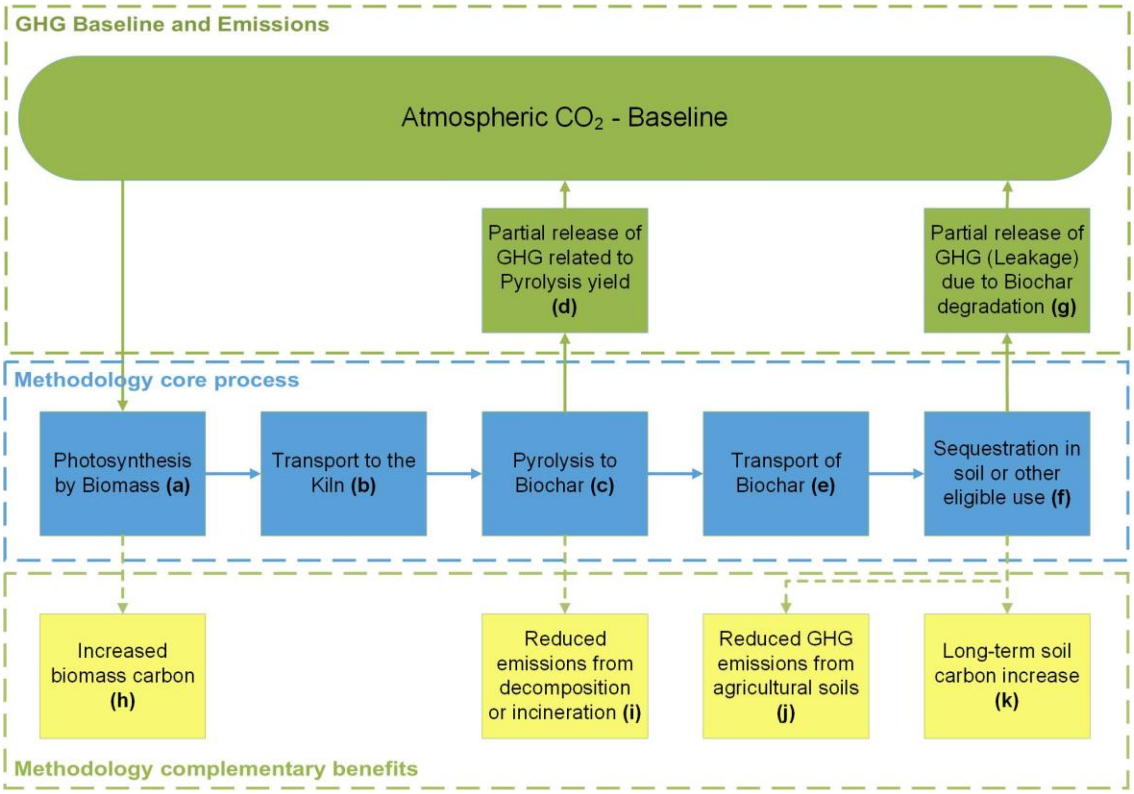

Figure 1. Process flow diagram of the process described in this Methodology.

Notes

(a) Biomass waste or invasive species;

(b) Locating Pyrolysis Kilns near Feedstock sources enables small transportation distances and results in negligible transport emissions and hence efficient transportation footprint;

(c) Biomass type and Pyrolysis conditions determine the long-term stability capacity of the carbon sequestered;

(d) Emissions at that stage mainly include methane emissions;

(e) The rural location of those kilns should facilitate local use of Biochar with significantly densified mass compared to the Feedstock, enabling low emissions transport of Biochar;

(f) Certificates Issued for Sequestration relating to 100-year horizon and Expected Effect;

(g) Depending on the stability of the Biochar, partial reversal of CO_2 into the atmosphere over a 100-year period is expressed in the Leakage value;

(h) Soil fertility increase via Biochar soil application may additionally generate greater biomass and photosynthetic carbon capture;

(i) Decomposing biomass generates CO_2 and/or CH_4 within a few years, or immediately if incinerated;

(j) Biochar in soil has additional potential to suppress N_2O and CH_4 emissions to atmosphere;

(k) Biochar catalyzes microbes to increase mineralization of soil organic carbon, potentially doubling the carbon sequestered from the initial Biochar treatment within less than a decade;

2. Eligible Activity

The eligibility of the Biochar production activity at a Facility to Issue Certificate under this Methodology is determined in the Facility Audit.

This Methodology is applicable to any geographical locations, except where local legislation prevents the additionality condition described in section 7.1 to be satisfied.

2.1 Nature of GHG Captured

This Methodology quantifies the net CDR from a Biochar production and use at a Facility. CO_2 is captured from the atmosphere through photosynthesis during growth of the Feedstock.

Biochar is defined as the Removal Output of this Methodology.

As this Methodology allows for the use of a diverse array of Biogenic Feedstocks, and in line the *C-Capsule Methodology Requirements*, the default GHG baseline is considered zero. Hence, the benefits associated with the avoidance of carbon dioxide or methane generation through decomposition or combustion of the feedstock is not considered in the overall GHG project level accounting in the default baseline scenario.

2.2 Eligible Biochar Production Systems

This Methodology is relevant to Biochar Kiln designs and operating processes that have a demonstrated net positive carbon sequestration capability. It is applicable when the results of multiple separate, yet closely related operations can be checked for consistency and aggregated as a whole.

Any Flame-Curtain “Kon Tiki” Kiln design or any Biochar production system that recirculates pyrolysis gases to the combustion front (and further reduces the emissions of non-CO_2 gases to the atmosphere) where confidence exists around the digital MRV protocol described in section 8 may be approved for use within the Methodology. The Kiln must be compatible with a set of sensors and digital data capture mechanisms as described in section 8. The data capture mechanism must be capable of delivering digital data to the Centralised Data Analysis system defined as part of this Methodology.

To facilitate the process of validation from multiple distributed operations, a common platform Kiln design is encouraged to remove an important variable from the assessment of performance consistency. An example of an eligible Flame-Curtain “Kon Tiki” Kiln design, compatible with the required sensors, digital data capture mechanisms and MRV protocols, is defined as “C-Go ONE”. The core elements of the design, operating procedures and illustrative Pyrolysis process temperatures are set out in Appendix 11.11.

2.3 Eligible Sources, Feedstock or Input

This Methodology is applicable when Biochar is produced from an eligible Feedstock that must meet all following conditions:

- All the eligible Feedstock must be defined as Biogenic waste (such as agricultural waste, biodegradable waste, urban wood waste or food waste) or invasive species;
- Feedstock must not have been imported from other countries; and
- Feedstock must be listed and meet the sustainability conditions provided in Table 1.

Sustainable procurement and use of biomass may be demonstrated by evidencing compliance with a relevant biomass certification scheme. Such as the Roundtable on Sustainable Biomaterials (RSB), International Sustainability and Carbon Certification (ISCC), Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), American Tree Farm System (ATFS), Canadian Standards Association – Sustainable Forest Management (CSA), Programme for the Endorsement of Forest Certification (PEFC) or any other certification scheme approved and/or endorsed by a relevant legislative body or international body.

Non-eligible feedstocks include natural forests, crops purposely grown for Biochar production and components of protected landscapes, unless specified as invasive and linked to a proactive removal initiative.

Table 1. List of eligible Feedstock and eligibility conditions for Issuance of Certificates under this Methodology.

Categories	Eligibility Conditions	Examples (non-exhaustive)
Animal manure	1) Waste must be by-products of animal husbandry.	1) Cattle, horse, and poultry manure.
Encroachment bush species	1) The species to be cleared shall be recognised as such by an appropriate state or national authorities. 2) The Facility has procedures in place to differentiate the invasive species from	1) Plants not native to the region of activity and are causing environmental harm.

	other local species, and avoid unintended clearing of existing native vegetation within the project area.	
Agricultural processing residues	1) Residues must be from food processing facilities or agricultural operations.	1) Coffee husks, cocoa husks, tobacco waste, hemp waste, sugarcane bagasse and other residues from food processing.
Forestry and other wood processing	1) Wood-based feedstock sources coming from forest must prove that biomass comes from sustainable sources and does not lead to deforestation or degradation of ecosystems. 2) Processed wood must not contain any toxic contaminants. It therefore cannot have been processed through a Facility using potentially toxic material.	1) Off-cuts, sawdust, and other material generated as a by-product of forest management, harvesting operations or from the manufacture of wooden products. 2) Thinning generated from forest wildfire fuel reduction activities in areas designated by the relevant authorities as overstocked. 3) Material from pruning or thinning of woody biomass such as shade trees, orchards, windbreaks, stream buffers, silvopasture. 4) Forestry waste and timber that has been damaged by a natural disaster (e.g. fire, pests, flood) and cannot be economically recovered or used as originally intended.
Human manure/sewage	1) Systems must be in place to ensure safe collection, containment, transport, and transformation of human excreta. These systems must follow national or international health, safety and efficiency standards. 2) Faecal matter must be dried before being added to the Kiln. 3) The Feedstock must be composed of a maximum of 70% human waste, mixed with another eligible Feedstock.	1) Waste gathered from dry toilets.
Residues from staple crops	1) Sustainable collection of residues to avoid decreasing soil health and crop. Sustainable collection is defined as leaving 50% of residues to the field to decompose (Battaglia, et al., 2021).	1) Residues from staple crops (e.g. corn, wheat)

At the Facility Audit, a specific Supply Envelope and Situation Analysis (section 8.3.2) must be defined and approved by the Issuer, providing an exhaustive list of the categories of Feedstock to be processed by the Facility.

The Issuer may consider a category of Feedstock listed above is not eligible for Certificates Issuance under this Methodology for reasons specific to a Facility. This may include geographical locations where the Issuer has reasons to believe the described Feedstock will not be available in sufficient quantity to allow sustainable production of Biochar without significant Environmental, Social and Governance (ESG) risks.

2.4 Eligible means of Transport

This Methodology has been developed to support the distributed Biochar generation using small scale and transportable Kilns, allowing the Sequestration process to take place close to the biomass production location. The Kilns should, wherever safe, practical and economically viable to do so, be located in the vicinity of the commercial operation generating the residue Feedstocks and/or of the source of biomass gathering from the natural environment, minimising or obviating the need for transport of bulky Feedstocks.

Feedstock and the produced Biochar to be utilized may be transported via ships, boats, rail and road vehicles.

2.5 Eligible Forms of Biochar Utilisation

This Methodology is applicable when Biochar produced at the Kiln is thereafter utilised in one of the following instances:

- Adding Biochar directly to the soil as a soil improver, including:
    - Application a top-dressing; or
    - Incorporation during tillage.
- Multi-stage uses with subsequent use in soil, including:
    - Mixing the Biochar with mineral or organic fertilisers;
    - Mixing the Biochar with organic materials such as compost or manure;
    - Use as a water filtration medium; and
    - Adding the Biochar to animal feed.
- Other non-agricultural uses such as:
    - Blending with cement or concrete for construction;
    - Blending with asphalt for road paving;
    - Geological sequestration in underground rock layers; and
    - Any other applications where long-term storage of the Biochar is demonstrated.

The final location of the site where the Biochar is utilised must be known. Other types of Biochar utilisation may be authorised by the Foundation if it satisfies itself of the durability of the CDR activity over a 100-year time horizon.

The following uses of Biochar are strictly excluded from this Methodology:

- Biochar is used for energy purpose such as burned as fuel; and
- Biochar is used in applications as a and reductant.

A proof of end-use of the Biochar compliant with this section will be required at the point of Issuance.

2.6 Aggregation of Kilns

This Methodology has been developed to allow Issuance of Certificates for very small-scale Kilns to be aggregated on a Registry. Multiple Kilns may be aggregated as a Facility and be eligible for Issuance of Certificates under this Methodology.

For a set of Kilns to be aggregated on the Registry and be eligible for Issuance of Certificates under this Methodology, all Kilns (including the location of both the Kiln & subsequent use of the Biochar) must be:

- Located in the same country;

- Use a similar Supply Envelope. The Supply Envelope shall be similar enough to allow the findings made at Facility Audits in relation to emissions (section 5.2), Carbon Stability (section 3), Biochar organic carbon content (section 5.1) and Carbon Performance Prediction Models (section 8.2.2) to be valid for all Kilns during the full Audit Period.

2.7 Minimum Operator Training

The Kiln Operators are fully responsible for adhering to local health and safety protocols and with all procedures and response plans highlighted in section 6.

It is recommended for the following training to be observed by the Operators of all Facilities operating under this Methodology:

- Online training and local demonstrations, as locally practical, and sharing of learnings and best practice from the Community of Practitioners.
- Operating guidelines supplied by the Kiln developer and Data Management Provider.

3. Leakage Buffer

3.1 Eligible Biochar Characteristics and Operating Conditions

Biochar comprises a mixture of carbon-rich chemical forms with characteristic degrees of recalcitrance to biodegradation. As a consequence, the total proportion of carbon stabilised in the Biochar will gradually reduce over time. An effective model of this behaviour is that of an exponential decay, with a Mean Residence Time (MRT) related to the effective half-life of the Biochar. Determination of this MRT permits the percentage carbon remaining at the end of a 100-year period to be predicted mathematically.

The difference between the initial value and that at the end of the 100-year period must be expressed in terms of a Leakage Buffer value. The Leakage Buffer is influenced by the nature of the Feedstock and the Pyrolysis process conditions and can be determined through proximate analysis of representative samples. The Leakage Buffer must be directly related to the Carbon Stability.

The long-term Carbon Stability of Biochar is determined by the ratio of hydrogen to organic carbon (H/C_{org}). The lower the H/C_{org} ratio, the greater the Mean Residence Time (MRT), and the lower the Leakage Buffer needed. The H/C_{Org} ratio and long-term stability of Biochar-based carbon can be related directly to the temperature of the Pyrolysis process, as determined by the IPCC (IPCC, 2018) and shown in Table 3.

Pyrolysis temperatures at the centre of the Kiln in excess of 600ºC result in H/C_{org} ratios from the pyrolysis of woody biomass below 0.2 (Appendix 11.6), corresponding to MRTs of potentially 500 years. Facilities comprising distributed, small-scale batch operations will not typically possess the technology required to establish accurate internal Pyrolysis temperatures consistently throughout the operation, but the effective Pyrolysis temperatures can be deduced from the H/C_{org} ratios analysed from resulting Biochar samples. Monitoring Kiln-wall temperatures in real-time enables the consistency of operations to be observed remotely in line with those from which samples are analysed. A more detailed scientific underpinning around the Carbon Stability of the Biochar produced in the Kilns eligible for this Methodology is provided in Appendix 11.6.

To enable Facilities with access to laboratories that only have the capability to measure elemental H/C ratios, or for cost reasons, an alternative to declaring H/C_{Org} ratio data for the Biochar, is to apply a correction factor to a certified elemental H/C ratio, as in Table 2. The basis for this alternative approach is set out in Appendix 11.7.

To permit Carbon Stability to be determined from standard elemental C and H analysis (in the absence of Facility-applicable biomass C_{Org} analysis) for this Methodology, a default value of 99.5% organic C/total C is to be applied to woody biomass, husks and grasses, 99% to shells and digestates, 98% organic C/total C to poultry litter and cattle manure, and lower levels to be determined directly for other categories (these should be determined on a case-by-case basis, evidenced by relevant scientific literature and be approved by the Issuer).

Table 2. Correction factor from certified elemental H/C ratio to H/C_{Org} ratio.

Biomass type	Default C_{Org}/C_{total}
Wood, husks, grasses	99.5%
Shells, digestates	99%
Poultry litter, cattle manure	98%
Others	To be defined on case-by-case basis (may be under 95%)[1]

3.2 Leakage Buffer value

The type of Kiln described as eligible for this Methodology being potentially low technology systems, the Pyrolysis temperature cannot be proved to be constant within the whole Kiln. In practice, there will be a range of temperatures within the Kiln depending on, among others, the location of the Feedstock and the residence time of the Feedstock within the Kiln. In particular, Feedstock added towards the end of the operation will have had less time to experience a full period of slow pyrolysis than material added earlier. This effect is compensated for during the data analysis and validation stage by removing the contribution from Feedstock added within 30 minutes of the operation to the final Biochar determination.

Therefore, the effective Pyrolysis temperature and corresponding Carbon Stability is calibrated against independent measurement of the mean H/C_{Org} ratio taken from samples of the resulting Biochar and verified at Facility Audit. For calibration purposes, an average H/C_{org} value 0.2 or below is taken to equate with the corresponding IPCC value of 11% Leakage, between 0.2 and 0.4 to 20% Leakage, and 0.4 to 0.7 to 35% Leakage, as defined in Table 3. A major goal of the data verification system is to ensure that the combination of temperatures and weight changes throughout the duration of the operation are consistent with the processes for which H/C_{org} calibrated data has been obtained, as multiple replicate operations continue to be carried out, consistent with an approved CPPM as set out in the section 8.2.2.

H/C_{Org} ratio must be determined by qualified analyses of the Biochar produced, laboratory following IBI Biochar Testing Guidelines or EBC Production Guidelines, with a representative sampling methodology (minimum 3 samples per Facility).

[1] Must be approved by the Issuer and evidenced by relevant scientific literature.

For all Facilities eligible under this Methodology, the Carbon Stability and the resulting Leakage Buffer ($B_{Leakage}$) must be fixed as defined by the IPCC, as defined in Table 3:

Table 3. Default level of Carbon Stability and associated Leakage buffers to be applied depending on the Pyrolysis temperature inside the Kiln (IPCC, 2018).

H/C_{Org}	Temperature	Carbon Stability	Leakage
< 0.2	High temperature Pyrolysis (> 600°C)	89%	11%
0.2 – 0.4	Medium temperature Pyrolysis (450 – 600°C)	80%	20%
0.4 – 0.7	Low temperature Pyrolysis (350 – 450°C)	65%	35%

Upon verification of the Leakage Buffer associated to the Facility, the Issuer must satisfy itself that the temperature conditions measured by the sensors provide sufficient confidence the Pyrolysis temperature requirements from Table 3 are met.

Relevant measurement data of Biochar characteristics originating from an example of eligible Kiln under various conditions are provided in Appendix 11.11.1.

