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# *Methodology for Biochar Projects*

## Version 1.0

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# 1 METHODOLOGY DESCRIPTION

## 1.1    Summary Description of the Methodology

Biochar is produced through the Pyrolysis of biomass.  Under this Methodology, potential Feedstocks include forestry and agriculture residues, Municipal Solid Wastes, and other biomass-based materials approved for use under the International Biochar Initiative's *IBI Biochar Standards* (2013). In the absence of Pyrolysis, these Feedstocks would otherwise be combusted or decompose, releasing carbon dioxide (if combustion or decomposition under aerobic conditions occurs) or methane (if decomposition occurs under methanogenic conditions).

Pyrolysis physically and chemically transforms the rapidly decomposing carbon in raw biomass into a more recalcitrant form, which can be applied to soil for long-term sequestration. A large portion of the Fixed Carbon in Biochar, as measured using the testing methods identified herein, is sequestered for a time period well in excess of 100 years. By transforming the biomass carbon to a highly stable form that resists degradation, and ensuring that it remains in this form, emissions from the decomposition or combustion of Feedstocks are significantly reduced. In addition to this sequestration, Pyrolysis also generates bio-oil and syngas, which if upgraded, may be used as renewable energy and thus reduces anthropogenic greenhouse gas (GHG) emissions.

This Methodology quantifies these GHG emission reductions and sequestration benefits that result from the implementation of Biochar projects.

## 1.2    Relationship to Approved Methodologies

Approved and pending methodologies for all sectoral scopes were reviewed to determine if an existing Methodology could reasonably be revised to meet the objective of this proposed Methodology. Two methodologies related to Biochar projects from the Clean Development Mechanism were identified, and are outlined in Table 1.

**Table 1: Summary of Related Methodologies**

| Methodology | Title | Primary Reduction Mechanism | Comments |
|---|---|---|---|
| **CDM AMS – III.E** | Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment --- Version 16.0 | Avoidance of methane emissions due to prevention of anaerobic decay of biomass in waste. Use of biomass in waste as energy source. | Controlled combustion Methodology, allowing for all final products (refuse-derived fuel/ stabilized biomass) to be combusted after thermochemical transformation. Goal of AMS III.E is to prevent Pyrolysis and to ensure biogenic combustion emissions. |
| **CDM AMS – III.L** | Avoidance of methane production from biomass decay through controlled Pyrolysis --- Version 2.0 | GHG emission avoidance and replacement of more-GHG-intensive service by Pyrolysis of organic matter. | Landfill avoidance and Pyrolysis Methodology, allowing for final products to be combusted after Pyrolysis. Goal of AMS III.L is to avoid landfill emissions through Pyrolysis and combustion. Required volatile: Fixed Carbon ratios are <50% (ASTM D1762-84). Waste pyrolyzed can consist of non-biogenic materials, and is expected to be combusted (bio oils/syngas) or disposed of after production. |

The stable carbon that is sequestered through Pyrolysis is not included in either of these small-scale methodologies, which are instead focused on avoided methane emissions. Given this distinction, Methodology adaptation would not be feasible, as significant changes are required to accommodate the emission reductions associated with sequestered carbon, which is the primary reduction captured by this Methodology.

## 1.3 Sources

This Methodology is based on the draft *Quantification Protocol Biochar Projects, v.1*, issued under the Alberta Specified Gas Emitters Regulation (Carbon Consulting and Leading Carbon 2011).

In addition, technical and good practice guidance was obtained from Environment Canada's annual GHG reporting, the US EPA's Emission Inventory, the Intergovernmental Panel on Climate Change (IPCC), and various other reliable sources of information. The Clean Development Mechanism's AM 0036 "Fuel switch from fossil fuels to Biomass Residues in heat generation equipment" (United Nations 2012a) provided guidance on biomass energy accounting. The Methodology also relies heavily on the International Biochar Initiative's "Standardized Product Definition and Testing Guidelines for Biochar that is Used in Soil" (the *IBI Biochar Standards)*. The good practice guidance and best science used to develop the quantification Methodology are presented in Section 10.