4. Event of Carbon Default

4.1 Risk Register, Procedure and Response Plans

After the production of Biochar, there are risks for Events of Carbon Default (EOCD) to occur. This relates to the loss of sequestered carbon in the Biochar that has previously been verified. Prior to utilisation, the Biochar may be intentionally combusted for use as a fuel source. This risk is mostly mitigated by the requirement that Biochar is used only as per section 2.5. During and after utilisation various other reversal risks exist. This Methodology acknowledges the risk of EOCD before and after utilisation of the Biochar (where mitigation measures do not prevent the EOCD from occurring) and conveys it in the Expected Effect defined in section 4.2.

The Risk Register below lists all potential risks of EOCD and quantify its likelihood and impact in Table 4. It should also define the procedure or response plan that shall be identified to help mitigate each risk item identified. All Facilities registered against this Methodology must provide a Risk Register in the same format as Table 4, listing, as a minimum, an assessment of all the risks factors listed in Table 4.

4.1.1 Non-Compliant Combustion

The most important risk of EOCD relating to this Methodology refers to the intentional combustion of the Biochar as fuel, in a similar way as it would be done with charcoal. However, the key difference between charcoal and Biochar is that the charcoal retains many of the combustible oils that will subsequently render it a fuel source, whereas Biochar has already burned these oils within the process to generate the high temperatures that occur. In the case of the Kilns described as part of this Methodology, the Biochar produced is therefore contains very little combustible material. Additionally, the same properties that confer high stability to the Biochar, namely a low H/C_{org} ratio, together with the moisture retention arising from the water quench also renders it unsuitable for burning. Biochar is consequently neither technically nor economically suitable as a fuel. Anyone attempting to use it as a fuel would quickly discover that it is unsuitable and too expensive compared to charcoal, which is produced at a lower temperature and retains the bulk of the volatile liquid components present in the Feedstock.

For the reasons stated above, consistently high temperature conditions unachievable in the context in which the Kilns are set up would be needed to allow combustion of the Biochar.

To limit the likelihood of the Kiln operator or any other party using the produced Biochar as fuel, the Issuer shall always ensure the data provided at Facility Audit provides reasonable certainty of the stability of the Biochar and the completeness of the quenching procedure.

The assessment around the likelihood of the Biochar produced at the Kiln being combusted, even partially, must be performed at the Facility Audit, following the discount method shown in Table 5, and based on the local conditions, including, but not limited to:

- Local regulation, including related enforced monitoring of Biochar use or emissions;
- Economic stability of the geographical region the Biochar is produced in, which can render more difficult the enforcement of eligible Biochar utilisation.

4.1.2 Falsification of the Proof of Utilisation

The proof of utilisation of the Biochar shall be in line with section 8.5.3. However, depending on the type of evidence provided, the likelihood of the Biochar operator falsifying the evidence (i.e. utilising the Biochar in a different way than what has been documented) will vary.

To limit the likelihood of the Kiln Operator, Facility owner, Registrant or any other party using the Biochar in a different way than what is defined in the proof of utilisation, the following shall be in place for any Facility to Issue Certificates under this Methodology:

- If a Verification Authority, the Issuer and/or the Registrant have reasons to believe the eligible Biochar produced by a Kiln has been used in a context outside of the scope of section 2.5, Certificate Issuance must be stopped for that Kiln until an investigation has being performed and concluded by a Verification Authority;
- The Issuer must satisfy itself with the proof of end use being compliant with section 8.5.3. The Issuer may appoint a Verification Authority for local investigation at any point;
- If an investigation concludes the Biochar produced by a Kiln has been used in a context outside of the scope of section 2.5; Certificate Issuance must be stopped until the Operator has received further training and adequate procedures are in place to ensure the utilisation of Biochar compliant with section 2.5. The Verification Authority must verify the utilisation of Biochar for a period encompassing at least 5 cycles of Biochar utilisation after the procedures are implemented and must be satisfied that the utilisation is consistently in line with section 2.5 before Issuance of Certificates can start again. Additionally, an investigation must be performed by the Verification Authority on the potential occurrence of an EOCD of any previously Issued Certificates for that Kiln.

The assessment around the likelihood of the proof of utilisation to be falsified must be performed at the Facility Audit, following the discount method shown in Table 5, and based on the local conditions, including, but not limited to:

- Type of evidence of the utilisation, a proof of end-use of the Biochar making use of GPS coordinates tracking and photographic evidence reduces the risk compared to a attestation from the Registrant indicating the intended use of the Biochar;
- The frequency of on-site validation approval as part of the MRV procedure;
- Local regulation around monitoring of Biochar utilisation activity.

4.1.3 Natural Risks

When Biochar is utilised for soil applications, natural risks are associated with climatic factors. A detailed description of the natural risks associated with Biochar sequestration of GHG, along with the associated scientific underpinning, is provided in Appendix 11.8.

Erosion by wind or water do not affect the performance of sequestration of carbon by the Biochar. Biochar remains stable within watercourses, and ultimately even more in the deep ocean. Therefore, the risk of EOCD relating to the change of land use is considered negligeable, as long as no fire is to occur within the vicinity of Biochar sequestration. However, the risk of combustion through fire is more significant as it can result in the immediate loss of sequestered carbon due to the combustion of Biochar.

In the case of a non-soil application project (e.g., Biochar incorporated to building materials) the carbon Sequestration will continue irrespective of subsequent year activities (Akinyemi & Adesina, 2020).

The assessment around the likelihood of the Biochar produced at the Kiln being combusted, even partially, must be performed at the Facility Audit, following the discount method shown in Table 5, and based on the local conditions and type of Biochar utilisation, including, but not limited to:

- Type of Biochar utilisation (e.g. Biochar used in cement can be assumed to never be used for combustion);
- For utilisation of Biochar in forestry projects, local regulation relevant to fires in forested landscapes (e.g. control/ monitoring of wildfires or slash and burn techniques);
- For utilisation of Biochar in forestry projects, historical evidence of natural fires, or the application of slash and burn methods;
- When Biochar has been used for soil application, whether or not it has been incorporated into the soil subsurface;
- In the case when Biochar is added to the soil surface, whether or not it has been mixed with other amendments (e.g. manures, composts, water) prior to application;
- If Biochar was applied to soils, the type of land use it has been applied to. Indeed, forest fires are more likely to occur at the temperature required to combust Biochar added into soils than fires occurring on agricultural or grassland (Enninful & Torvi, 2008).

4.1.4 Non-Natural Risks

Other risks are defined as non-natural risks, meaning those associated with project management, financial viability, government policies, or community and stakeholder resistance, among others. Since this Methodology considers only waste biomass as an eligible feedstock for Biochar production, social risks (i.e., community resistance or non-acceptability) substantially decrease and can be neglected.

It is possible that the Registrant may go bankrupt at some point after verification and Issuance of Certificates and a Registrant may terminate the project before the end of the 100-year period following the Biochar production. Biochar will continue to act as a carbon sink irrespective of the fate of the project and/or continuation of Biochar application in the case of Registrant bankruptcy. Therefore, non-natural risk due to project and financial viability are considered to have a negligible impact on the previous year project claims because once used in a form compliant with section 2.5, carbon in the Biochar will remain as Sequestered.

4.2 Expected Effect

The Expected Effect shall be quantified as part of the Facility Audit and approved by the Issuer as a reasonable estimate of the CDR activity not experiencing an EOCD within the first 100-year following production. The Expected Effect may impact potential buffers to be applied at the Issuance of Certificates for insurance purposes. The Expected Effect quantification process shall be derived from all of the risk factors of EOCD detailed in section 4.1 and Table 4.

If either the likelihood or the magnitude of the risk described in the project Risk Register are defined as “Negligible”, then that risk category can be ignored in the calculation of the Expected Effect.

The Expected Effect shall be calculated discounting all of the relevant percentage points provided in Table 5 to an initial value of 100%. For each mitigation factor defined in Table 5 (numbered from 1 to 11), the “Action taken” relevant to the specific situation of the Facility must be selected, and the relevant discount factor applied.

The resulting Expected Effect from must be calculated by subtracting the discount factors relating to the applicable actions from the total value. Applying all the relevant discount factors will result in a percentage lower than 100%, relating to the probability of no reversal of the CO_{2eq} *embedded into the Certificate, and defined as Expected Effect.*

Due to the nature of the risk factors of EOCD and given the novel nature of the MRV approach defined in this Methodology, the maximum Expected Effect defined at the Facility level is fixed at **95%**. This maximum “cap” in Expected Effect will be revised at every new versioning of the Methodology by the Foundation, following the data gathering and analysis resulting from the use of the Kilns.

Table 4 Tabulation of risks and response plans
** The magnitude of that risk category depends entirely on the magnitude of the following categories.*

Risk Category	Description	Likelihood	Magnitude	Evidence	Procedures/ Response plans
Proof of utilisation	Falsification of the proof of utilisation of the Biochar by the Operator or the Registrant.	Low – High	Low – High*	The proof of end-use of the Biochar may be the use of mobile or desktop applications tracking records of GPS location coordinates, GPS-tagged photographic evidence or any other tracking software that allows for chain of custody record generation from Biochar production to the utilisation of Biochar in soils (this could include, for example, the use of QR code, blockchain technology or NFT). Alternatively, it can be an offtake agreement, documentation of the sale or shipment of the product, indicating the intended use of the Biochar.	a) Investigation can be initiated at any time by the Verification Authority, the Issuer and/or the Registrant, Certificate Issuance must be stopped for that Kiln until an investigation has being performed and concluded; b) The Issuer of Certificates must satisfy itself with the proof of end use being compliant with what has been approved at Facility Audit; c) If an investigation concludes the Biochar has been used incorrectly, Certificate Issuance must be stopped and an investigation must be performed on the potential occurrence of an EOCD. Section 4.1.1 and 8.5.3.
Risk of fires on the area of soil utilisation	Biochar added into soils is combusted through fire occurring on the vicinity	Negligible – High	Low – Medium	Biochar will normally be applied locally to agricultural soils according to the definition of each facility. Historical evidence of natural fires, or the application of slash and burn methods, should be recorded in the Risk Register exercise.	Report fires occurring on land treated with Biochar within each Facility and determine their extent. Soil carbon analysis may be applied to establish if carbon stock has significantly reduced as a result, or indeed increased as a result of this natural biomass Pyrolysis process. Appendix 11.8.
Natural risks – Climatic and Geology	Biochar stability could be influenced by climatic and geological factors (e.g. erosion, floods)	High	Negligible	Biochar remains stable within watercourses, and ultimately even more in the deep ocean. The critical metric is the quantity added to the soil, not the quantity that remains in the initial vicinity. Therefore, the risk of EOCD relating to the change of land use is considered negligeable.	Not applicable. Appendix 11.8.

Non-natural risks	Project, Financial & Political risks	Low – High	Negligible	Project management and financial risks are considered minimal due to the independence of CDR achieved at the Facility.	Not applicable. Section 4.1.4.
Intentional Combustion of Biochar	The Biochar is being burnt for fuel or as a reductant instead of following the eligibility conditions of this Methodology	Negligible – Medium	Low - Medium	In the case of the Kilns described as part of this Methodology, the Biochar produced is therefore very little combustible. Additionally, the same properties that confer high stability to the Biochar, namely a low H/C_{Org} ratio, together with the moisture retention arising from the water quench also render it unsuitable for burning.	The system monitoring of the Kiln temperatures ensures that the high temperatures required to generate high quality Biochar are achieved. Weight loss data also provides a measure of the yield, correlating with loss of volatile gaseous and liquid fractions. Procedures and response plans include: a) Failure to reach target temperatures and yields will invalidate claims to be producing Biochar. b) The Issuer shall always ensure the data provided at Facility Audit provides reasonable certainty of the stability of the Biochar and the completeness of the quenching procedure. Section 4.1.1.

Table 5. Calculation of the Expected Effect.

Risk Category	Mitigation Factor	Action taken	% Discount
Proof of utilisation	1) Type of proof of use	Extract from a mobile or desktop applications tracking records of GPS location coordinates, or any other tracking software that allows for chain of custody record generation from Biochar production to the utilisation of Biochar in soils. Alternatively, photographic evidence with attached GPS and time stamps proving the Biochar has been sequestered in the vicinity of the place of production (< 200 km).	0
		An offtake agreement or documentation of the sale or shipment of the Biochar to an end user. An attestation of utilisation signed by the user must be included.	2
	2) Frequency of on-site Audit at the site a Biochar utilisation	Yearly inspections of > 10% of the utilisation sites documented for the Facility. The selection of the utilisation sites from the Facility must be left to the Issuer of the Verification Authority.	0
		Inspection every 5 years of > 10% of the utilisation sites documented for the Facility. The selection of the utilisation sites from the Facility must be left to the Issuer of the Verification Authority.	1
		On-demand or randomised inspections only (mandated by Issuer or Foundation)	2
	3) Existence of Local regulation around monitoring of Biochar utilisation activity.	Applicable local enforcement of Biochar utilisation	0
		No local enforcement of Biochar utilisation	1
Fire on the area of utilisation	4) Combustibility of the Biochar, related to the H/C_{Org} ratio	H/C_{Org} ratio < 0.4.	0
		H/C_{Org} ratio between 0.4 – 0.7	2
	5) Economic & political stability of the geographical region where the Biochar is produced[2]	Stable socio-economic landscape allowing a credible enforcement of eligible Biochar utilisation	0
		Unstable socio-economic landscape rendering more difficult the enforcement of eligible Biochar utilisation	1
	6) Type of Biochar utilisation	Non-soil application	0
		Soil application	0

[2] Discount must only be applied when the H/C_{Org} ratio of the Biochar is defined as above 0.4 (factor #10).

	7) If used for soil application, has Biochar been incorporated into the soil subsurface[3] ?	Biochar evidenced as incorporated into the soil subsurface (through photographs, satellite imagery or equivalent)	0
		Biochar added directly to the soil surface (or no information)	1
	8) If used for soil application, type of land-use existing where Biochar has been added to[3]	Agricultural soil application	0
		Natural forest or forestry projects	1
	9) If used in forests, local regulation relevant to fires in forested landscapes[4]	Relevant regulation in place	0
		No Regulation in place	1
	10) If used in forests, historical evidence of natural fires, or the application of slash and burn methods[4]	Project located in an area where fire greater than 100 ha has occurred within 50 km radius of the utilisation area in prior 12 months	4
		• Project is located in high fire risk region; or • No data available	2
		Project is located in low fire risk region	0
	11) If added directly to the soil surface, Biochar mixed with other amendments (e.g. manures, composts, water) prior to application[5]	Biochar added with other amendments	0
		Biochar added on its own	2

[3] Discount must only be applied when the type of Biochar utilisation (factor #4) is defined as "Soil application".
[4] Discount must only be applied when the type of Biochar utilisation (factor #5) is defined as "Natural forest or forestry projects".
[5] Discount must only be applied when the type of Biochar incorporation into the soils (factor #9) is defined as "Biochar added directly to the soil surface".

5. Quantification of Greenhouse Gas Removals

Life cycle assessment studies of Biochar indicate that the climate benefits of Biochar material are highly variable and dependent on many factors. The total GHG benefits of Biochar are influenced by the carbon content of the Biochar (section 5.1), the Carbon Stability of the Biochar over a 100-years period (section 3) and the emissions associated with the overall Biochar production and utilisation process (section 5.2). These elements are heavily influenced by the Kiln design, the temperature conditions inside the Kilns and the type of Feedstock used.

This Methodology provides a credible and robust framework to quantifying measurable and durable net CDR activity resulting from Biochar production and utilisation. All project emissions (CH_4, N_2O and CO_2) and stable GHG sequestered by the Biochar are expressed in tonnes of CO_{2eq} per tonne of Biochar produced.

5.1 Stable CO_{2eq} Embedded in the Biochar

The stable organic carbon content of the Biochar produced at the Facility constitutes the basis of net CDR quantification and must be converted to tonnes of CO_{2eq} per tonne of Biochar. This value is derived from the organic carbon content and the decay rate of the said carbon over a 100-year time horizon.

Care must be taken due to the very diverse biomass is used to produce Biochar in different locations, so that the laboratory analyses are made for each type or Feedstock separately. For this reason, Facilities shall only be aggregated as using the same Supply Envelope to be eligible for Issuance of Certificates under this Methodology (see section 2.6).

This stable organic carbon content is related to the temperature profile measured by the Databox during the Biochar production process. It shall be quantified during the Facility Audit and approved by the Issuer. It must be calculated as:

$$C_{S.CO2eq} = \frac{44}{12} \times C_{Org} \times (1 - B_{Leakage})$$

Where:

- ***$C_{S.CO2eq}$**: the amount of GHG durably sequestered into the Biochar over a 100-year time horizon [tonnes of CO_{2eq} / tonne of Biochar].*
- ***C_{Org}**: the organic carbon content of the Biochar produced. It is expressed in dry weight of organic carbon over dry weight of Biochar [tonnes of organic carbon / tonne of Biochar].*
- ***$B_{Leakage}$**: Buffer representing the long-term Leakage of GHG throughout the first 100-years after Biochar production and use [%]. It is defined in section 3.*

The organic carbon content (C_{Org}) must be determined by qualified analyses of the Biochar produced, laboratory following IBI Biochar Testing Guidelines or EBC Production Guidelines, with a representative sampling methodology (minimum 3 samples per Facility)[6]. When applicable for the Feedstock used for Biochar production, Facilities may adopt values from

[6] To enable Facilities with access to laboratories that only have the capability to measure elemental H/C ratios, or for cost reasons, an alternative to declaring H/C_{Org} ratio data for the biochar, is to apply a correction factor to a certified elemental H/C ratio, as in Table 2.

IPCC (IPCC, 2019) for different Feedstocks (Table 6) or refer to other peer reviewed scientific literature.

Table 6. Default organic carbon content in Biochar based on the type of Feedstock defined in the Facility's Situation Analysis (IPCC, 2019).

Feedstock	Values for C_{Org}
Animal Manure	0.38
Wood	0.77
Herbaceous (excluding rice husks and rice straw)	0.65
Rice husks and rice straw	0.49
Nut shells, pits, and stones	0.74
Biosolids (paper sludge)	0.35

The characterisation process will be based on remote monitoring of operations by the using the Databox to ensure Kiln operations falls within a typical range and use statistically relevant averages. The determination of Biochar characteristics, including H/C_{org} ratio and organic carbon content should be determined on an individual basis and derived from an analysis of the physical attributes of the Supply Envelope.

5.2 Emissions Inventory

The system boundary for the emissions inventory is set cradle-to grave and shall include emissions from supply of the biomass, from biomass conversion to Biochar, and from Biochar distribution and use.

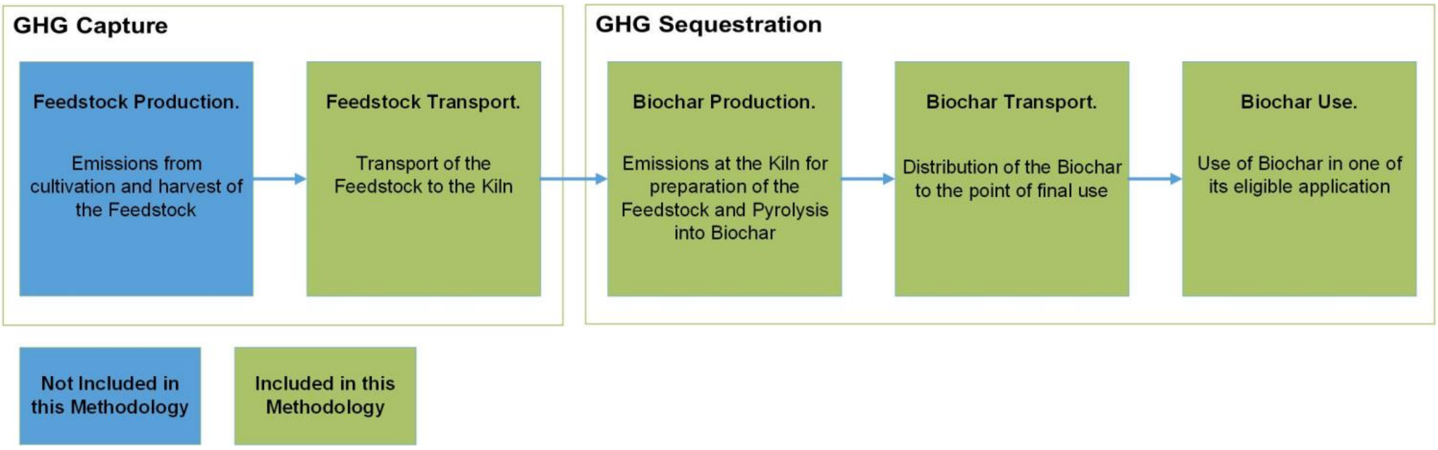

Figure 2. System Boundaries for life cycle assessment of a biochar activity within this Methodology.

This Methodology seeks to quantify the Certifiable Quantity and carbon content of Biochar produced by the Facility, considering GHG emissions arising from the process to calculate the eligible volume of Certificates to be Issued for the Facility. These emissions and the rules around inclusion in the volume of Certificates to be issued are defined in Table 7, and further detailed in 11.9. When emissions are defined in Table 7 as to be included, direct metering, standard LCA methods or relevant data from scientific literature must be applied to the quantification of those emissions (this does not mean a full LCA of the Biochar production activity must be provided).

The default baseline emission scenario for the project activity is zero, which is not taking into account methane emissions derived from decay of manure or combustion of waste biomass.

Table 7. List of potential emissions of GHG from Facilities registered against this Methodology.

Emissions Type	Type of GHG	Inclusion	Justification
Feedstock production	$CO_2/CH_4/N_2O$	Excluded.	Waste biomass is considered renewable as per eligibility conditions. Purpose grown crops are ineligible, hence there are no emissions from feedstock production. Appendix 11.9.
Feedstock transport	$CO_2/CH_4/N_2O$	Included. Excluded is distance < 200 km.	Direct metering or standard LCA methods must be applied to determine transport emissions. Considered negligible if less than 200 kilometres between the sourcing sites and the Kilns. Appendix 11.9.2.
Combustion and decomposition of Feedstocks	$CO_2/CH_4/N_2O$	Excluded.	Possible emissions from decay or combustion of biomass in the absence of project activity are excluded. Baseline emissions are assumed to be zero.
CO_2 release from pyrolysis	CO_2	Excluded.	Because the CO_2 released during biochar production has been recently captured from the atmosphere and stored in plant tissues through photosynthesis, biomass is considered carbon neutral. Appendix 11.9.3.
Methane release from Pyrolysis.	CH_4	Included. Default value of 60g CH_4/kg Biochar.	In eligible Kilns, 60g CH_4/kg Biochar is conservatively proposed (Cornelissen, et al., 2016) unless evidence of measured emissions applicable to the Facility. Appendix 11.9.3.
Soot release during Pyrolysis.	Other	Included. Excluded for Flame Curtain/ TLUD Kilns.	The total soot emissions of Flame Curtain Kilns and TLUD are significantly lower emitting than other cooking stoves commonly used and considered negligible further in this Methodology. For other Kiln designs (including retort and gasifier Kilns) soot emissions shall be determined at Facility Audit through standard LCA methods, direct metering or scientific literature relevant to the conditions observed at the Facility (i.e. Kiln design and Supply envelope). Appendix 11.9.3.
Electricity and/or fossil fuels consumed during Pyrolysis	CO_2	Included.	Included if the emissions are associated directly with the project activity. These emissions can be considered negligeable if renewable energy use is evidenced through the redemption of electricity product Certificate Accredited under the International Attribute Tracking Standard or another tracking scheme approved by the relevant national authorities. Appendix 11.9.6.
Biochar transport	$CO_2/CH_4/N_2O$	Included.	Direct metering or standard LCA methods must be applied to determine transport emissions.

		Excluded is distance < 200 km.	Considered negligible if less than 200 kilometres between the utilisation sites and the Kilns. Appendix 11.9.2.
Pre-treatment of feedstocks	CO_2	Included.	Emissions associated directly to project activity and need to be part of the emissions inventory. Appendix 11.9.4.
Biochar application	CO_2	Included.	Emissions associated directly to project activity and need to be part of the emissions inventory. Appendix 11.9.4.
Operator Transport	CO_2	Excluded.	Local operators trained, minimising skilled operator transport requirements.
Production of steel sheet, welding etc	CO_2	Excluded.	Purpose-built equipment and facilities shall be included if they are solely built for CDR purposes. In that case, they are built mainly for the purpose of Biochar production for utilisation and associated benefits, not only for CDR purposes. Appendix 11.9.7.
Manufacturing and disposal of the processing equipment	CO_2	Excluded.	Purpose-built equipment and facilities shall be included if they are solely built for CDR purposes. In that case, they are built mainly for the purpose of Biochar production for utilisation and associated benefits, not only for CDR purposes. Appendix 11.9.7.

5.3 Certificate Issuance

The effective total Certificates eligible from the process is calculated by subtracting the emissions from the long-term storage of carbon in the Biochar over a 100-year horizon (Cornelissen, et al., 2016). It can be expressed as:

$$V_{Issued} = Q_{Biochar} \times (C_{S.CO2eq} - E_{Facility})$$

Where:

- ***V_{Issued}***: *Volume of Certificates to be Issued at the Facility [tonnes of CO_{2eq}].*
- ***$Q_{Biochar}$***: *Amount of Biochar produced at the Facility [tonnes of Biochar].*
- ***$C_{S.CO2eq}$***: *the amount of GHG durably sequestered into the Biochar over a 100-year time horizon [tonnes of CO_{2eq} / tonne of Biochar].*
- ***$E_{Facility}$***: *Emissions of the Facility per tonne of Biochar, as defined in section 5.2 [tonnes of CO_{2eq} / tonne of Biochar].*

5.4 Facility Capacity

The Facility Capacity shall be defined at Facility Audit as the maximum expected Biochar production over a 1-year period. A Facility cannot request Issuance of Certificates for more than the amount of Biochar defined by the yearly Capacity verified by the Issuer.

The yearly Capacity of the Facility must be defined as the lowest value between:

- the maximum aggregated Kilns Capacity (as described in section 5.4.1); and
- the availability of the specific Supply Envelope defined at the Facility Audit (as described in section 5.4.2).

The Capacity may be updated from time to time provided that the Issuer approves that change and satisfy itself the newly submitted Capacity provides a more realistic estimate of the maximum yearly Biochar production at the Facility consistent with the constraints on Supply Envelope and Biochar utilisations.

5.4.1 Maximum Aggregated Kilns Capacity

Unless clear operating evidence can be shown to exceed the typical Feedstock processing rate or the number of days a Kiln is operated in a year, the maximum aggregated Kilns Capacity (expressed in tonnes of CO_{2eq}) is calculated using the following formula:

$$Capacity = 0.400 \times 365 \times P_{Conversion} \times Q_{Kilns}$$

Where:

- *Capacity: maximum aggregated Kilns Capacity [tonnes of Biochar];*
- *0.400 tonnes (400 kg) dry matter being the maximum amount of Feedstock that can be realistically processed in a single day, per Kiln [tonnes of Feedstock / day];*
- *365 being the number of days in a year a Kiln could realistically be run for;*
- $P_{Conversion}$*: Efficiency of the conversion of Feedstock into Biochar by the Kiln in the specific conditions described at the Facility [tonnes of Biochar / tonnes of Feedstock];*
- Q_{Kilns}*: Number of Kilns aggregated as part of the Facility.*

5.4.2 Feedstock Availability

In some cases, the yearly Capacity of the Facility can be limited by the amount of biomass eligible as part of Supply Envelope available in the region. The Situation Analysis (section 8.3.2) must determine the maximum supply of Feedstock appropriate to a given Supply Envelope.

To avoid the use of non-eligible Feedstock and prevent potential damage to the local ecosystem or community, a Facility cannot Issue Certificates for amounts of Biochar above that achievable within a defined Supply Envelope as defined by the Situation Analysis. An estimate of the quantity of Feedstock from the Supply Envelope accessible within a distance under 500 km of the Facility for the whole Audit Period must be calculated and provided as part of the Facility Audit.

6. ESG (Environmental, Social, Governance) Risks and Mitigation

Description of Risk	Likelihood	Impact	Mitigation Actions
Biomass removed as a Feedstock to make Biochar when it would be better left in situ for agronomic or other environmental reasons	Low	Low	Throughput of Feedstock monitored against estimated Supply Envelope from initial site Facility Audit and environmental assessment. The Issuer will appoint a Verification Authority to investigate if this Capacity is significantly exceeded.
Injury to operator from contact with hot surfaces	Low	Medium	A curtain wall should exist and provide a barrier between the operator and the potentially hot inner Kiln walls. Suitable gloves must be provided, and their use included in the Operating Guidelines.
Injury to operator from inhalation of smoke	Low	Medium	Operating Guidelines should warn the operator of the risks and advise to restrict the frequency of approaching the vicinity of the Kiln to loading operations only.
Operator deliberately loads the Kiln with non-approved materials in an attempt to claim greater Biochar production Certificates	Medium	High	The unique fingerprint of temperature and weight time-profiles is associated with approved operations. Deviations from this will be detected from the daily data download, prompting investigation by a Verification Authority with the potential sanction of withdrawing permits to operate from the registration system. A mass balance between Feedstocks/Biochar production determinable from the Kiln data collection and Situation Analysis will identify anomalous throughputs that signal the potential of illegal logging. GPS data corresponding to the Kiln locations will alert the need to study satellite images of tree cover change in the vicinity. The Issuer will appoint a Verification Authority to investigate if this Capacity defined by the Situation Analysis is exceeded.
Operator attempts to generate fake operating data	Low	High	The data is collected from the sensors automatically at pre-determined time intervals which cannot be determined externally by the Operator. The validated data profile falls within a Carbon Performance Prediction Model and a defined Capacity, and excursion outside this automatically signals a concern requiring investigation by the Verification Authority.
Change of land use resulting in competition with local food security	Low	Low	As noted under above, the physical scale of the Kilns and their standard operating conditions limits Capacity, which is related to the Supply Envelope of each registered Facility. The eligible list of Feedstocks approved as part of this Methodology does not incentivise a change of land use resulting from Kiln operations.
The Kiln is not used in the location corresponding to the biomass Supply Envelope relating to a specific situation from which data will be aggregated	Low	Low	All digital data is labelled with the unique electronic tag of the data capture box, and its GPS location at the place and time of data synchronisation. Any deviations from the initially agreed location will be immediately evident. Locational anomalies signalled by the GPS will signal an Issue of concern and will invalidate claims to be making Biochar that can be included in the aggregated results. Justification and validation by a Verification Authority will be required to establish future validity.
Distributed Biochar production as a carbon removal mechanism is inappropriately claimed by local or national governments as evidence.	Low	Low	The aggregation of data from multiple distributed Biochar Kilns will be restricted to distinct Facilities. Each of which is bounded by national boundaries based upon common fiscal as well as political conditions. Aggregated data will be associated with relevant geographical metadata that can be uniquely related to specific political/fiscal situations, in a fully traceable manner.

7. Additionality

The Facility must be able to demonstrate additionality, meaning that the project must convincingly demonstrate that the CDR activity and Issuance of Certificate are a result of carbon finance and is not required by existing laws.

The inclusion of the sensors and DB within the Kiln is entirely for the purpose of capturing, aggregating and certifying data from distributed Biochar Kilns. The extra financial support available from the sale of carbon credits is an essential element to cover the cost of:

- Supplying and maintaining the sensors and DB;
- Communicating, analysing and storing the data;
- Validation sufficient to support the certification of the CDR activity;
- Taking Certificates to the carbon market;
- Getting Kilns on the grounds in potentially remote locations;
- Training the local Operators to produce Biochar using the Kilns; and
- Remunerate the Operators for running the Kilns.

A direct consequence of the additional nature of this activity is to further incentivise the uptake of Biochar generation to a scale that can deliver a certifiable and materially significant benefit as a CDR mechanism, accessible to a wide range of small-scale agricultural and forestry-based operations that would otherwise be excluded from participating and contributing for financial reasons.

All projects eligible for Issuance of Certificates under this Methodology must evidence additionality based on the following conditions:

- Absence of legally binding obligation for an Operator to perform its Biochar production activity (section 7.1); and
- Activity Penetration of Biochar production activity from the processing of biomass waste as set in section 7.2, or using a bespoke method evidencing that the project is facing one or more financial barrier to deployment (this could include, for example, a counterfactual analysis of the project financials). Acceptance of a bespoke method of evidencing barrier to implementation is at the full discretion of the Issuer.

7.1 Legally Binding Obligation

The Registrant must demonstrate that the Biochar production activity performed by the Facility is not required by existing laws, regulations, or other binding obligations. Therefore, the production of Biochar from the biomass waste must not be mandated or legally required by the relevant authorities.

7.2 Activity Penetration

This Methodology uses a standardised approach for the demonstration of additionality, by pre-determining additionality for given classes of project activities based on the penetration of the activity in the relevant region.

All Facilities registered under this Methodology are required to produce Biochar from a Feedstock defined as Biogenic waste (such as agricultural waste, biodegradable waste, urban wood waste or food waste) or invasive species. In countries where less than 5% of the eligible Feedstock defined in section 2.3 is processed to produce Biochar, it is deemed that this activity is facing significant economic barriers to entry and need the support of a carbon crediting method. Therefore, such projects are considered additional. To meet the activity penetration additionality requirement, the Registrant must demonstrate that the activity penetration of Pyrolysis of Biogenic wastes to produce Biochar is below 5%.

Alternatively, if Biochar production and utilisation from Biogenic waste has been commercially available the applicable country for less than three years, it is considered that the project activity faces barriers to its uptake, and this requirement would be met.

The Foundation may reassess the required activity penetration threshold (currently set at 5%) within three years of the initial approval of the Methodology. At that time, the Foundation will base its assessment on national boundaries, focusing on countries where Biochar made from waste biomass has been used. Also, where sub-national regulations or policies may impact the likelihood of the project activity being implemented, the Foundation may use such boundaries as the basis of the reassessment of the activity level of penetration.

8. Monitoring, Reporting and Verification (MRV)

MRV is the multi-step process to measure the net CDR activity achieved by a Facility, report the findings to an accredited third party, and verify the activity so Certificates can be Issued.

8.1 Process Summary

The digital MRV process described in this Methodology requires a Data Management System audited and approved by a Verification Authority as compliant with this Methodology. This Data Management System is operated by the Data Management Provider, who may be the Registrant, or a third-party provider contracted to the Registrant.

The process starts with the need for a Facility Audit and calibration of the MRV system approved by a Verification Authority and the Issuer. This is followed by recurring production data aggregation verified by the Issuer. This increases the speed of validation and verification while reducing the overall cost of generating mitigation outcomes and incentivizing the use of digital technologies.

Weight and temperature data from each Kiln is captured remotely in real time to provide a time- and date-stamped digital record of individual batch operations that reflects critical quality and quantity parameters. Data is stored digitally and may be downloaded to a central data repository. Upon downloading, additional metadata, comprising the Kiln GPS location and unique electronic ID of the data capture device are attached to the datafile to provide a unique and traceable record of operations. Data must be stored on a central repository by the Data Management System for subsequent audits. The integrity of the datafiles uploaded is protected via the incorporation of data encryption linked to each individual databox. Subsequent analysis of individual datasets from each batch operation provides a mechanism to validate the quality of the operation or to identify anomalous behaviours that will require remedial action and potentially to require local inspection of a facility and its means of operation. The MRV process observed, along with the roles and responsibilities of actors described in this Methodology, can be summarised as in Table 8.

In Table 8: step 1) refer to the Data Management System Audit, described in section 8.2; steps 2) to 6) refer to the Facility set up and audit which requirements are defined in section 8.3; steps 7) to 10) refer to the production digital MRV protocol as defined in sections 8.4, 8.5, 8.6 and summarized in Figure 4.

Table 8. MRV Process summary, including roles and responsibilities.