## 1.4 Definitions

Biochar:    Biochar is a solid material obtained through the thermochemical conversion of biomass in an oxygen-limited environment. Biochar differs from charcoal in the sense that its primary use is not for fuel, but for biosequestration or atmospheric carbon capture and storage. To be credited by this Methodology, Biochar must comply with all requirements of the most recent version of the International Biochar Initiative's *Standardized Product Definition and Product Testing Guidelines for Biochar that is Used in Soil* (aka *IBI Biochar Standards*)*.*

Biogenic Biomass:    Material that is produced or originating from a living organism.

| Biomass Residues: | Biomass by-products, residues and waste streams from agriculture, forestry and related industries. (United Nations 2006). Any Biomass Residue meeting the Feedstock expectations of the IBI Biochar Standards (2013) is eligible for Biochar production under this methodology, provided it meets the applicable Sustainable Feedstock criteria in Appendix 4. |
|---|---|
| Chain of Custody: | Documenting/tracking the location and ownership history of feedstock step-by-step from its harvesting source to the final product of Biochar. |
| Developed/Industrialized Nation: | There are no established conventions for designating "developed" or "developing" nations. This Methodology will follow the listing of industrialized nations and economies in transition included within Annex I Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (United Nations 2012g). |
| Developing Nation: | Following the definition of developed nation provided above, a Developing Nation will be considered to include all nations not listed within the Annex I parties to the UNFCCC (United Nations 2012g), which have been identified as Developing Nations or least developed countries. |
| Diluent/Dilutant: | Inorganic material that is deliberately mixed or inadvertently comingled with biomass feedstock prior to processing. These materials will not carbonize in an equivalent fashion to the biomass. These materials include soils and common constituents of natural soils, such as clays and gravel that may be gathered with biomass or intermixed through prior use of the feedstock biomass. Diluents/dilutants may be found in a diverse range of Feedstocks, such as agricultural residues, manures, and Municipal Solid Wastes. (International Biochar Initiative 2012). |
| Efficiency: | *Efficiency* is defined as the net quantity of useful energy generated by the energy generation system per quantity of energy contained |

in the fuel fired. In case of boilers that are used only for thermal energy generation (and not for power generation), the Efficiency is defined as the net quantity of useful heat generated per quantity of energy contained in the fuel fired in the boiler. In case of power plants producing only electric power (not cogeneration plants), the Efficiency is defined as the net electricity generated by the power plant as a whole divided by the quantity of energy contained in the fuel fired.

| | |
|---|---|
| Feedstock: | The material undergoing thermochemical processes to create Biochar. Feedstock materials for Biochar consist of Biogenic Biomass, but may also contain Diluents. (International Biochar Initiative 2013). |
| Fixed Carbon: | Fixed Carbon is the component of the Biochar that has been shown to be stable through the application of the Ultimate Analysis or otherwise, as required in the Methodology to assess the stability of the sequestration of the carbon. |
| Material Change: | Material Changes in Feedstock reflect shifts in Feedstock type from one source of biomass to a distinctly different source of biomass. In mixed Feedstocks, whether processed or unprocessed, a 10% or greater shift in total Feedstock composition shall constitute a Material Change in Feedstock. |
| | Material Changes in production processes reflect increases or decreases in process temperature or residence time. A Material Change in thermochemical production parameters has occurred if process temperature (also known as heat treatment temperature) changes by +/- 50˚C, or if the thermochemical processing time (residence time) changes by more than 10%. See Appendix 4 of the *IBI Biochar Standards (2013)* for more information on how to determine Feedstock types that constitute a Material Change in type. |