MRV Step	Roles	Frequency	Comments	*Indicative timeline*
1) Data Management Provider audit and approval	Verification Authority	Annually	Performed on a Data Management Provider providing a Data Management System who may be used by multiple Facilities and Registrants.	
2) Initial Facility setup	Registrant	Once	Must include: a) successful completion of Operator training; b) definition of the Supply Envelope and performance of the Situation Analysis; c) aggregation of Kilns within a Facility; and d) standard operating system and CPPM calibration.	*A few months (depending on project developer and Data Management System)*
3) Provision of data to the Verification Authority for approval	Registrant	At each Facility Audit (max every 3 years, earlier if changes are requested to Facility by the Registrant)	Data relating to eligibility conditions, emissions, MRV protocol and Data Management System as defined in section 8.3.4.	
4) Pre-approval of Facility data not verifiable by the Issuer	Verification Authority		Under normal circumstances, this approval will not require local verification and data can be verified remotely.	*1-2 months (depending on the Registrant and Verification Authority)*
5) Provision of full Facility Audit data and evidence to the Issuer	Registrant		This must include the full extent of the Facility data, Audit Report and the required evidence as defined in sections 8.3.5 and 8.3.6.	
6) Facility verification and approval	Issuer		Remote verification. If needed, the Issuer may request on-site audit by the Verification Authority.	*A few weeks (once all data and evidence are provided to the Issuer)*
7) Biochar Production data submission	Operator	Variable	Kiln run with Feedstocks within the defined Supply Envelope, following the operating guidelines. Data automatically collected from sets of operations of the Kiln(s) submitted to the Data Management System for analysis.	
8) Aggregation, processing, and analysis of data	Data Management Provider	Variable	Performed at the Facility level through the Data Management System.	
9) Submission of Biochar production data to the Issuer	Registrant	Variable	Data and evidence submitted along with the eligible volume of Certificates to be Issued, through a process called Issue Request.	
10) Verification and Issuance of Certificates	Issuer	Variable	Once the data is verified against the proof of production and utilisation, Certificates are issued on the Registry.	*Up to 10 days (once all data and evidence are provided to the Issuer)*

8.2 Data Management System

The digital MRV process described in this Methodology requires a Data Management System including, among other, Databoxes, Sensors, a CDA system, algorithms and a Data Export App. It is operated by the Data Management Provider. The Registrant can operate its own Data Management System or may contract a third-party Data Management Provider.

8.2.1 Requirements

The Data Management Provider shall be audited annually and validated by a Verification Authority as providing a Data Management System compliant with this Methodology. The Verification Authority needs to satisfy itself that the Data Management System can provide reliable data for issuance of Certificates as defined under this Methodology.

Additionally, the following shall be verified and approved by the Verification Authority:

- The Verification Authority shall check that the Data Management System functions with reliable Carbon Performance Prediction Models (CPPM) to predict Carbon Stability and Certifiable Quantity. Each CPPM must be consistent with a pre-defined Supply Envelope. The Data Management Provider must be capable of developing and evidencing consistency of Carbon Performance Predictions Models (CPPM) as defined in section 8.2.2;
- The data gathered by the Data Management System must meet the consistency standards determined for Facilities within this Methodology, based on capturing at least the minimum set of data as set out in section 8.4 and reported as set out in section 8.5;
- The Registrant or third-party service provider operating the Data Management System must have existing systems in place to allow verification and audit of its database as set out in section 8.6;
- The Data Management System and storage shall be compliant with **BS ISO 15489-1:2016**;
- Raw data are to be archived and available for third-party inspection upon request by the Issuer or the Verification Authority;
- The Certifiable Quantity of the Biochar produced can be quantified and documented in a reliable manner using the Data Management System;

Data Management System and the data already processed through it (including relating to already Issued Certificates) must be audited by a Verification Authority on an annual basis, at the minimum.

8.2.2 Carbon Performance Prediction Models

The Carbon Stability and the Certifiable Quantity of Biochar produced by a Kiln are determined relative to a 100-year time horizon. This is related to the rate of Feedstock loading, the rate of mass decrease, the Kiln metered temperature profiles during the Pyrolysis process, and the duration of process. Such relationship between metered data, Carbon Stability and Certifiable Quantity of Biochar produced at the Facility are defined by Carbon Performance Prediction Models (CPPM). A CPPM must be defined and calibrated specifically for a defined Supply Envelope, Biochar production Kiln design and set of operating conditions.

Validation of such CPPM shall be determined through independent laboratory analysis of the H/C_{org} ratio of Biochar samples taken from multiple operations (minimum 3 samples). A CPPM must establish an initial laboratory-based technical analysis process to calibrate the sensors with a CPPM based on criteria derived from scientific literature.

The CPPM must be calibrated by means of cross-referencing load cell readings to the physical addition of standard weights to the Kiln. This calibration shall include on-site measurement of the Feedstock and resulting Biochar weights on a dry mass basis. Moisture content, using a moisture meter, or determined by weighing samples of feedstock and biochar before and after oven drying, must also be carried out to establish the corresponding dry mass contents.

Calibration of a CPPM is deemed sufficient if the measured Feedstock and resulting Biochar weights can be replicated via predictions derived from the analysis of uploaded data from a minimum of 20 separate batch operations (or the equivalent daily performance over 20 days of a continuous operation). The basis for determining consistency and the flags that would signal anomalous behaviours and potentially invalid operations may be established on a Facility basis and reported following the calibration period as the basis for onward auditing.

A CPPM shall evidence the performance of periodic (at least every three years) analysis of the remotely captured performance data by a Verification Authority. Permitting the consistency of the process with the validated samples to be determined via aggregation, and thereby to determine the stability of the Biochar carbon from aggregated Kiln operations on a statistical basis. Over time, the application of data analysis and local validation events will permit CPPM to be refined with increasing confidence for a specific operational setup, permitting the data acceptance/exclusion process to become increasingly automated and reducing dependence upon local validation events.

Each CPPM shall be approved by a Verification Authority as a reliable method to quantify Biochar Certifiable Quantity and Carbon Stability.

8.3 Facility Audit

The Registrant must provide the Verification Authority and the Issuer with the elements defined in, respectively sections 8.3.4 and 8.3.5. The overall Facility Audit and Data Management System approval process is illustrated in Figure 3.

8.3.1 Sample Proof of Biochar Production and Utilisation

The Verification Authority shall check that the Facility is capable of metering and quantifying the Biochar output in a reliable manner, using a validated Carbon Performance Prediction Model (CPPM) and as defined in section 8.4.

A sample of the expected evidence of Biochar Certifiable Quantity and Carbon Stability extracted from the Data Management System must be approved by the Verification Authority. The Verification Authority shall satisfy itself of a proof of quantity following such format provides a reliable quantification of Biochar Certifiable Quantity and Carbon Stability. Any request of Issuance of Certificates for that Facility must then follow the format of the sample validated by the Verification Authority. The sample proof of production of the Biochar must be in line with section 8.5.1.

Equally, a sample of the expected evidence of Biochar utilisation must be submitted along with the Audit Report. The sample proof of utilisation must be approved by the Issuer. The

Issuer needs to satisfy itself that the proof of end-use provides sufficient confidence that the Biochar will effectively be used as described in section 2.5. The sample proof of utilisation of the Biochar must be in line with section 8.5.3.

8.3.2 Situation analysis

Each location and Supply Envelope must be subject to a Situation Analysis, which may impact the eligibility and Capacity of the Facility.

For each Facility, a Situation Analysis shall be performed and included in the Facility Audit. A Situation Analysis comprises the assessment of a proposed Facility using a given biomass Supply Envelope to establish the expected Certifiable Quantity of Biochar production that may be achieved over the Audit Period. This provides an initial criterion for validating the maximum annual Capacity sustainably achievable by a defined Facility and Supply Envelope.

The Situation Analysis must be approved by the Issuer.

8.3.3 Audit Period

An Audit Period is a period of time during which the CDR activity by a Facility is eligible for Certificates Issuance. A valid Audit Period of a Facility must:

- Start on the first day of a calendar month;
- End on the last day of a calendar month.

The Audit Period of a Facility Audit must be of three years under this Methodology, after which a new Facility Audit must be performed. A new Audit may be performed before the end of that period would changes were to occur at the Facility level (e.g. if more Kilns are added to the aggregated Facility).

8.3.4 Verification Authority Approval

The Verification Authority must satisfy itself that the Facility is able to demonstrate the following:

1) Eligibility of the Biochar production and use activity as defined in section 2. This includes validation of the eligibility of all of the elements defined in section 2.
2) Quantification of Facility emissions defined in section 5.2 (when applicable);
3) The Biochar sample proof of production provided by the Registrant, as defined in section 8.3.1, provide sufficient confidence over the Certifiable Quantity and Carbon Stability;
4) All requirements set in sections 8.4 and 8.5 are in place. Relevant models and equipment are calibrated;
5) The Carbon Performance Prediction Model (CPPM) to be used at the Facility allows a statistically accurate determination of the record of a Certifiable Quantity and confidence that the produced Biochar reaches the Carbon Stability requested for the Facility;

The Verification Authority need to satisfy itself that all of the information it is provided and listed above with is a true reflection of reality at the time of Audit.

Table 9. Data to be Verified by the Verification Authority.

Data/Parameter	Unit	Description	Determination Method
$E_{Transport, F}$	Tonnes of CO_{2eq} / tonne of Biochar	The Feedstock transport emissions from the point of production to the Kilns.	Only applicable when transport over a distance > 200 km. Section 11.9.2.
$E_{Transport, B}$	Tonnes of CO_{2eq} / tonne of Biochar	The Biochar transport emissions from the Kiln to the point of Biochar Utilisation.	Only applicable when transport over a distance > 200 km. Section 11.9.5.
E_{CH4}	Tonnes of CO_{2eq} / tonne of Biochar	The Methane emissions resulting from the production of Biochar.	Defined as a default value of 60 $g_{CH4}/kg_{Biochar}$ unless appropriate evidence of a lower emission factor is provided. Section 11.9.3.
$E_{Processing}$	Tonnes of CO_{2eq} / tonne of Biochar	The emissions from pre-treatment of Feedstock and Biochar processing operations.	If applicable. Section 11.9.4.
E_{Energy}	Tonnes of CO_{2eq} / Tonne of Biochar	The emissions from any external energy use relative to the Kiln operation.	If applicable. Section 11.9.6.
$E_{Utilisation}$	Tonnes of CO_{2eq} / tonne of Biochar	The emissions from the utilisation of the Biochar after production	If applicable. Section 11.9.8.

8.3.5 Issuer Approval

The Issuer must satisfy itself that the Facility is able to demonstrate the following:

1) Eligibility of the Biochar production and use activity as defined in section 2. This includes validation of the eligibility of all of the elements defined in section 2.
2) Achievement of Biochar stability requirements as defined in section 3;
3) Quantification of the Expected Effect as defined in section 4.2;
4) Quantification of facility emissions defined in section 5.2;
5) Quantification of the organic carbon content of the Biochar as defined in section 5;
6) Implementation of environmental and Social Safeguards defined in section 6;
7) The additionality minimal requirements as set in section 7 are met;
8) Implementation of the Monitoring, Reporting and Verification (MRV) protocols as defined in section 8;
9) The Facility is monitored through a Data Management System approved by a Verification Authority (section 8.2);
10) The Certifiable Quantity of the Biochar produced and utilised is quantified and documented in a reliable manner; and
11) The elements defined in section 8.3.4 have been audited and validated by a Verification Authority.

The Issuer need to satisfy itself that all of the information provided in the Audit Report are a true reflection of reality at the time of Audit.

Table 10. Data to be approved by the Issuer.

Data/Parameter	Unit	Description	Determination Method
C_{Org}	Percent (%)	The organic carbon content of the Biochar produced. It is expressed in dry weight of organic carbon over dry weight of Biochar.	Determined by laboratory analyses of the Biochar produced, with a representative sampling methodology. Needs to be evidenced by providing the full laboratory results to the Issuer. Laboratory analyses are only needed once, at Facility Audit, using a representative sample analysis (minimum 3 samples, each taken from a separate batch or operating day) and are considered valid for the whole Audit Period. Or using the default values provided in Table 6 (if Applicable).
H/C_{Org} ratio	Percent (%)	The ratio of hydrogen to organic carbon (H/C_{org})	Determined by laboratory analyses of the Biochar produced, with a representative sampling methodology. Needs to be evidenced by providing the full laboratory results to the Issuer. Laboratory analyses are only needed once, at Facility Audit, using a representative sample analysis (minimum 3 samples, each taken from a separate batch or operating day) and are considered valid for the whole Audit Period. Section 3.2.

$B_{Leakage}$	Percent (%)	A buffer applied to the Issuance of Certificate commensurate to the predictable reversal of CDR activity after the Biochar production over a 100-year period. This is linked to the Level of Carbon Stability of the Biochar.	Determined from the Pyrolysis temperatures observed in the Kiln during Biochar production in Table 3. The Verification Authority must satisfy itself that the temperature conditions measured by the sensors provide sufficient confidence the Pyrolysis temperature requirements from Table 3 are met. At the Facility Audit, the Verification Authority must also ensure that H/C_{Org} ratio of the Biochar produced at the Facility is low enough to ensure the minimum level of Carbon Stability relating to the described Leakage Buffer.
$C_{S.CO2eq}$	Tonnes of CO_{2eq} / tonne of Biochar	The stable carbon content over a 100-year period of the Biochar expressed in CO_{2eq}.	Equation in section 5.1. Derived from the Leakage Buffer ($B_{Leakage}$) and the Organic Carbon Content (C_{Org}).
$E_{Transport, F}$	Tonnes of CO_{2eq} / tonne of Biochar	The Feedstock transport emissions from the point of production to the Kilns.	Verified by Verification Authority. Only applicable when transport over a distance > 200 km. Section 11.9.2.
$E_{Transport, B}$	Tonnes of CO_{2eq} / tonne of Biochar	The Biochar transport emissions from the Kiln to the point of Biochar Utilisation.	Verified by Verification Authority. Only applicable when transport over a distance > 200 km. Section 11.9.5.
E_{CH4}	Tonnes of CO_{2eq} / tonne of Biochar	The Methane emissions resulting from the production of Biochar.	Verified by Verification Authority. Defined as a default value of 60 $g_{CH4}/kg_{Biochar}$ unless appropriate evidence of a lower emission factor is provided. Section 11.9.3.
$E_{Processing}$	Tonnes of CO_{2eq} / tonne of Biochar	The emissions from pre-treatment of Feedstock and Biochar processing operations.	Verified by Verification Authority. If applicable. Section 11.9.4.
E_{Energy}	Tonnes of CO_{2eq} / Tonne of Biochar	The emissions from any external energy use relative to the Kiln operation.	Verified by Verification Authority. If applicable. Section 11.9.6.
$E_{Utilisation}$	Tonnes of CO_{2eq} / tonne of Biochar	The emissions from the utilisation of the Biochar after production	Verified by Verification Authority. If applicable. Section 11.9.8.
EE	Percent (%)	Expected Effect defined as the probability for CDR activity to achieve durable Sequestration for 100 years without an EOCD.	Using the tool provided in section 4.2. The Issuer may request additional evidence and verification by the Verification Authority if needed.
Capacity	Tonnes of Biochar / year	The Facility Capacity defined as the maximum expected Biochar production over a 1-year period.	Minimum between: a) the maximum aggregated Kilns Capacity (as described in section 5.4.1); and b) the availability of the specific Feedstock envelope defined at the Facility Audit (as described in section 5.4.2).

8.3.6 Audit Reports Requirements

The Issuer must satisfy itself of the veracity of all data provided as part of the Audit Report. The Audit Report for a Facility Audit under this Methodology must include, at a minimum:

- The name of the Facility;
- The physical location of all the Kilns included within the Facility;
- The name of the Registrant;
- The name of this Methodology;
- Unedited project photos;
- The Audit Period defined in line with section 8.3.3;
- The specific Supply Envelope for eligible for Biochar production at the Facility. This must include a description of the type of Feedstock used at the Facility, in line with section 6.4;
- A complete Situation Analysis;
- The yearly Biochar production Capacity of the Facility;
- The sample proof of Biochar production as defined the section 8.3.1;
- A description of the type of Biochar utilisation and a sample proof of utilisation as defined in section 8.3.1;
- A definition of the H/C_{Org} ratio (when applicable) and Organic Carbon Content, in line with this Methodology. Laboratory results with name and seal (or signature) of the laboratory must be provided along with the Audit Report;
- Calculation details of the Facility’s Leakage buffer as defined in section 3;
- Calculation details of the Facility’s Environmental Effect as defined in section 4.2;
- Determination details of the Facility’s Capacity as defined in section 5.4;
- A description and documentation relating to the mitigation actions in place to manage risks of EOCD identified and highlighted in the Methodology, as defined in section 4.1;
- Calculation details of the applicable Emissions defined in section 5.2, providing a realistic assessment of the Facility’s Emissions per tonne of Biochar produced;
- A description of the mitigation actions for any environmental and/or social risks identified and highlighted in the Methodology, as defined in section 6;
- The detailed description of the specific data capture device(s) used to monitor Biochar production at the Facility, including all the details defined in section 8.4.1; and
- The details of the Carbon Performance Prediction Model (CPPM) to be used to quantify Biochar Certifiable Quantity and Carbon Stability.

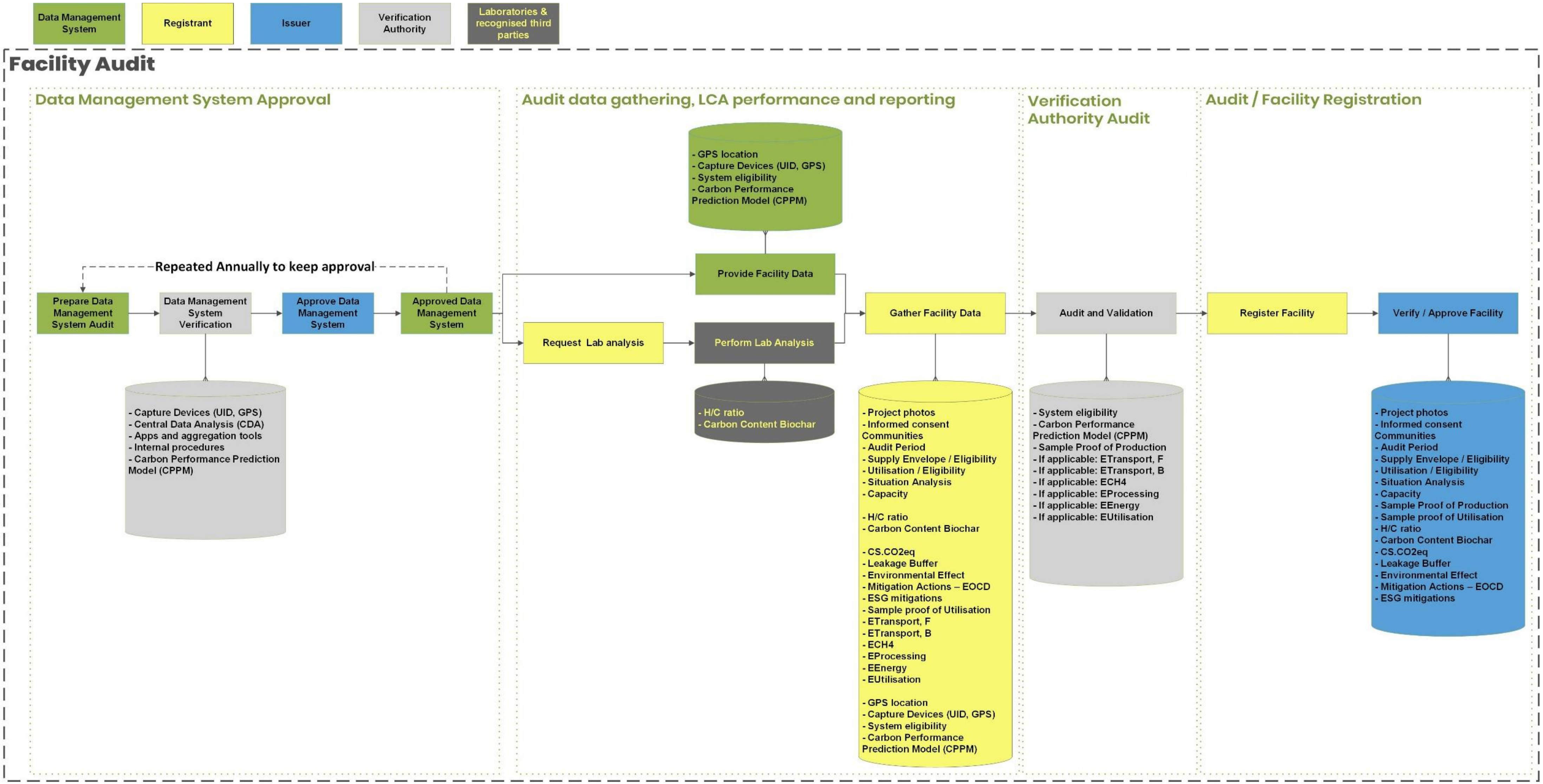

Figure 3. Illustration of the Facility Audit Process and associated data / verification requirements.