| | |
|---|---|
| Mobile Biochar Operations: | Mobile Biochar Operations are Biochar facilities that are built on a trailer or that otherwise can be relocated. These operations may be moved on a daily or similarly frequent basis. |
| Municipal Waste / Municipal Solid Waste (MSW): | Solid, non-hazardous refuse that originates from residential, industrial, commercial, institutional, demolition, land clearing or construction sources (Canadian Council of Ministers of the Environment 2005). Municipal solid waste includes durable goods, non-durable goods, containers and packaging, food wastes and yard trimmings, and miscellaneous inorganic wastes (US Environmental Protection Agency 2011). |
| Project Proponent: | An individual or entity that undertakes, develops, and/or owns a project. This may include the project investor, designer, and/or owner of the lands/facilities on which project activities are conducted. The Project Proponent and landowner/facility owner may be different entities. |
| Proximate Analysis: | This methodological approach establishes the loss of material as samples are heated to predefined temperatures and typically reports volatile matter, Fixed Carbon, moisture content, and ash present in a fuel as a percentage of dry fuel weight. International Standards under ASTM exist for this measure; the relevant method is ASTM D1762-84 (2007). |
| Pyrolysis: | The thermochemical decomposition of a material or compound into a carbon rich residue, non-condensable combustible gases, and condensable vapors, by heating in the absence of oxygen, or low oxygen environment, without any other reagents, except possibly steam (United Nations 2012c). |
| Soil Amendment: | Any material added to soil to improve its physical and chemical properties, such as water retention, permeability, water infiltration, drainage, aeration and structure; for the goal of |

providing an improved rooting environment (Davis and Wilson 2005).

Solid Waste Disposal Site (SWDS) | Designated areas intended as the final storage place for solid waste. Stockpiles are considered a SWDS if (a) their volume to surface area ratio is 1.5 or larger and if (b) a visual inspection by the Department Of Environment or responsible governing body confirms that the material is exposed to anaerobic conditions (i.e. it has a low porosity and is moist).

Ultimate Analysis: | A quantitative analysis in which percentages of all elements in the substance are determined. International Standards under ASTM (www.astm.org) exist for Ultimate Analysis; the relevant method is ASTM D3176-09 (2005).

Verification Statement: | A verification statement provides assurance that, through examination of objective evidence by a competent and independent third party, a GHG assertion is in conformity with applicable requirements.

Verifier: | A competent and independent person, persons or firm responsible for performing the verification process. To conduct verification the verifier must be ACR-approved.

# 2 APPLICABILITY CONDITIONS

1. This Methodology is applicable to projects that convert various Feedstocks into Biochar, where the only Feedstocks that meet the definition of Biomass Residues above are eligible under this Methodology. The project must not claim carbon credits for any Feedstock that is purposefully grown in an agricultural or forestry system whose primary function is to serve as a Feedstock to be converted to Biochar. Only waste residues (from agricultural and forestry products, Municipal Solid Wastes, and other sources of biomass-based Feedstock materials) are eligible as Feedstocks. Concerns of Feedstock sustainability pertaining to the overharvesting of agricultural residues and the depletion of soil organic Carbon Stocks are addressed in Appendix 4. Baseline conditions claiming the combustion, aerobic or anaerobic decomposition, or combustion for bioenergy production of any Feedstock must be substantiated using the Additionality test described in Section 2.

2. The Feedstock used to create Biochar offset credits must originate from a biomass source or be biogenic in nature; must meet the Feedstock expectations of the *IBI Biochar Standards* (2013); and must meet the applicable Sustainable Feedstock criteria in Appendix 4. If Biochar has been produced from Feedstocks of mixed origin, the carbon content of the Feedstock must be evaluated to assess the percent biomass or biogenic carbon content eligible for offset credit. All non-biogenic material that is pyrolyzed must be accounted for within the project emissions.

3. All Biochar produced by the project must comply with all the requirements of the most recent version of the International Biochar Initiative's *Standardized Product Definition and Product Testing Guidelines for Biochar That is Used in Soil* (International Biochar Initiative 2013). Project Proponents must annually present appropriate documentation of such compliance.

4. The ratio of hydrogen to organic carbon, as measured according to the "Standard Test Method for Estimating Biochar Carbon Stability" by the International Biochar Initiative (2013), is equal to or less than 0.7. The quantity of stable sequestered carbon of Biochars with a hydrogen to organic carbon ratio of greater than 0.7 cannot be conservatively assured.

5. The Biochar produced by the project must be applied to land or mixed with another soil, compost, or amendment medium. Suitable evidence of application to soil or mixing with Soil Amendments is required.

Biochar that is specifically designed and intended as a Soil Amendment presents a disincentive to combustion due to changes in its physical and chemical characteristics, or poor return on investment as a fuel source. Assurance of the stable sequestration value of Biochar is therefore provided through attestations related to the material's end use. Such end use attestations must be guaranteed by the presentation of substantive proof, through the application of Biochar to soil, the type of product sold, the blending of Biochar with other amendment materials, and additional features described below.