8.4 Monitoring

8.4.1 Standard Operating System Parametrisation

The following operating system parametrisation shall be respected by all Facilities operating under this Methodology.

1) Initial setup and successful completion of Operator training.
2) Aggregation of Kilns within a Facility.
3) Initiation of a Situation Analysis by the Registrant, including:
   a) determination the locally applicable Feedstock Supply Envelope;
   b) determination of the relevant Facility Capacity depending on the number of Kilns and the Supply Envelope (section 5.4); and
   c) agreed mechanism for local and remote verification and validation.
4) A Carbon Stability Prediction Model (CPPM) to determine long-term stability of carbon within the Biochar relative to a 100-year time horizon must be selected. The CPPM shall be applicable to the defined Facility's Kiln design and Supply Envelope.
   When no applicable CPPM have been yet researched, developed and approved for the defined Supply Envelope, a new CPPM applicable to the Supply Envelope or local conditions must be developed as defined in section 8.2.2.
5) The H/C_{Org} ratio measured at the Facility is in line with the selected CPPM.
6) Calibration of the Facility is deemed sufficient if the temperature and weight profiles correspond to targets and falls within the defined CPPM for a minimum of 20 separate batch operations, or the equivalent daily performance over 20 days of a continuous operation (If above requirements are satisfied, Certificates may be Issued for these 20 operations).
7) For operations that replicate previously calibrated operations relating to comparable Supply Envelope, determine the target sensor data range within which operations will be validated and outside which operations will be invalidated.

8.4.2 Minimum Data Metering Equipment

All Kilns operating under this Methodology shall be equipped with the following data metering equipment:

- Temperature and weight Sensors sufficient to determine that the guidelines have been followed and thus able to determine the Certifiable Quantity and Carbon Stability of the Biochar produced from the Carbon Stability Prediction Models; and
- Databox (DB) comprising sensor data capture, storage and communication components.

Over the whole time of Kiln operation, the DB must be capable of gathering data relating to, at the minimum:

- Time and date;
- GPS location of the Kiln;
- Weight of Kiln content;
- Inside Kiln wall temperature of the top section of the Kiln;
- Inside Kiln wall temperature of the bottom section of the Kiln.

Signals from the sensors must be captured digitally into a uniquely identified datafile per batch operation, starting from when the Kiln is first lit and ending after it has cooled. The system must be able to store multiple datasets for individual Kilns, all of which can be downloaded together when required. The monitoring system must have the capacity to support operation when and where needed.

Adequate digital security protocols must exist before allowing access to the data via computer or mobile. Data extracted from the DB must be accessible only to authorised users via the combination of a physical key and password-protected data access either via a computer programme or app on a mobile phone. Each individual databox must have a unique electronic identifier. Each dataset must be tagged with a range of metadata including the electronic identifier, date and time and GPS location. Data must be encrypted.

In case any fault with the data metering equipment and or DB is identified by any party, Issuance of Certificates must be stopped for the affected Kilns until the Issuer can satisfy itself such fault is rectified, repaired or addressed.

An example of an eligible system is provided in Appendix 11.10.

8.4.3 Measurement Protocol

Data is stored in memory in the DB is downloaded and transmitted to the Central Data Analysis (CDA) system for analysis. Data can be transmitted via a Data Export App on a mobile phone. At the moment of download, the Data Export App must also captures:

- GPS coordinates through embedded GPS system; and
- Unique Kiln electronic identifier.

The combination of data is associated with a unique datafile tag and the encrypted datafile sent to the CDA system.

8.5 Reporting

8.5.1 Biochar Production Reporting

The reporting of the data gathered by the DB must follow the process below:

1) The Data Export App extracts weight and temperature data from each individual batch process operation gathered by the DB. Data from each Kiln is associated with a unique Kiln electronic identifier, date, time and GPS, that are also captured. Each batch datafile is assigned a unique datafile identifier.
2) The Data Export App uploads the entire stored database to the Central Data Analysis (CDA) system.
3) The Data Export App removes previously uploaded data from the DB, to avoid filling the onboard DB memory and removing the risk of double-counting datafiles.
4) All data in the CDA system is stored on a secured database for subsequent analysis.
5) The accumulation of data from multiple separate batch operations builds an increasingly robust Carbon Performance Prediction Model (CPPM) to signify valid operations conforming with the minimum level of Carbon Stability.

8.5.2 Data Aggregation

A CDA system must exist and be integrated in an approved Data Management System. The CDA system must be capable of gathering and analysing data collected from the Kiln operations, generating statistically framed determinations of total Certifiable Quantity and mean Carbon Stability from discrete sets of multiple Pyrolysis operations.

Aggregation of multiple datasets within a defined Supply Envelope determines the typical range of operations consistent with locally verified CPPM.

The minimum quantity of aggregated reported datafiles that may constitute a verifiable dataset eligible for Issuance of Certificates with statistical consistency is 20, which may be generated as Kilns x datafiles ≥ 20 *(2 Kilns x 10 datafiles each or 4 Kilns x 5 datafiles each)*. Results from a minimum number of batch runs (20) corresponding to a given Supply Envelope shall be aggregated by the CDA system.

Data from the DB shall be transmitted to the CDA system via the Data Export App for analysis and processing. Upon reception of the operation data, the CDA system will:

1) Match the weight increase and decrease data over the period of operation to the expected and reported Feedstock loading rates. This will ensure loading of Feedstock by the Operator is slow enough to ensure a good curtain-flame.
2) Ensure the gradual shift in mean Kiln wall temperatures from the lower to the upper thermocouple is consistent with the steady addition of biomass layers indicative of a curtain-flame operation.
3) Check that rates of weight loss are consistent with pyrolysis rates consistently observed for the Supply Envelope Pyrolysis operation.
4) Determine the time of occurrence and extent (added weight of water) of the water quench. The water quench indicates the end (and hence duration) of the process and permits rates of pyrolysis to be determined. The weight of Biochar is determined by subtracting an estimate of the un-pyrolyzed biomass from the final dry weight.
5) Feedstock added towards the end of the operation will have had less time to experience a full period of slow pyrolysis than material added earlier. This effect is compensated for during the data analysis and validation stage by removing the contribution from Feedstock added within 30 minutes of the operation to the final Biochar determination.
6) Validate each datafile using algorithms developed to track the anticipated temperature/weight/time profile relating to the Pyrolysis process. Consistency with anticipated profiles signals datafile validation and acceptance. Anomalous profiles must result in exclusion of the data by default.
7) Aggregate multiple validated datasets from different operations of each Kiln included in the Facility.
8) Aggregate validated results from a Facility from a minimum number of batch runs (20 or more) to deliver to the Issuer a statistically representative estimation of a Record of a Certifiable Quantity, for certification and entry of Certificates into the Registry.

8.5.3 Biochar Utilisation

The proof of utilisation of the Biochar may be provided in one of the following format:

a) Extract from a mobile or desktop applications tracking records of GPS location coordinates, or any other tracking software that allows for chain of custody record generation from Biochar production to the utilisation of Biochar in soils (this could include, for example, the use of QR code, blockchain technology or non-fungible token).
b) Photographic evidence with attached GPS and time stamps proving the Biochar has been sequestered in the direct vicinity of the place of production (I.e. within 200 km of the Kiln’s GPS location).
c) If none of a) or b) are available, an offtake agreement or documentation of the sale or shipment of the Biochar to an end user, indicating the intended use of the Biochar. The end-user must be deemed likely to use the Biochar in an eligible form by the Issuer.

A proof of utilisation of the Biochar in line with the sample provided in the Audit Report will be required along evidence of Biochar production at Certificate Issuance. If no proof of utilisation as defined in the Audit Report is available, an alternative piece of evidence may be accepted at the full discretion of the Issuer.

8.6 Verification

Datasets aggregated over time from multiple operations within a Facility will span a range of measurements reflecting the nature of the process. The verification of Biochar production and utilisation using this Methodology is based on a three-stage approach and is illustrated in Figure 4:

1) Data from Kilns operation is captured by the CDA system. This data must be saved on the CDA system and may be audited by the Verification Authority and Issuer at any time;
2) The Issuer verifies the adherence to standard operating conditions including temperature and weight profiles that correspond to targets and falls within the Facility definitions and Carbon Performance Prediction Model (CPPM);
3) On-site visits and sample analysis on periodic basis or as signalled by the Issuer by data falling outside the CPPM or of the Facility Capacity.

Data from each batch operation is determined to be valid if it falls within a pre-defined CPPM and Capacity, permitting a record of Certifiable Quantity of Biochar. Over time, the application of data analysis and local validation events will permit CPPM to be refined with increasing confidence for a specific operational setup, permitting the data acceptance/exclusion process to become increasingly automated and reducing dependence upon local validation events.

The Issuer must ensure that the evidence of Biochar production and utilisation provided at the point of Certificate Issuance is in line with the samples provided at Facility Audit (sections 8.3.1 and 8.5.3).

The Issuer must satisfy itself that the temperature and weight profiles provided fall within the CPPM defined at Facility Audit; and that the Certifiable Quantities and equivalent Carbon Stability determinations are correct. If the Issuer deems the submitted data to not appear consistent with the bulk of aggregated data or CPPM, it must be excluded from inclusion until local validation is carried out by a Verification Authority. In case the Issuer has reasons to believe any of the information provided to them is incorrect, it may require the Verification Authority audit either of:

- The Data Management System, the Registrant and, if applicable, the third-party Data Management Provider. This is likely to be a remote, digital audit; or
- At the Kiln and Operator level. This is likely to constitute a local on-site audit.

The Verification Authority must determine the origin of the anomaly and to ensure learnings are made and training given to the Operator. Data from further Kiln operation will not be accepted until guidance and further training has been carried out and the Operator is subsequently approved by the Verification Authority to be successful in establishing Kiln operation in conditions that ensure the Biochar's Carbon Stability. During the investigation, the Issuer must suspend Issuance of Certificates for the Facility.

At its full discretion and at any time, the Issuer may request an audit of any Biochar utilisation site documented for a Facility to investigate the continuity of Biochar sequestration. Such audit may be performed by a Verification Authority (if mandated by the Issuer) and may be performed onsite or remotely, depending on the utilisation site.

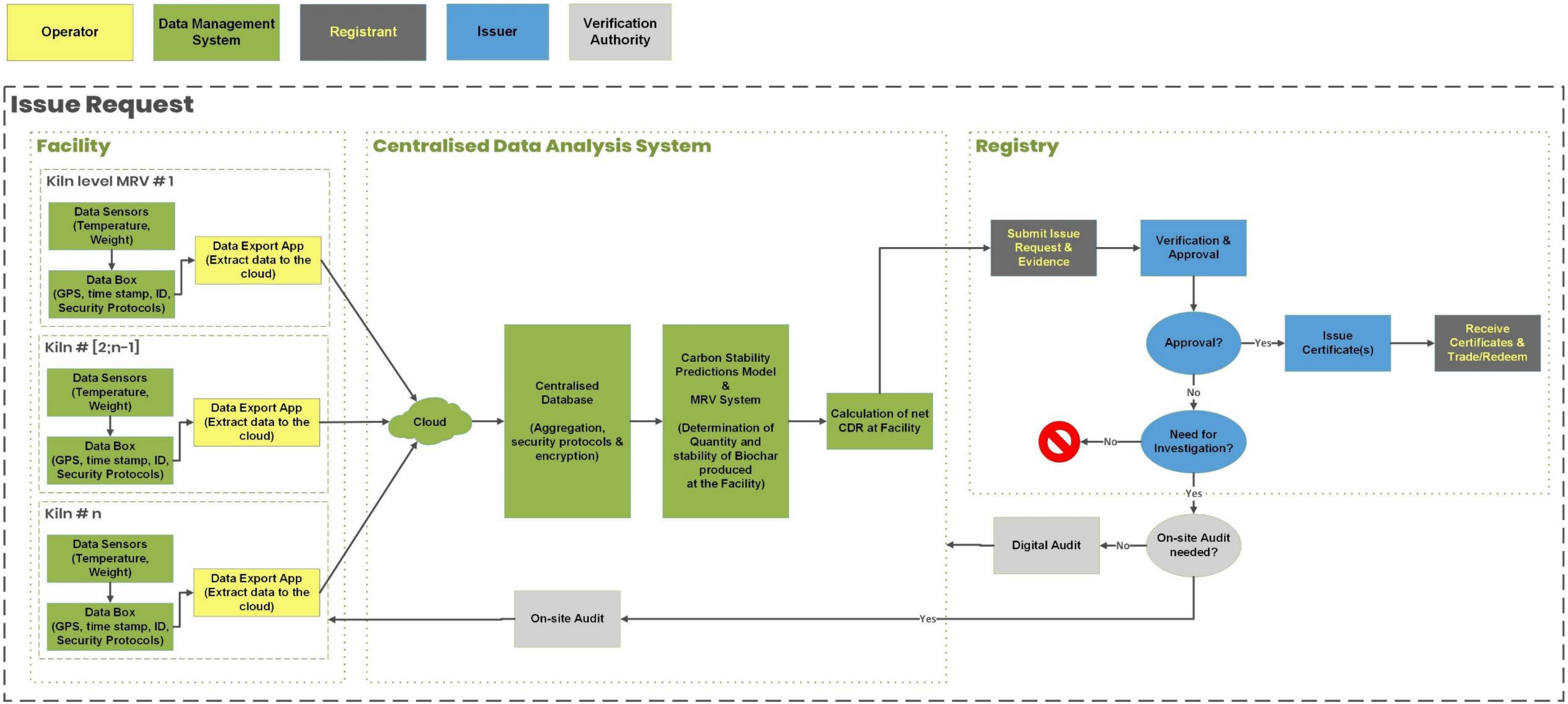

Figure 4. Illustration of the digital MRV protocol for Monitoring, Reporting and Verification of net CDR activity.

9. Approval

9.1 Data Management Providers

Any entity operating a Data Management System compliant with section 8, audited annually and approved by a Verification Authority can act as a Data Management Provider for Facilities under this Methodology (including Registrants). The entity below is an example of a Data Management Provider operating an eligible Data Management System but does not constitute an exhaustive list of authorised entities.

BionerG Ltd – has been proved to provide relevant services for operating a Data Management System, including application of CDA process associated with collection and validation of data from all Kilns, to be supplied upon demand to the Issuer as required for verification and certification.

9.2 Eligible Verification Authorities

Verification Authorities have to receive approval by the Foundation. Approval will be granted for entities able to evidence at least one of the following:

- Accreditation to the **ISO-14064** standard for GHG accounting and verification;
- Accreditation by the UNFCCC as Designated Operational Entities to operate under the Clean Development Mechanism (CDM);
- Accreditation by the CDP as an Accredited verification solution provider;
- Recognition by a relevant intergovernmental, governmental or local regulatory body as an authorised entity to perform GHG accounting and verification.

Alternatively, approval may be granted where the Foundation satisfy itself the entity can undoubtedly provide all the verification required as part of this Methodology.

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11. Appendices

11.1 Innovative and Open-Source Digital MRV protocol

This Methodology has been designed to allow Issuance of Certificates for highly distributed Biochar production systems. The associated remote Monitoring, Reporting and Verification (MRV) protocols allow Facilities to be located in potentially remote locations, where the positive social and environmental impacts of Biochar production and use are highest.

As such, the philosophy embedded in this Methodology is to provide a "bottom-up" approach to Methodology co-development, inviting multiple stakeholders to take part in making this process more and more robust and accessible.

11.2 Not all Kilns are Made Equal

Due to the distributed nature of the processes described in this Methodology, aspects such as Methane emissions control and other type emission are not consistently required to be metered as accurately as it would on a large-scale, high technology Biochar Facility. However, it is important to note that not all 'low-technology' Biochar technologies are the same, and that the net emissions savings derivable directly and indirectly from Biochar generated using the described Kiln system could be significant. To dismiss all 'low-technology' Kiln systems as 'not able to generate much (if any) emissions removals' not only over-simplifies the assessment, but in so doing inadvertently denies the opportunity to participate in carbon removal by smaller-scale, distributed systems as may be more suitable and affordable to farmers and smallholders in many parts of the developed and developing worlds, or, for example, to assist sustainable forestry operations for distributed in-situ charring of thinning or to reduce brash for fire-risk reduction purposes.

For these reasons, this Methodology focuses on providing route to market for low tech, affordable, transportable Kiln with proven high performance in terms of Biochar stability and Pyrolysis emissions.

Whilst the actual range of potential benefits that can be derived from so-called 'low-tech' Biochar production will differ from one situation to another, it is clear that judging the value of such technology should not be restricted to the pyrolysis operation in isolation, but should be taken in the broader contest of emissions and societal benefits that can only be realised if such low-cost, locally-operational systems are initially made available to those users for whom this may be the only affordable option.

11.3 Additional benefits

It is important to recognise that the carbon sequestration value of Biochar (in addition to societal benefits within poorer developing world societies) can be significantly greater than that arising just from the Pyrolysis process itself.

These potential benefits listed below are not included as part of the C-Capsule Certificates (C-Capsule only seek to certify measurable and durable CDR activity), it is reasonable to anticipate subsequent stacking of a subset of tailored climate-related and other environmental and societal benefits as the core Kiln technology described in this Methodology is rolled-out and optimised with local experience. This Methodology openly invites additional labelling schemes to assess and certify these added benefit to add labels the C-Capsule Certificates Issued for the Facility. This will provide a set of additional attributes to the Certificates, bringing more value to the Kiln Operators.

11.3.1 Added Environmental Benefits

This version of the Methodology relates only to the carbon sequestered within the Biochar relating to 100-year horizon. Complementary GHG benefits may accrue from effects stimulated by the Biochar. These are not captured in the current Methodology, but may be incorporated at a later stage, based upon ongoing research and data capture.

The quantity of CDR arising from the application of this methodology has the potential to be significantly greater long-term than that associated with the quantity of stable carbon within the biochar alone.

1) The waste biomass Feedstock will generally be in the form of some type of residue that might otherwise have been left to rot, with associated methane and CO_2 emissions.
2) When applied to agricultural soils, the total carbon sequestered over the 100-year horizon is not solely that remaining from the initial allocation of Biochar. Biochar stimulates microbial processes and helps retain moisture and nutrients in the rhizosphere of plants. Especially when applied to poorer, degraded soils, the total carbon stored in the soil may, over time, become substantially greater than that of the biochar itself. The result of applying Biochar to poor and degraded soils has the potential to generate more than double the amount of carbon increase in the soil within a decade, due to its support of microbial processes and effectively accelerated humification (Blanco-Canqui, et al., 2019).
3) Biochar has the potential to improve – potentially double – the effectiveness of fertilisers, composts and manures as soil improvers. The capacity to reduce the need for synthetic fertilisers to deliver equivalent plant yields (by 30% or more) can have a significant benefit on the overall carbon footprint associated with fertiliser use. Recent price hikes are making fertilisers even less affordable to many lower-income farmers, so this effectiveness uplift may confer significant economic benefits.
4) Whilst the uptake of nitrates by plants from nitrogen fertilisers is a broadly pH-neutral process, in the common case of over-application, the accumulation of H+ ions released during nitrification can result in increasing acidification over time (Guan, 2016). The generally alkaline nature of Biochar can have a significant 'liming' benefit: helping to neutralise such soils, improving plant growth and overall soil carbon quality.
5) Nitrous oxide emissions (with 100-year GWP x260 that of CO_2) as well as methane emissions (with 100-year GWP x27 that of CO_2) can be significantly reduced as a result of the incorporation of biochar with such treatments. Cayuela et al (Cayuela, et al., 2013) found that Biochar has a significant effect on denitrification, consistently decreasing N_2O emissions by 10% – 90% in 14 different agricultural soils, by facilitating the transfer of electrons to soil denitrifying microorganisms, in addition to its liming effect.
6) The incorporation of Biochar with synthetic fertilisers also reduces leaching and run-off and the damage to waterways of excessive run-off and eutrophication
7) There is some evidence that adding Biochar to ruminant feeds can not only improve livestock health but also reduce flatulence-related methane emissions. In any case, the presence of Biochar within their faeces during open grazing can assist its soil improvement qualities, due to its effect as a pH and nutrient-release regulator.
8) Biochar can help crop yields by typically at least 20%, improving above and below ground carbon stocks on a seasonal basis, and also in the long-term if the associated residues subsequently become Feedstocks for additional Biochar production (Agegnehu, et al., 2017).

Such effects can only be observed and quantified over a period of years, so in the absence of robust data relevant to the application scope covered within this methodology, cannot be added to the carbon value at the initial Issuance of the Certificates.

If robust data is subsequently captured to permit the quantification CDR activity arising from any such benefits, this may be included in determining future Certificates generated from within this methodology. It may also permit the Issuance of supplementary Certificates associated with Certificates Issued previously in cases where the accumulation of additional carbon storage arising from the initial application of the biochar can be established.

11.3.2 Social Benefits

The role of low-tech, affordable, Biochar production Kiln to help deliver social benefits, especially in the developing world, should not be overlooked when assessing the reasons to promote their use.

1) Biochar can significantly reduce the uptake of toxins such as heavy metals by plants and thereby into the food chain, especially from contaminated soils, or in urban farms where waste waters are used for irrigation.
2) Biochar is finding increasing value as a water-treatment medium, which can be used instead of more expensive and high-carbon footprint activated carbons, before being subsequently used as a valuable soil improver.
3) Biochar also has a potentially valuable role in compost toilets, with associated potential benefits in relation to odours, emissions and health.
4) The accessible nature of this Methodology and associated Kiln will permit the profits brought by CDR Certificates to directly benefit small holder farming in developing countries.

11.4 Methane emissions

The Kiln system uses the ‘flame-curtain’ system of pyrolysis. This has superior emissions performance to many simpler ‘low-technology’ Biochar systems. A detailed evaluation of the emissions from such systems by Cornelissen (Cornelissen, et al., 2016) has been carried out and concluded: “The Kon-Tiki flame curtain pyrolysis is a new type of low-cost biochar and charcoal production technology with pyrolysis gas combustion. It can easily be built and used by farmers both in the developed and developing world. It was shown that the quality of biochar produced from various feedstocks complies with international quality standards like IBI and EBC. Gas and aerosol emissions were very low compared to all other low cost and traditional charcoal and biochar production devices”.

Quantitatively, Cornelissen (Cornelissen, et al., 2016) found average CH_4 emissions to be about 30 g/kg of Biochar. Using the 100-year GWP x 27.2 (IPCC, 2022) would give an equivalent CO_{2e} g/kg value of 690g/kg. The average CO_2 emission factor for the Kon-Tiki is ~4300 g/kg of char. So, CH_4 emissions would account for roughly 19% of total Kon-Tiki emissions (including both CO_2 and CH_4 emissions), based on this analysis. Furthermore, this comparison is based upon a 100-year horizon. The biochar produced from Kon-Tiki (‘flame-curtain’) kilns can possess H/C_{org} ratios well below 0.4 and generally below 0.2, consistent with carbon stabilities over several hundred years, rendering the relative value of the Biochar carbon proportionately greater than that of the short-lived methane emissions arising from the pyrolysis event itself.

In practice the Kiln system described in this Methodology has been regularly found to operate at internal temperatures in the range 620ºC – 720ºC, and even higher. This is a direct result of the release of energy associated with the hydrogen fuel released from the more volatile components, and the way in which the energy and heat is largely retained within the pyrolysis region. This reduces the availability of hydrogen for methane production within the reaction zone. At these higher temperatures, any methane produced is significantly more likely to be pyrolyzed to hydrogen than in lower-temperature Biochar Kilns (such as basic retort kilns). This positive feedback process in turn fuels the high Biochar Pyrolysis temperatures within the 'flame-curtain' Kiln system.

Moreover, the more aromatic ring structures generated during high-temperature stabilisation processes have the potential to play a catalytic role in the pyrolysis of the methane (See following figure, taken from a recent evaluation by Sánchez-Bastardo (Nuria Sánchez-Bastardo, 2021).

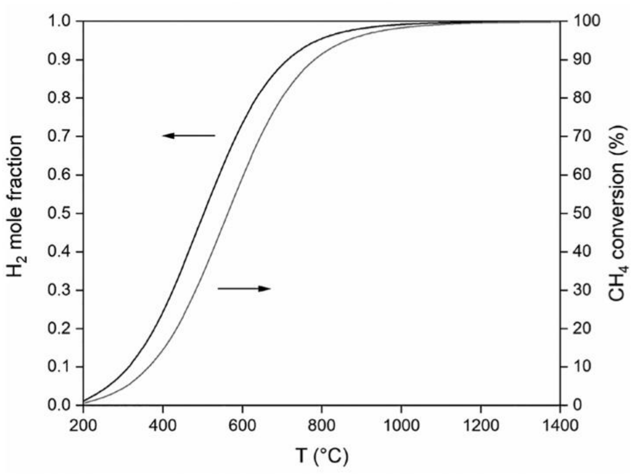


Figure 5. Hydrogen mole fraction (in the gas phase excluding carbon) and methane conversion in the thermodynamic equilibrium of methane pyrolysis at 1 bar and different temperatures (calculated using Aspen Plus software).

The above analysis gives a strong indication that a substantial proportion of the pyrolysis gases are indeed being consumed efficiently within the reactor. The inclusion of optional drying racks or other heat exchange systems above or around the kiln would further enhance the overall thermal efficiency, but are not included as standard fittings, to help keep down the initial costs to smallholders.

Avoided emissions are excluded from this methodology, but it should be noted that the use of waste biomass as the feedstock implies that the net benefit for atmospheric emissions from the application of this technology may be substantially greater than that assigned to the balance of emissions from the biochar pyrolysis process itself (as indicated in Appendix 11.3.1). The UNFCCC guidelines for methane emissions from stockpiles (as may be encountered with rice husks, empty fruit bunches of oil palm, sawmill waste, etc), characterised by large surface area to volume ratio and thereby limited anaerobic conditions, specify a conservative value of 0.28 methane correction factor for baseline calculations (UNFCCC/CCNUSS, n.d.). For large stockpiles of sugarcane bagasse, for example, where the volume with anaerobic degradation relative to surface area may be higher than in this estimate, the equivalent correction factor may be higher than 0.28. Based on a 20% biochar/biomass yield ratio, it is clear that the conversion of waste biomass from such sources to biochar could result in substantial GHG emissions avoidance.

11.5 Biochar Utilisation Examples

The eligible utilisation of Biochar can be further described in the following guidelines and examples:

- Adding biochar directly to the soil as a soil improver. *Typical treatment dosages between 5 and 20 t/ha, but stability is primarily determined by the biochar properties, not dosage level.* This includes:
  - Application a top-dressing; or
  - Incorporation during tillage.
- Multi-stage uses prior to subsequent use in soil, including:
  - Mixing the biochar with mineral or organic fertilisers. *Blended typically 1:1 with inorganic fertilisers, the biochar can reduce fertiliser run-off and associated GHG emissions associated with the fertiliser production.*
  - Mixing the biochar with organic materials such as compost or manure. *Mixing with organic materials can result in additional longer-term carbon benefits arising from the interaction between the biochar, available organic carbon and microbes and enhanced moisture retention, resulting in long-term net increase in fixed soil carbon, and increased mean biomass carbon stocks.*
  - Use as a water filtration medium. *Use as a filtration medium serves only as an additional process step prior to it being applied subsequently as a soil improver.*
  - Adding the biochar to animal feed. *Including biochar in animal feed has potential to reduce GHG impacts directly through reduction in methane emissions and indirectly, through improved efficiencies of meat and milk production. It also provides an energy-efficient mechanism to deposit biochar together with organic materials upon grazing land for long term sequestration.*
- Other non-agricultural uses such as:
  - Blending with cement or concrete for construction. *Blending biochar with construction materials provides a stable environment for carbon sequestration. The biochar carbon will remain stable even if the construction materials are subsequently demolished and physically crushed as an aggregate for future foundations. It offsets the equivalent quantity of cement or concrete GHG emissions.*
  - Blending with asphalt for road paving. *Blending biochar with asphalt binding materials provides a stable environment for carbon sequestration in the absence of soil microbes and root extrudates. The biochar carbon will remain stable even if the asphalt is subsequently deconstructed and reheated at temperatures well below the temperature encountered in the biochar pyrolysis process.*

11.6 Biochar long-term stability – Scientific Underpinning

The determination of biochar stability is based upon the methodology developed by the International Biochar Initiative (Budai, et al., 2013). The key parameter is defined as BC_{+100}, being the proportion of biochar added to the soil predicted to remain after 100 years. This is related to the Mean Residence Time (MRT) as follows:

$$BC_{+100} = e^{-100/MRT}$$

Using this single exponential relationship to represent the long-term stability of biochar, a Mean Residence Time of 1000 years, for example, corresponds to 37% (l/e=0.37) remaining after 1000 years, or 90.5% remaining after 100 years. In practice, biochar comprises a broad range of chemical forms exhibiting corresponding degrees of long-term stability. The persistence of carbon deposits arising from ancient wildfire and anthropogenic activities resulting from the recalcitrance of a certain charcoal components has often been reported and cited as evidence for the carbon sequestration potential of biochar in soils (Kaal, et al., 2007) (Scott, 2010) (Woolf, et al., 2010).

Long-term carbon stability is conferred via increasing aromaticity and condensation of aromatic rings or 'graphitisation' within the biochar, resulting in increasing recalcitrance to biodegradation and oxidation. An advanced laboratory-based method of measuring and demonstrating the increasing aromaticity characteristic of the 'graphite-like' structure is to measure the % benzene polycarboxylic acid (BPCA) – the 'backbone of charred organic material'.

A doubling of the %BPCA content of biochar as the pyrolysis temperature is raised from 400°C to 700°C, irrespective of feedstock type, confirms the relationship between pyrolysis temperature and aromatisation, resulting in greater resistance to degradation.

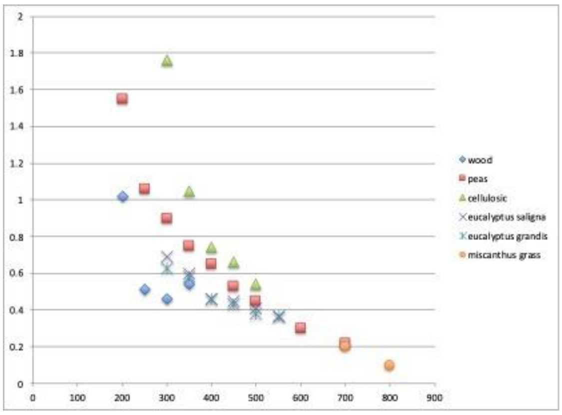
In practice, a range of pyrolysis temperatures will occur within small and medium-scale biochar kilns such as a flame-curtain kiln, due to variations in biomass feedstock size and loading times. However, the analysis of BPCA contents of the resulting biochar permits an effective representative temperature to be determined. In a study by Rasse (Rasse, et al., 2017) using a biochar kiln operating with pyrolysis temperatures in the range 500 – 750°C and using Miscanthus as a feedstock, the resulting condensation of the biochar was actually found to be higher than that of a laboratory-generated reference biochar produced at 682°C. Separate studies by Wiedner (Wiedner, et al., 2012) applying BPCA analysis to samples from a biochar kiln, similarly found relatively high degrees of condensation. Consequently, the existence of a range of temperatures in a working kiln is not a fundamental impediment to overall production of highly stable biochar.

Determining BPCS is not a practical or cost-effective option for multiple, small-scale distributed systems. For practical purposes applicable to multiple small-scale, distributed pyrolysis system, so-called 'alpha' tests – readily available and costing less than 100 USD – are needed. In their assessment of suitable options, Budai (Budai, et al., 2013) identified H/C_{org} (Enders, et al., 2012)as the most suitable and representative. Its suitability is based on systematic calibrations and correlations with a wide range of advanced lab and field-based analytical methods ('beta'- and 'gamma'- tests).

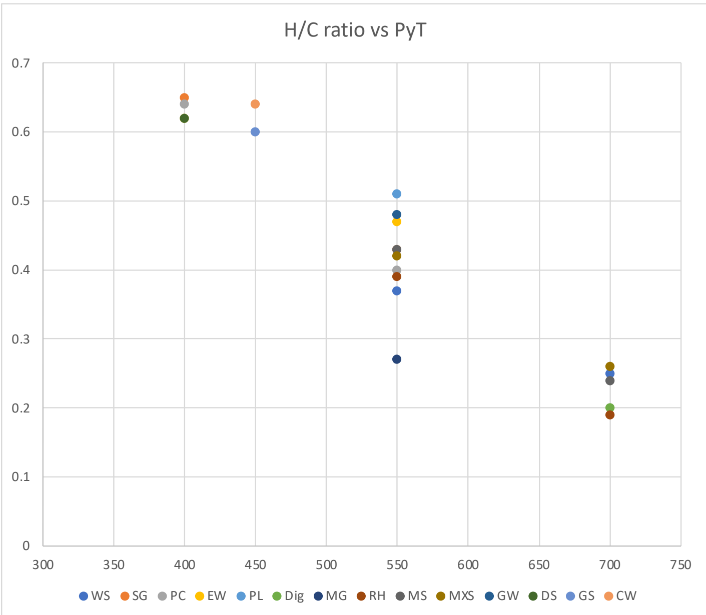
Materials with low H/C values are graphite-like materials (i.e. soot, black carbon, activated carbon), which exhibit high stability compared to uncharred biomass, which possesses higher H/C values and lower resistance to degradation. Hence, as biochar increasingly resemble graphite-like materials, characterized by low H/C ratios, they are expected to be more stable or inert, and less prone to degradation (Masiello, 2004). Increasing production temperatures result in lower H/C ratios (Krull, et al., 2009) as the abundance of C relative to H increases in line with the increasing degree of condensation in the biochar.

MRTs in excess of 500 years are typically found for biochar (defined as possessing H/C_{org} ratios <0.7), increasing to millennia as H/C_{org} ratios fall below 0.4. In the Rasse study (Rasse, et al., 2017), the H/C ratio for the biochar from the commercial kiln were 0.18, rather lower than that from the lab reactor (0.24), consistent with the observation of higher degrees of condensation.

The degree of condensation and resulting long-term stability of biochar generated at given pyrolysis temperatures or ranges of temperatures may vary between different biomass feedstocks. In an earlier study of a potential biochar stability metric ('recalcitrance index') by Harvey (Harvey, et al., 2012), H/C_{Org} ratios were determined for biochar produced from a variety of different feedstocks at different temperatures. By plotting out the supporting stability data as a function of temperature, it can be seen that the variation in stability associated with different biomass feedstocks can be quite large at lower pyrolysis temperatures, but these differences are significantly reduced at pyrolysis temperatures above 500°C, and H/C ratios below 0.4.