End Use:

Substantive proof that Biochar is being applied to soil can be presented through agricultural records that indicate the application of Biochar to soil or its use as a horticultural product; by indicating that Biochar has been mixed or blended with other Soil Amendments, microbial inoculants, fertilizers and other nutrient products; or by presenting information on two of the following:

a. Size of Particles

A size limit of less than 2 inches (5.08 cm) as the longest dimension has been placed on Biochar, such that larger pieces that could be perceived as fuel substitutes are avoided within all packaging and shipments of offset-eligible Biochar. Smaller particles facilitate easier blending with additional amendments, and with soil.

b. Comparison of Heating Value and Price

Presenting evidence of a low heating value to price, when compared to fuel charcoal demonstrates a disincentive to combustion. Since Biochar provides greater per-volume or per-weight value as a non-combusted good, combustion is less likely to occur when compared to a charcoal of greater heating value or lower price point. Biochar priced outside of its heating value is not cost-effective as a fuel. Providing price and heating value (or BTU) information indicates that there is an economic disincentive to the combustion of Soil Amendment Biochar,

as it is of higher value when applied to soil. It is perceived that the majority of Soil Amendment Biochars are sold at a higher price-per-volume and/or price-per-weight than fuel charcoal, pricing Biochar outside of its heating value, and therefore not cost-effective as a fuel.

c. Marketing

Indicating that Biochar is promoted and sold as a Soil Amendment (through the inclusion of marketing materials, links to a website, or other similar information).

6. The technology used for producing Biochar must meet all applicable local, regional, state, and national air quality Standards in the nation of Biochar production. Project Proponents must present relevant documentation to indicate that regulatory expectations have been met.

7. The facility creating the Biochar is operating under applicable facility permits, with the Biochar and co-products handled and utilized in keeping with all local, regional, state and federal regulations. Project Proponents must present relevant documentation to indicate that regulatory expectations have been met.

8. The Project Proponent must demonstrate uncontested and exclusive claim to the ownership of the GHG benefits derived from the project activities. The Project Proponent must have documentation to address and resolve all potential claims to GHG benefits by the Feedstock producer, Biochar producer, retailer and end-user. Any transfer of carbon rights must be clearly documented.

# 3 PROJECT BOUNDARIES

## 3.1 Greenhouse Gas and Carbon Pool Boundaries

Sources, Sinks and Reservoirs (SSRs) included in the project and baseline quantification include those that are within the project site (the physical, geographic location of where the Pyrolysis of the Feedstocks into Biochar occurred), as well as others that are off-site. A generalized process flow diagram of a typical project and baseline are presented in Figure 1 and Figure 2, respectively. The SSRs represented in those figures were compared and their relevance evaluated to determine if they should be included or excluded from the quantification Methodology. While Biochar may translocate, we assume that the proportion of carbon calculated to be stable remains sequestered regardless of its location, given that the stable carbon test methodology is conservatively based on harsh environments unlikely to be experienced by translocated biochar.

Tables 2 and 3 provide justification for the inclusion or exclusion of each of the potential SSRs in the project and baseline conditions.
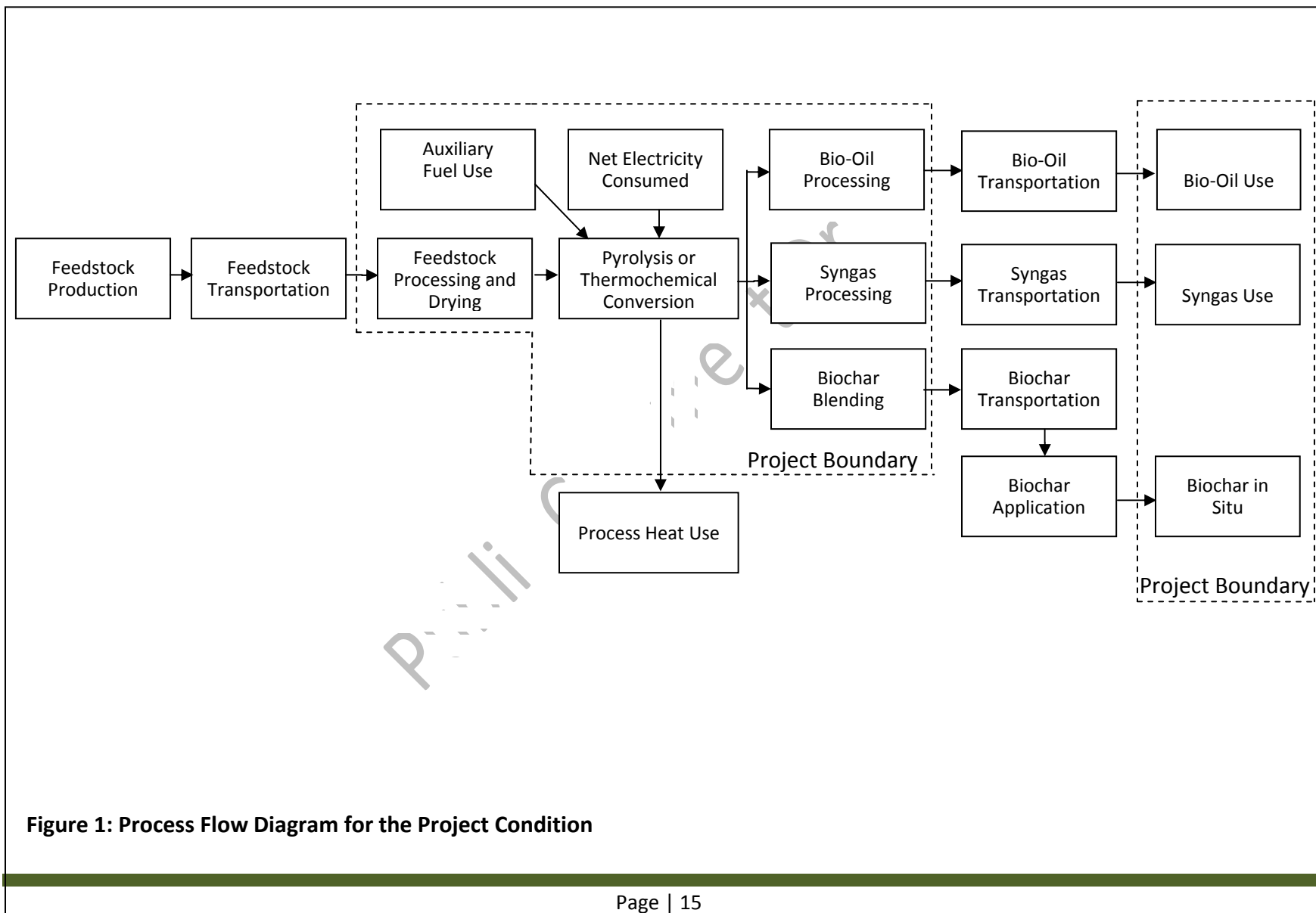