The H/C_{Org} ratios of 21 biochars generated from 14 different feedstocks at one or two different pyrolysis temperatures (PyT) analysed by 7 different laboratories shows a similar trend (Bird, et al., 2017), with a mean H/C_{Org} ratio decreasing from around 0.4 to 0.2 as the temperature increases from 550°C to 700°C. This particular study notes that some of the variation relates to different methods used by the different laboratories, and dose not solely reflect the difference between the feedstocks.



Where WS=wheat straw; SG=switchgrass; PC=pine chips; EW=eucalyptus wood, PL=poultry litter, Dig=digestate, MG=municipal greenwaste, RH=rice husk, MS=miscanthus straw, MXS= mixed softwood, GW=greenhouse (tomato) waste, DS=durian shell, GS = grass straw, CW = chestnut wood (Bird, et al., 2017).

Li et al (Li, et al., 2019) further confirm this relationship between H/C ratio (and other biochar properties) and PyT in the range 200°C – 850°C, drawing upon a total of 154 peer-reviewed studies, comparing the two broad groups of woody and herbaceous feedstocks.

This ever-increasing body of experimental data and underpinning understanding of the origins of long-term stability of biochar provides a clear basis for assessing statistically the likely long-term stability of biochar C from the aggregation of data from multiple distributed small-scale biochar kiln operations.

Note that the use of the molar H/C_{org} ratio is proposed by the IBI instead of the H/C ratio, as the former does not include inorganic C present in biochar mostly in the form of carbonates (e.g. calcite and, to some extent, dolomite) (Schumacher, 2002) and is not part of the condensed aromatic structure of C and thus is not expected to remain in the soil on the target centennial scale. For woody biomass the difference is relatively small, but it may need to be taken into account if high ash-content biomass feedstock are used.

The relationship between Slow, high-temperature pyrolysis and the generation of increasingly stable biochar components as observed via BCPA analysis (Schmidt, et al., 2017) (Rasse, et al., 2017) (Wiedner, et al., 2012) and the relationship between increasing condensation and H/C ratios permits a clear correlation to be established between pyrolysis temperature and duration and biochar stability. Lehmann (Lehmann, et al., 2021) note that the effectiveness of biochar as a CDR mechanism stems from the one to two orders of magnitude longer persistence of biochar than the biomass from which it is made. Whereas estimating this effect is more accurately achieved by measuring the biochar properties, the easier and less expensive approach is to measure the production conditions – temperature and type.

Using source data by Major (Major, et al., 2010), Zimmerman (Zimmerman, 2010), Singh (Singh, et al., 2012), Zimmerman and Gao (Zimmerman & Gao, 2013), Fang (Fang, et al., 2014), Herath (Herath, et al., 2015), Kuzyakov (Kuzyakov, et al., 2014), Dharmakeerthi (Dharmakeerthi, et al., 2015) and Wu (Wu, et al., 2016), the IPCC developed a method (IPCC, 2019), for estimating the fraction of biochar carbon (of type 'p') remaining (unmineralized) after 100 years, expressed in terms of tonnes of sequestered C $tonne^{-1}$ biochar C: $Fperm_p$ (see Table 3).

11.7 Determination of C_{org} from elemental analysis of C (total)

The International Biochar Initiative (IBI) specifies the use of C_{org} rather than C_{total} as the preferred basis for the estimation of Biochar long-term stability (BC_{+100}). The difference arises from the presence of inorganic carbon (C_{inorg}) which, for example in the most common form of calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) may break down and release CO_2 to the atmosphere more readily that the carbon predominantly bound within the aromatic structures present in Biochar following a slow high-temperature Pyrolysis process. The presence of such salts in Biochar may confer the positive benefits of contributing to the liming effect and nutrient value of the Biochar, which may in turn may increase crop yields after application to the soil, but they are not included in this Methodology as a contributory mechanism for CDR.

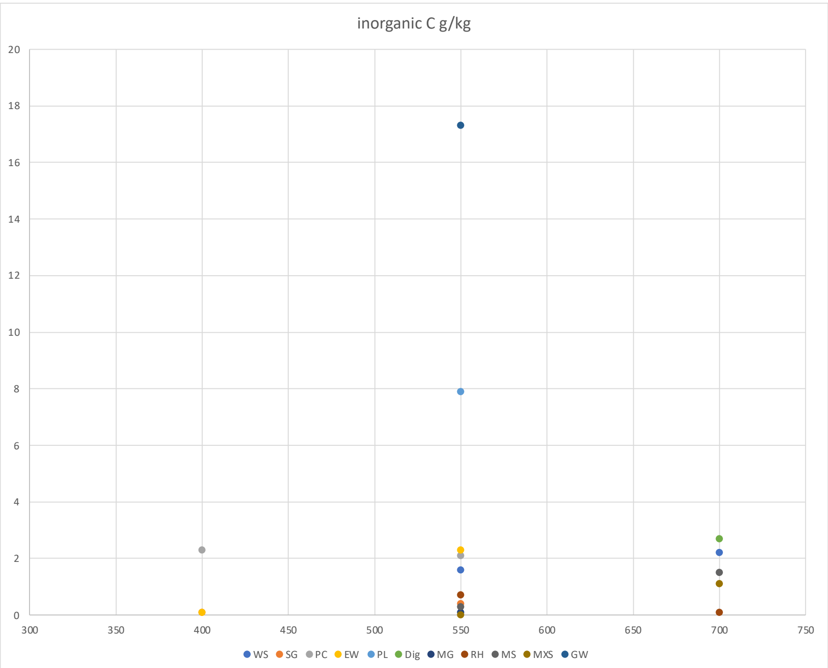
C_{org} may be estimated using the following relationship:
$C_{org} = C_{total} - C_{inorg}$

Various different methods may be used to determine C_{inorg} but of these the result of detailed evaluation of different methods concludes that titration is the most reliable (Calvelo Pereira, et al., 2017) (Wang, et al., 2014). The result of detailed analysis may be summarised in the following table:

Table 11. Detailed carbon content analysis (Calvelo Pereira, et al., 2017) (Wang, et al., 2014).

		Cinorg (g/kg)	Cinorg (%)	Ctotal (%)	Cinorg/Ctot
greenhouse tomato waste	GW	17.3	1.73	30.7	5.635%
poultry litter	PL	7.9	0.79	41.4	1.908%
durian shell	DS	3.3	0.33	65.5	0.504%
cattle manure		3.2	0.32	16.4	1.955%
digestate	Dig	2.7	0.27	59.1	0.457%
pine chips	PC	2.2	0.22	77.1	0.286%
wheat straw	WS	1.9	0.19	67.8	0.280%
eucalyptus wood	EW	1.2	0.12	71.3	0.168%
miscanthus straw	MS	0.9	0.09	77.0	0.117%
mixed softwood	MXS	0.55	0.055	86.4	0.064%
rice husk	RH	0.4	0.04	46.8	0.086%
switchgrass	SG	0.25	0.025	77.8	0.032%
municipal greenwaste	MG	0.1	0.01	79.7	0.013%

Plotting this data against Pyrolysis temperature for those biomass Feedstocks for which data at two different temperatures was captured indicates that inorganic C levels are not significantly altered by the Pyrolysis temperature.



The two 'outliners' in this dataset are the 'greenhouse tomato waste' (GW) and 'poultry litter' (PL), for which data is only available at a single temperature. The nature of the biomass feedstock has a significantly greater influence upon inorganic C levels than variations in pyrolysis temperature. From Table 11 above, it may be concluded that the difference between total C and organic C in the Biochar should be taken into consideration for certain feedstocks such as poultry litter or cattle manure, but that for Feedstocks such as softwood, the difference is less than 1% and will not have a material impact on the determination of stability from the H/C ratio.

To permit Carbon Stability to be determined from standard elemental C and H analysis (in the absence of Facility-applicable biomass C_{inorg} analysis) for this Methodology, a default value of 0.5% inorganic C/total C is to be applied to woody biomass, husks and grasses, 1% to shells and digestates, 2% inorganic C/total C to poultry litter and cattle manure, and higher levels to be determined directly for other categories.

Table 12. Summarised inorganic carbon content to total carbon content in Biochar, based on the Feedstock.

Biomass type	**Default C_{inorg}/C_{total}**
Wood, husks, grasses	0.5%
Shells, digestates	1%
Poultry litter, cattle manure	2%
Others	tbd (may exceed 5%)

11.8 Natural Risk

Erosion by wind or water do not affect the performance of sequestration of carbon by the Biochar. Increased rainfall or wind may result in Biochar being washed away from the vicinity of the initial deployment, transporting Biochar outside its original point of utilisation (Gholami, et al., 2019). However, Biochar remains stable within watercourses, and ultimately even more in the deep ocean. The critical metric is the quantity added to the soil, not the quantity that remains in the initial vicinity. Therefore, the risk of EOCD relating to the change of land use is considered negligeable, as long as no fire is to occur within the vicinity of Biochar sequestration.

However, risk of combustion through fire, including intentional slash and burn practices or wildfires represents a significant risk since it can result in the immediate loss of sequestered carbon due to the combustion of Biochar. This risk can be substantially mitigated through the incorporation of the Biochar into the soil subsurface. In this case where Biochar is added on the soil surface, the risk of loss due to fire is heightened since the Biochar remains exposed on the soil surface. This risk can still be mitigated by mixing the Biochar with other amendments (e.g. manures, composts, water) prior to application. Risk of combustion of Biochar is indeed reduced dramatically in such instances (IBI, 2010).

Except for high-intensity wildfires in forest settings, the heat generated during a fire does not typically combust the organic matter in soils, particularly in agricultural settings (Enninful & Torvi, 2008). Furthermore, in the case of the Kilns described as part of this Methodology (sections 2.2 and 3.1), the Biochar produced is very little combustible. The same properties that confer high stability to the Biochar, namely a low H/C_{org} ratio, together with the moisture retention arising from the water quench also render very resistant to combustion, as opposed to Biochar produced at a significantly lower temperature method. Similarly, it has been proven that application of Biochar increases the water retention capacity of the soil (Głąb, et al., 2016), itself acting as a risk mitigation against loss due to combustion. Therefore, when Biochar is applied to soil, the risk of its combustion through intentional or natural fires decreases significantly, and when applied in combination with amendments or to the soil subsurface, its combustibility is further reduced.

In the case of a non-soil application project (e.g., Biochar incorporated to cement or bricks) the carbon Sequestration will continue irrespective of subsequent year activities (Akinyemi & Adesina, 2020). GHG benefits associated with Biochar applied at project year one is not dependent on continuation of application of Biochar in year two. For obvious reasons, when Biochar is incorporated into building materials, combustion is nearly impossible (EBC, 2021).

11.9 Emissions Inventory

11.9.1 Feedstock Production Emissions

The eligible Feedstock (section 2.3) being characterised as Biogenic waste or invasive species, is considered as renewable. Therefore, the emissions from the production of the Feedstock are not accounted as part of this Methodology.

Three additional arguments are made to further justify an approach not seeking to quantify the Feedstock production emissions:

- Although this Methodology do not seek to quantify the avoided methane emissions from decay of Biogenic waste, the fact it focuses solely on Feedstock that would otherwise been burnt (CO_2 emissions), left to decompose (CH_4 emissions) or further damage the local ecosystem (harmful invasive species) is considered a reasonable argument to not account for the emissions linked to the growth of the Feedstock;
- This Methodology is aimed at providing a solution for small scale, distributed Biochar production rural areas, and extensive cradle to grave LCA are not viable for such small-scale projects;
- This Methodology focuses on eligible Feedstocks considered as waste from another industry. A reasonable assumption to make is that producer of the primary product the Feedstock originates from (or local authority) is therefore already required to report the emissions linked to the production of the Feedstock.

11.9.2 Feedstock Transport

If the Verification Authority satisfies itself of the Kiln being located in the immediate vicinity of the commercial operation generating the residue Feedstock, then the Feedstock transport emissions may be considered negligible. In the context of this section, “immediate vicinity” is defined as an area located at a distance below 200 km by road or track.

In the case where the Feedstock production does not occur at immediate vicinity of the Facility, Feedstock transport emissions shall be determined through standard LCA methods or direct metering.

When applicable, these emissions should be subtracted from the overall Eligible Quantity.

11.9.3 Biochar Production emissions

During Biochar production, emissions include carbon dioxide (CO_2), methane (CH_4) and soot. Carbon in the Feedstock is Biogenic, and therefore part of a natural carbon cycle.

Because the CO_2 released during Biochar production has been recently captured from the atmosphere and stored in the biomass through photosynthesis, the Pyrolysis is considered CO_2 neutral. However, emissions of CH_4 and soot have a more powerful global warming potential than CO_2 and must therefore be considered separately (IPCC, 2022).

These emissions should be subtracted from the overall Eligible Quantity.

Methane (CH_4) emissions

Methane emissions from low-scale distributed Biochar Kilns can be related to the type of system being used and feedstock type, as identified in a study by Cornelissen (Cornelissen, et al., 2016).

For Flame-Curtain Kilns eligible under this Methodology, it was found that CH_4 emissions were, on average 30 g/kg Biochar, with the highest emission factor described for the different feedstock mixture described found to be 60 g/kg Biochar (Cornelissen, et al., 2016). CH_4 emissions were found to be lower for retort Kilns (Sparrevik, et al., 2015).

For this Methodology, a baseline value of **60g CH_4/kg Biochar** is therefore conservatively set. Conversion of this value into tonnes of CO_{2eq} shall be performed using the 100-year Global Warming Potential (GWP_{100}) provided by the latest version of the IPCC report at the time of Facility Audit: currently equal to 27.2 tonne CO_{2eq}/tonne CH_4 (IPCC, 2022).

Where emission metering data applicable to a Facility and its defined Supply Envelope is available to support a lower average level of emissions of methane per tonne of Biochar, the baseline may be substituted by the corresponding measured emissions scientific literature relevant to the conditions observed at the Facility (i.e. Kiln design and Supply envelope), at the full discretion of the Verification Authority. Evidence of the metering data applicable to the Kiln operating conditions and Supply Envelope must be provided at Facility Audit.

Soot emissions

The heat and combustion dynamic characteristic of flame curtain pyrolysis is observed to be effective in combusting the main pyrolysis gases, but not so effective in combusting less inflammable aerosols (Cornelissen, et al., 2016). The total suspended particulate, including $PM_{2.5}$ and PM_{10} particulate matter, of Flame Curtain kilns is considered comparable to household-scale cooking stoves or TLUDs (Top-lit Up-draft stoves). TLUDs are identified as significantly lower-emitting than other more traditional cooking stoves commonly used throughout many of the regions where the distributed small-scale Biochar Pyrolysis Kilns are most likely to be deployed (Scharler, et al., 2021), so the net soot-related emissions impact in the case of Flame Curtain "Kon-Tiki" and TLUD Kilns is considered negligible.

For other Kiln designs (including retort and gasifier Kilns) soot emissions must be quantified and included as part of the calculation of the Eligible Quantity. The emissions shall be determined through standard LCA methods, direct metering or scientific literature relevant to the conditions observed at the Facility (i.e. Kiln design and Supply envelope). The applied soot emissions must be evidenced by measurement data or by sufficient data extracted from scientific literature relevant to the Kiln design.

11.9.4 Pre-treatment of Feedstock and Post-processing Operations

The following emissions shall be determined through standard LCA methods, direct metering, or scientific literature relevant to the conditions observed at the Facility:

- Biomass handling on site (transport or conveying of the biomass within the facility);
- Drying, chipping, comminution, and/or sieving of the biomass;
- Biochar quenching and other post-processing operations (e.g. packaging, activation);
- Biochar handling on site (transport or conveying of the biochar within the facility).

These emissions should be subtracted from the overall Eligible Quantity.

11.9.5 Biochar Transport

Biochar is typically 20% - 25% concentrated, so transport of Biochar to the end location will have a proportionately lower carbon footprint.

This Methodology has been developed to support the registration of distributed Biochar generation through the use of small scale and transportable Kilns. If a Verification Authority satisfies itself of the Kiln being located in the immediate vicinity of the point of Biochar use, then the Biochar transport emissions may be considered negligible. In the context of this section, “immediate vicinity” is defined as an area located at a distance below 200 km by road or track.

In the case where the use of Biochar does not occur in the immediate vicinity of the Facility, Biochar transport emissions shall be determined through standard LCA methods or direct metering.

When applicable, these emissions should be subtracted from the overall Eligible Quantity.

11.9.6 Energy Use

The emissions from the electricity and/or fossil fuels consumed during the eligible Pyrolysis process must be determined and included through standard LCA methods or direct metering. These emissions should only be included if they are directly and entirely related to the Biochar production activity. When applicable, these emissions should be subtracted from the overall Eligible Quantity.

These emissions can be considered negligeable if renewable energy use is evidenced through the redemption of electricity product Certificate Accredited under the International Attribute Tracking Standard or another tracking scheme approved by the Foundation or the relevant national authorities.

11.9.7 Manufacturing of Equipment

According to the *C-Capsule Methodology Requirements*, welding, construction emissions, manufacturing of processing equipment and disposal of the equipment must be assessed as part of the Facility Audit when they are solely built for the purpose of CO_2 removal. These emissions are included if they are estimated to be significant (more than 1 % of the total emissions).

All equipment used in the Biochar production process is used for production of Biochar for its agronomical and industrial benefits, not only for the CDR activity associated. Therefore, these emissions are excluded from the emissions inventory.

This argument is even more valid using the C-Go ONE Kiln design described in this Methodology, which minimises welding need relative to bending. It utilises efficiently manufactured standard components for Kiln support. Moreover, it utilises efficiently manufactured standard components for Kiln support. It has been estimated that the Kiln design maximises use of steel sheet (87%) relative to other kiln designs (60%).

11.9.8 Biochar Use

Standard LCA methods, direct metering, or relevant data from scientific literature must be applied or to determine the emissions arising from the end-use of the Biochar, to the extent that it is known by the Registrant. It should include at least all greenhouse gas emissions from handling of Biochar until it is used in one of the eligible forms described in section 2.5, from which it cannot be separated.

When applicable, these emissions should be subtracted from the overall Eligible Quantity.

11.9.9 Energy Production

If the Facility sells electricity as renewable energy, project electrical generation that displaces fossil fuel-based electricity will not be included as part of this Methodology as it does not qualify as CDR activity.