**Figure 1: Process Flow Diagram for the Project Condition**
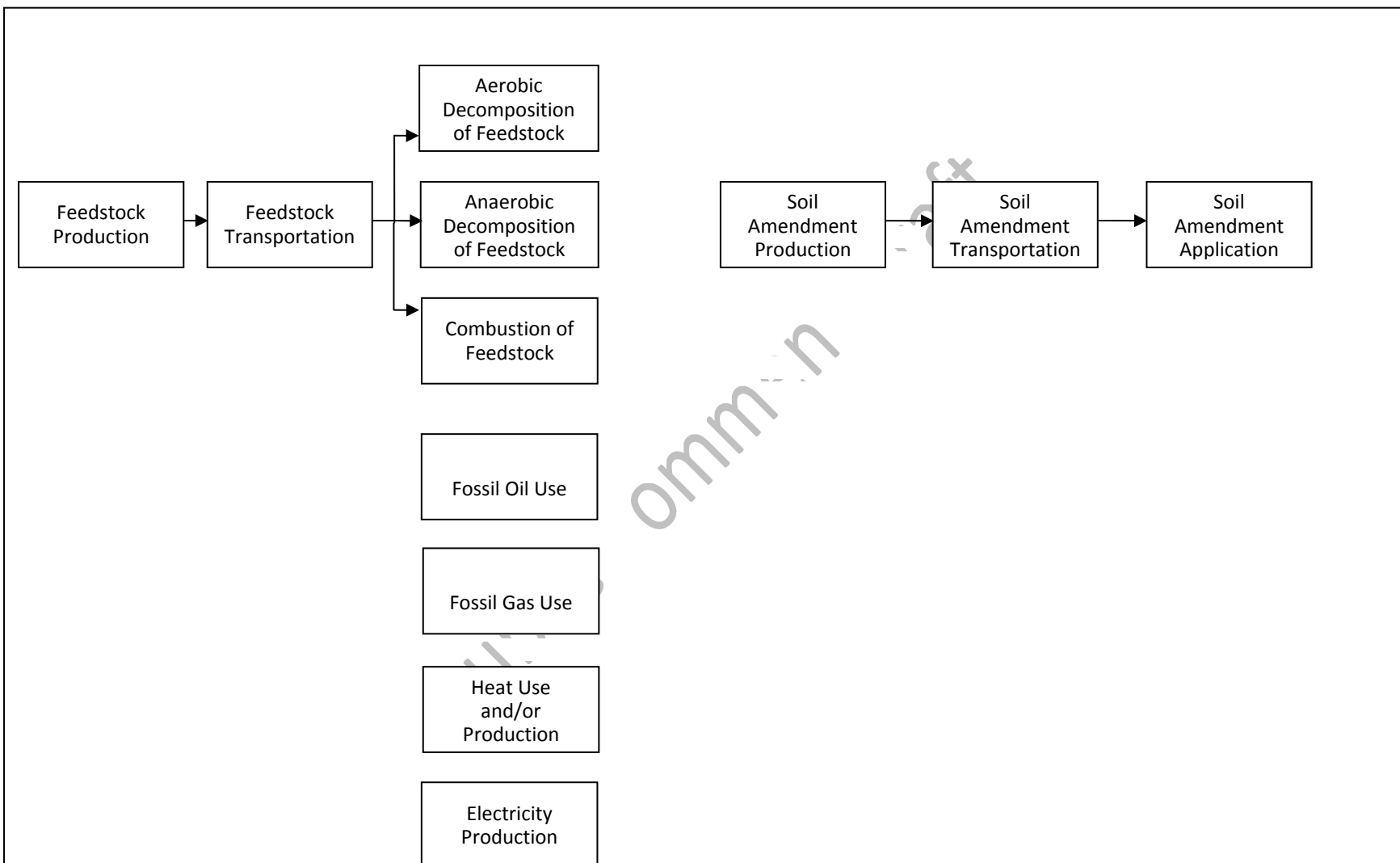
**Figure 2: Process Flow Diagram for the Baseline Condition**