11.10 BionerG Data Capture Mechanism Specifications

Temperatures are monitored via two or more thermocouples fitted through the walls of the kiln. Weights are monitored via two or three load cells, depending on the layout of the support structure. Signals from the sensors are captured digitally in the databox, which automatically logs data into a uniquely identified datafile per batch operation, starting from when the kiln is first lit and ending after it has cooled.

The databox can store multiple datasets, all of which can be downloaded together when required. Following automated confirmation that the data has been captured and stored in the central data repository, the original data is subsequently deleted from the databox at the next download event to avoid internal storage memory overload.

The databox contains a rechargeable battery with sufficient capacity to support several days of operation. This may be recharged via a mobile battery pack or a solar panel. An external panel on the databox provides a visual indication of the state of charge.

For security, both a physical key and a password is required to permit access to the data via computer or mobile phone. Only registered users with a personal ID and password may use the mobile App to upload data to the central repository or to update the software. Each individual databox has a unique electronic identifier (EI). Each dataset is tagged with a range of metadata including the EI, date and time and GPS location. Data is encrypted.

Full technical specification required for operation are supplied to registered kiln operators when the databoxes and sensors are supplied.

11.11 C-Go ONE Kiln

Interested project developers are invited to use the C-Go ONE Kiln design specifications as a common platform from which to build their own systems and to provide feedback for improvement of the Kiln design and MRV protocols described in this Methodology. The collective experience of constructing and operating a common Kiln design platform, shared directly or via accompanying websites, facilitates the development of a Community of Practitioners that will further serve to improve the aggregated CDR performance from the distributed network of Pyrolysis operations.

11.11.1 Temperature measurements proxies

The effective temperature of the pyrolysis process for the C-Go ONE curtain flame kiln biochar process is based primarily upon the pattern of temperatures recorded at regular time interval throughout the process from two separate thermocouples set into the side wall of the kiln. One ("Thermocouple A") is located close to the base of the kiln, the other ("Thermocouple B") is located nearer the top of the wall.

Thermocouple A identifies the start of the process and records the higher temperatures at the beginning, reflecting the proximity to the initial ignition of the kindling material and early stage layering of biomass. As subsequent layers of biomass are added in accordance with the curtain flame process, so the temperatures recorded by thermocouple B start to rise. Over time, consistent with the rate of slow pyrolysis being carried out, and corresponding changes in the weight of material contained within the kiln, temperatures at thermocouple B increase and exceed the temperatures at thermocouple A, which gradually declines over time as less combustible remains within the lower levels.

A water quench causes a significant drop in both thermocouple temperatures and signals the start of the final cooling phase and stabilisation of the resulting biochar mass.

The temperature data captured digitally from the two thermocouples is generally lower than that actually taking place within the body of the kiln, as the thermocouples are thermally linked to the kiln walls which are cooled by rising air from the outside. This can be routinely demonstrated by the use of a remote IR thermometer pointed at either the core of the kiln or at the thermocouples themselves.

In tests to date, each thermocouple records temperatures up to 400°C at different periods of the pyrolysis process (excluding short-term variations that can occur if a flame event takes place temporarily in the close vicinity of either thermocouple), and that this consistently correlates with pyT within the kiln exceeding 600°C.

As noted in section 11.1, condensation of aromatic rings that determine the long-term stability of the biochar C is effected in kilns that exhibit a range of pyTs. Calibration of the process can be carried out by analysing the H/C_{org} ratio of samples of the resulting biochar. For practical operational reasons, occasional sampling, linked to the statistical analysis of multiple datasets aggregated from multiple operations should be performed. This will confer confidence in the quality of the biochar and the equivalent high pyT values that correlate with actual thermocouple datasets.

Figure 5. Temperature indicated using an EVENTEK ET323D infrared thermometer (range -50°C to +850°C)

11.11.2 Expected Temperature and Weight profiles

The relationship between the process of adding biomass feed, the temperatures recorded at the two thermocouples and the variations in weight data over time generates a unique digital time series profile. The C-Go verification system applied to each time-series datafile establishes whether the profile is statistically consistent with other profiles within the aggregated dataset or displays anomalous signals that merit on-site inspection. Data determined to be statistically anomalous is not accepted as valid until and unless a site inspection is carried out to check the circumstances. As increasing quantities of data are collected, analysed and aggregated over time, the levels of statistical confidence will increase, as should the experience of operators in operating in a consistent manner. The ratio of local inspections and calibrations required relative to routine distributed operations is expected to decrease over time, whilst building confidence in the system. The methodology applies a process of starting with default lower levels of confidence (leakage values etc), that may be enhanced over time as increasingly consistent operations, aggregation of greater quantities of data, and calibration dataset are accumulated for each Facility.

11.11.3 Kiln Design Specifications

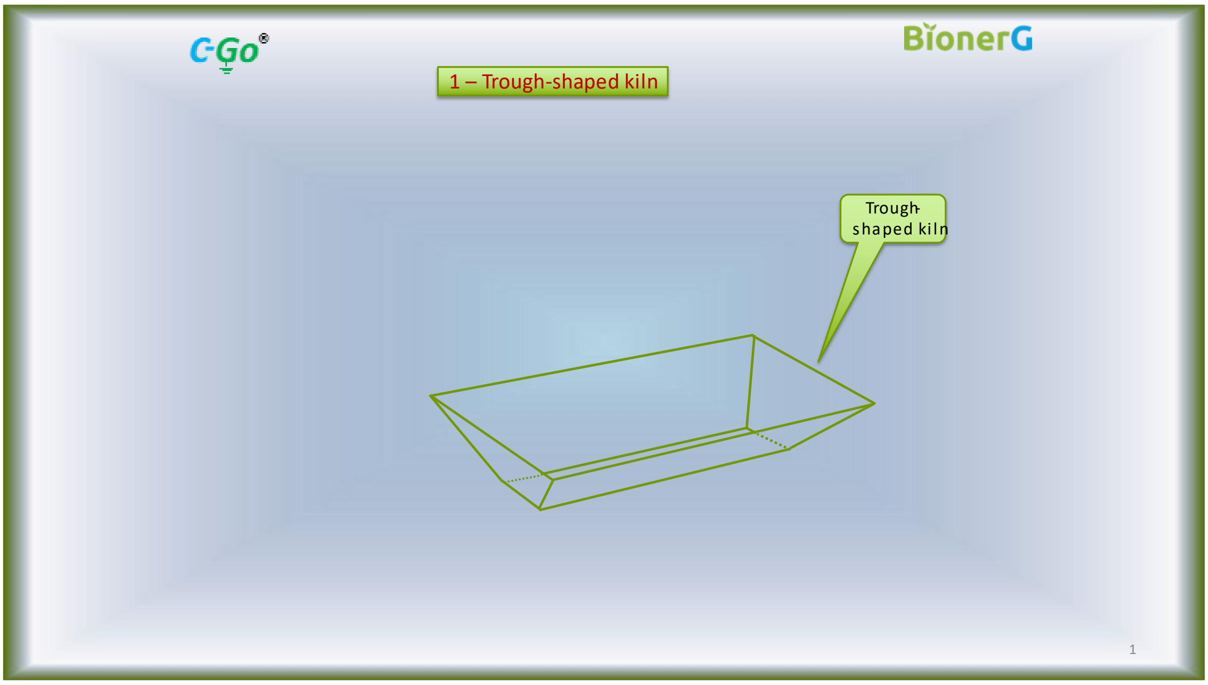


Figure 6. Eligible Kiln shape.

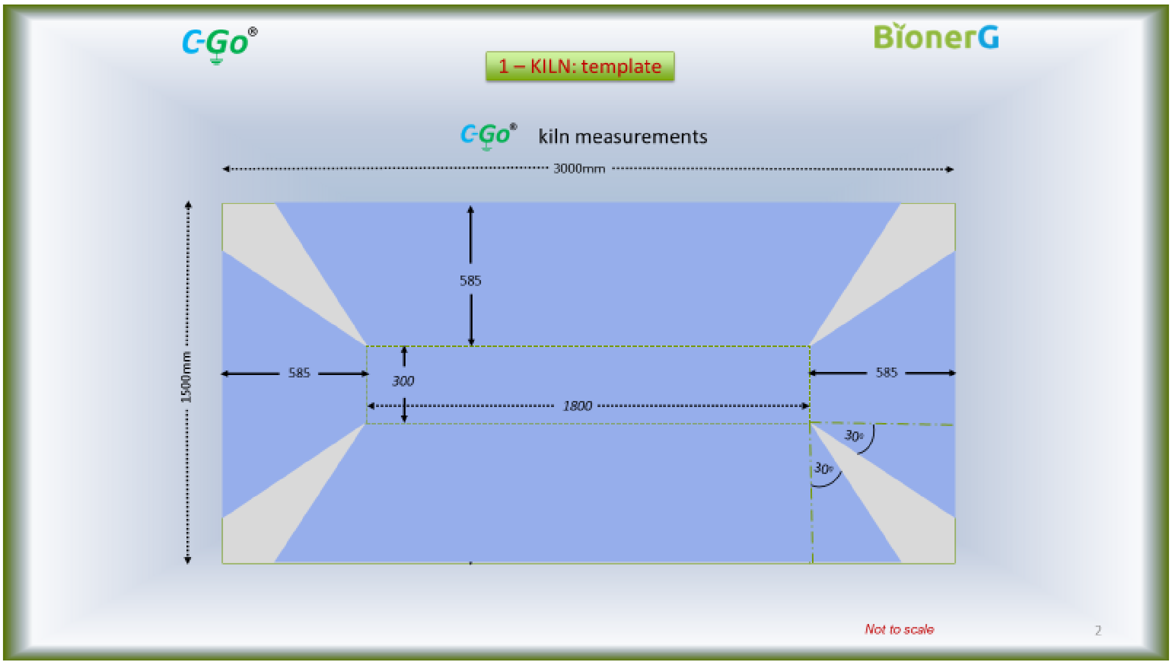


Figure 7. Eligible Kiln measurements.

11.11.4 Operation of the C-GO ONE Kiln

Routine Operation Summary

1) An initial quantity of kindling material, stacked vertically, is ignited from the top to initiate a form of a top-lit updraft process. After combustion has been established, the resulting hot material is spread[66] across the base of the kiln, and a layer of biomass feedstock loaded above. Volatile materials contained within the biomass feedstock combust, generating flames and releasing heat. Air supporting the flames comes from below and is

depleted of oxygen, resulting in the Pyrolysis process whereby the more recalcitrant solid fractions are not burned, but instead are heated and converted to increasingly more stable forms of carbon, namely biochar. By repeating this process, layer by layer, a controlled process of Biochar production via slow pyrolysis is established. Temperatures within the bulk of the Kiln are maintained at a suitably high level to generate stable carbon within the Biochar.

2) A trained operator can manage the process of adding layers of fresh biomass feedstock to the Kiln by eye. The combination of temperature and weight sensors collecting data at regular time intervals can accurately monitor this process to determine if operations fall within the Minimum Consistency Criteria (MCC).
3) A water quench stops the process, stabilising the Biochar and preventing unnecessary further reduction towards ash, so that Biochar of high quality for agricultural applications is generated. This provides a clear data signal that further assists the calibration of weights and temperatures.
4) A digital data capture box is fitted to each Kiln. This captures temperature and weight measurements digitally in real time during operation of the Kiln. The combination of temperature and weight measurements provides an essential record of Biochar production, in terms of quality and quantity.
5) The databox is charged via an external battery store, solar panel or other device.
6) A separate digital datafile is generated for each batch operation, uniquely identifiable via date and time stamps associated with the data, and a tag recording the unique electronic identifier of the databox/kiln combination.
7) Datafiles from multiple operations are stored within the databox until synchronised using a computer programme or Data Export App. The Data Export App tags each datafile with the GPS location of the databox and with the unique electronic identifier of the databox at the moment of downloading. It deletes old datafiles that have been successfully stored in the cloud-based data repository from the databox at the next downloading event, to avoid double-counting and to avoid over-filling the databox storage capacity.

Operating Manual

The C-Go ONE kiln uses a unique design (patent filed), adapted from the more general ‘curtain-flame’ principle of making biochar, using a layer-by-layer batch process. The process builds up biochar over several hours, by layering fresh biomass upon material that is in the process of turning (being pyrolyzed) to biochar in a kiln that generates a low-oxygen environment for the flames due to its shape. Apart from a small quantity of kindling material that must be ignited to get the process started, the pyrolysis process is self-supporting, and the kiln requires no external energy supply. Temperatures within the kiln can readily exceed 600°C which ensures the biochar is of high quality and stability, suitable for agronomic purposes as well as carbon sequestration.

The inclusion of a shield wall helps the process by generating a flow of air upward and inwards, which helps to send any escaping gases back into the kiln for further combustion, and away from vicinity of the kiln operator. It also acts as an effective heat shield, so that operators are not exposed to the hot inner kiln walls when loading it with fresh biomass.

The following illustrates a typical operation and also gives examples of how the process may be improved in a particular situations.

1) Build one or two small stacks of kindling material at the base of the kiln. Paper or other dry combustible materials may be added if available to help get this first stage working quickly (Figure 8).

Figure 8. kindling material placed in the kiln.

2) Once the material is burning well and starting to generate some ash, spread it out along the base of the kiln. Starting by lighting two stacks may be found to be better than a single stack in the middle, to ensure that the pyrolysis that follows is evenly developed throughout the length of the kiln, making best use of the size of the kiln and speeding the process as a whole (Figure 9).

Figure 9. Kindling ready to be spread out and fresh feedstock added on top. In this case, the kiln was still quite wet at its base from a previous operation and the kindling was set up on top of a piece of wood, but this is not generally necessary.

3) After spreading the initial flaming kindling material along the base of the kiln, add a layer of biomass feedstock and wait for it to start to burn, so that it generates heat within. In the case illustrated in Figure 10, the kindling had not been fully ignited before adding the biomass, so there is a region at the near end that has not yet started to operate. If the initial kindling process allows good spread of burning embers along the length of the kiln, the process as a whole will proceed better.

Figure 10. A layer of biomass added upon the original kindling material.

4) From this stage onwards, biomass should be added periodically, with the objective of maintaining a high rate of flame-curtain combustion as evident by the flames emerging from the top, but also aiming to contain the heat inside. The heat should be released by the burning of gases and the more volatile oils, but not by burning the solid material beneath which will be converted to biochar. The operator should avoid putting out the source of heat or losing the flame front from near the upper surface when adding feedstock. Experience will soon guide the operator into the appropriate moment and place to add new feedstock, without smothering the operation. Material does not need to be added in full layers. Feedstock pieces may be added whenever the presence of flames suggest that material should be added to keep the heat in and to use the flame to start pyrolyzing new material rather than simply releasing heat to the atmosphere. Strong flames may be covered to keep heat in, but with different types of feedstock, it may also be necessary to build up good heat and flames before adding other feedstocks (such as finely processed husks) which might otherwise extinguish the process if there is not enough heat and air flow within. Experience will determine the best balance (Figure 11, Figure 12, Figure 13 and Figure 14).

Figure 11. New layers building up significant heat release.

Figure 12. New layer added, trapping heat and the pyrolysis process within.

Figure 13. At this stage, the temperatures within the kiln can be routinely above 600 °C. In this particular measurement: 691 °C which is at the high end of target. With experience, temperatures within the kiln can be gauged by the colour.

Figure 14. Despite the very high temperatures within the kiln, the shield walls should remain much cooler and safe to touch. In this case 36.1 °C was recorded. This is due to the strong upward flow of air between the kiln and shield walls. A matt black patch has been painted on the wall where the measurement is being made, to improve the accuracy of the IR temperature reading, relative to the reflective metal shield itself.

5) The end of the process is determined by the point when the kiln is so full, no more biomass can be safely added. It is OK to add biomass near the end to keep the heat in and pyrolysis process going. In the case of Figure 15 the top layer of material was left a bit too long, resulting in more flames than necessary. Another layer could have been added earlier to keep the heat in, and the decision to stop taken before a lot of flames break through.

Figure 15. Kiln close to capacity, and ready to stop.

6) The quench water may be introduced via one of the pipes built into the kiln, but in practice it is generally fine, and easier, to pour the quench water into one corner of the kiln, without risk from steam to the operator. This will take a few minutes. The cool water meeting red- or white-hot biochar causes steam release that helps break open the biochar structure, which improves the quality of the biochar for subsequent applications, and reduces the effort required for crushing and grinding later (Figure 16).

Figure 16. Pouring in quench water (gravity fed).

7) End of Quench (around 200 litres) is reached when the water covers all the biochar and the pyrolysis has stopped. This is when it helps if the kiln is horizontal, so water is not spilling out at one end whilst there is still material to be quenched at the other. It is also why the side walls need to be reinforced so they do not sag down. A degree of distortion will inevitably occur during the first few days of operation, provided that the reinforcing struts are in place (Figure 17).

Figure 17. End of quench. All biochar has been quenched and the pyrolysis stopped. Some feedstocks at the surface will not have been pyrolyzed, because they were added near the end to keep the heat in. They may be removed at this stage. If left out to dry they can be used as feedstock in the next cycle.

Once cooled (after an hour or two), the water may be drained via either or both the drain pipes near the base of the kiln. The process may be assisted by raising the 'dry' end of the kiln via the scissors jack. When as much water as possible has been removed this way, the bolt underneath the base may be loosed and removed to drain any liquid (onto the ground or into a bucket) that would otherwise remain at the very bottom of the kiln. Figure 18 shows biochar left overnight to drain. Remember to close all the water outlets after!

Figure 18. Biochar left overnight to drain.

8) The quenched water may be captured in a separate ground-level container (maybe sunk into the ground if needed). Some fine biochar particles will be carried through and will settle at the bottom overnight. This water may be recycled for the next quench. Around 50 litres will be retained as moisture in the biochar, and some will have evaporated during the quench. The exact quantities will determine the rate at which quench water will need to be topped up from an external source. The quenched water may alternatively be used directly for plant irrigation. It will need to be analysed locally, but is likely to be rather alkaline, with nutrients dissolved (Figure 19).

Figure 19. A typical sample of water drained from the kiln. Overnight a fine layer of microscopic biochar particles settles out, and the water remaining is extremely clear.

9) The kiln is most easily emptied manually using a suitable form of spade. The height of the kiln is set by the height of the stands, but in general it is worth keeping the overall height as low as ergonomically convenient for loading and unloading. At this height, the biochar can be transferred directly into a bag, wheelbarrow or other container.