**Table 2: GHG Sources**

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| **Baseline** | Feedstock Production | $CO_2$ | No | Excluded. This is a conservative assumption. |
| | | $CH_4$ | No | |
| | | $N_2O$ | No | |
| | Feedstock Transportation | $CO_2$ | No | Excluded. This is a conservative assumption. |
| | | $CH_4$ | No | |
| | | $N_2O$ | No | |
| | Aerobic Decomposition of Feedstock | $CO_2$ | No | Biogenic $CO_2$ emissions are excluded. This is a conservative assumption. |
| | | $CH_4$ | Yes | Included as primary sources of emissions in the baseline. |
| | | $N_2O$ | Yes | |
| | Anaerobic Decomposition of Feedstock in a Solid Waste Disposal System or Lagoon | $CO_2$ | No | Biogenic $CO_2$ emissions are excluded. This is a conservative assumption. |
| | | $CH_4$ | Yes | Included. Primary source of emissions in the baseline. |
| | | $N_2O$ | Yes | |
| | Combustion of Feedstock | $CO_2$ | No | Biogenic CO2 emissions are excluded. This is a conservative assumption. |
| | | $CH_4$ | Yes | Included. Primary source of emissions in the baseline. |
| | | $N_2O$ | Yes | |

| | | | |
|---|---|---|---|
| Soil Amendment Production | $CO_2$ | No | Excluded. This is a conservative assumption. |
| | $CH_4$ | No | |
| | $N_2O$ | No | |
| Soil Amendment Transportation | $CO_2$ | No | Excluded. This is a conservative assumption. |
| | $CH_4$ | No | |
| | $N_2O$ | No | |
| Soil Amendment Application | $CO_2$ | No | Excluded. This is a conservative assumption. |
| | $CH_4$ | No | |
| | $N_2O$ | No | |
| Fossil Oil Use | $CO_2$ | Yes | Included. The emissions associated with the use of fossil oil, fossil gas and heat energy that would have been required to compensate for the heat produced in the project condition must be accounted for. |
| | $CH_4$ | Yes | |
| | $N_2O$ | Yes | |
| Fossil Gas Use | $CO_2$ | Yes | |
| | $CH_4$ | Yes | |
| | $N_2O$ | Yes | |
| Heat Use and/or Production | $CO_2$ | Yes | This emission source is not to be included if the emissions associated are covered under an existing cap-and-trade or |
| | $CH_4$ | Yes | |

| | | | |
|---|---|---|---|
| | $N_2O$ | Yes | other regulatory framework in the jurisdiction of Biochar production.[1]<br><br>If Biomass Residues would have made energy in the baseline, these emission sources cannot be included. |
| Electricity Production | $CO_2$ | Yes | Included. The emissions associated with the production of grid electricity to compensate for the equivalent amount of power produced in the project condition.<br><br>This emission source is not to be included if the project occurs in a Developed Nation or the emissions associated could potentially be covered under an existing cap-and-trade regulatory framework in the jurisdiction of Biochar production.[1] |
| | $CH_4$ | **Yes** | |
| | $N_2O$ | **Yes** | |

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[1] If the project occurs in a region in which there is an emissions trading program or any other mechanism that includes GHG allowance trading, these emissions cannot be accounted for unless evidence is provided that the GHG emission reductions associated with generating renewable energy (in the case of fossil oil use, fossil gas use or heat production) or renewable electricity (in the case of electricity production) have not and will not be otherwise counted or used under the cap-and-trade program or other mechanism.

| | | | |
|---|---|---|---|
| | | | This emission source is also not applicable if the environmental benefit associated with the renewable electricity is already claimed and sold (for example as a Renewable Energy Certificate (REC)).[2] |
| | | | If Biomass Residues would have generated energy in the baseline, this emission source cannot be included. |

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[2] If environmental credits, RECs or other forms of credit documentation have been issued, the Project Proponent shall either not include this emission source or provide evidence that the RECs have not been used and have been cancelled from the environmental credit.

**Table 2: GHG Sources (continued)**

| | Source | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| **Project** | Feedstock Production | $CO_2$ | No | Excluded. The production of the Feedstock material would be equivalent to the production of residues on a unit of production basis. The exclusion of purpose grown crops ensures that the equivalency is maintained. As such, it is conservative to exclude consideration of this source. |
| | | $CH_4$ | No | |
| | | $N_2O$ | No | |
| | Feedstock Transportation | $CO_2$ | Yes | Included. Potentially important emission source. Can be excluded if the Project Proponent can demonstrate the emissions are *De Minimis* or the Feedstocks originate at the site of the Pyrolysis unit. |
| | | $CH_4$ | No | Excluded for simplification. This emission source is assumed to be very small. |
| | | $N_2O$ | No | |
| | Electricity Consumed | $CO_2$ | Yes | Included. The $CO_2$ emissions associated with the consumption of grid electricity are likely to have a material impact on projects. |
| | | $CH_4$ | No | Excluded for simplification. This emission source is assumed to be very small. |
| | | $N_2O$ | No | |

| | | | | |
|---|---|---|---|---|
| Feedstock Processing and Drying | $CO_2$ | Yes | Included as this source/sink is likely to have a material impact on projects. | |
| | $CH_4$ | Yes | | |
| | $N_2O$ | Yes | | |
| Pyrolysis, or Thermochemical Conversion, of Non-Biogenic Feedstock | $CO_2$ | Yes | Included as this source/sink is likely to have a material impact on projects. Biogenic emissions are excluded. | |
| | $CH_4$ | Yes | | |
| | $N_2O$ | Yes | | |
| Auxiliary Fuel Consumption | $CO_2$ | Yes | Included as this source/sink is likely to have a material impact on projects. | |
| | $CH_4$ | Yes | | |
| | $N_2O$ | Yes | | |
| Biochar Transportation | $CO_2$ | No | Excluded. Transportation would be equivalent to the Baseline Scenario transportation for Soil Amendments. Further, the quantity of emissions from transporting this material is minimal, given the economic limitations of transporting Biochar a significant distance. | |
| | $CH_4$ | No | | |
| | $N_2O$ | No | | |
| Bio-Oil Processing | $CO_2$ | Yes | Included as this source/sink is likely to have a material impact on projects. | |
| | $CH_4$ | Yes | | |
| | $N_2O$ | Yes | | |
| Bio-Oil Transportation | $CO_2$ | No | Excluded as under the majority of configurations, bio-oil is consumed on-site or included within the broader fuel delivery network. | |
| | $CH_4$ | No | | |
| | $N_2O$ | No | | |

| | | | Shipping distances for this material would be minimal given the economic limitations associated with transporting these materials significant distances. |
|---|---|---|---|
| Bio-Oil Use | $CO_2$ | No | $CO_2$ emissions are excluded because they are biogenic. |
| | $CH_4$ | Yes | Included as this source/sink is likely to have a material impact on projects. |
| | $N_2O$ | Yes | |
| Syngas Processing | $CO_2$ | Yes | Included as this source/sink is likely to have a material impact on projects. |
| | $CH_4$ | Yes | |
| | $N_2O$ | Yes | |
| Syngas Transportation | $CO_2$ | No | Excluded as under the majority of configurations, syngas is consumed on-site or included within the broader fuel delivery network. Shipping distances for this material would be minimal given the economic limitations associated with transporting these materials significant distances. |
| | $CH_4$ | No | |
| | $N_2O$ | No | |
| Syngas Use | $CO_2$ | No | $CO_2$ emissions are excluded because they are biogenic. |
| | $CH_4$ | Yes | Included as this source/sink is |

| | | | |
|---|---|---|---|
| | $N_2O$ | Yes | likely to have a material impact on projects. |
| Process Heat Use | $CO_2$ | No | This source is excluded as there are no emissions associated with its direct use. |
| | $CH_4$ | No | |
| | $N_2O$ | No | |
| Biochar Application | $CO_2$ | No | Excluded. Emissions associated with the activity of applying Biochar to soil will be equivalent to the Baseline Scenario of applying Soil Amendments. |
| | **$CH_4$** | **No** | |
| | **$N_2O$** | **No** | |
| | | | |
| | | | |

**Table 3: Carbon Pools**

| | Carbon Pools | Included? | Justification/Explanation |
|---|---|---|---|
| Baseline | Carbon sequestered in Feedstocks for the project | No | Carbon Dioxide emissions from the combustion or decomposition of Feedstocks, which are all waste residues, are considered biogenic. |
| Project | Stable carbon sequestered in Biochar | Yes | This is the primary source of emission reductions captured by this Methodology. |
| | Above ground biomass where Biochar is integrated | No | It is assumed that the integration of Biochar into soils will increase their productivity and therefore increase above ground biomass. It is therefore conservative to |

| | | |
|---|---|---|
| | | exclude this pool. |
| Soil organic carbon where the Biochar is integrated | No | Additions of Biochar to soil have been observed to both enhance the stabilization of existing, native carbon in that soil (referred to as negative priming) and to cause it to decompose more rapidly (called positive priming). Woolf and Lehmann (2012), in a review of the literature on priming, found negative priming to be orders of magnitude larger than positive priming. While positive priming may occasionally occur, it is more rare and limited to specific soil and environmental conditions not commonly found where Biochar is applied. A correction factor has been applied to the negative emissions attributed to Biochar sequestration to address the risk of positive priming. |

## 3.2 Temporal Boundaries

The Crediting Period for this project type is seven years.

The minimum project term is seven years: This is the minimum length of time for which a Project Proponent commits to project continuance, monitoring and verification.

# 4 PROCEDURE FOR DETERMINING THE BASELINE SCENARIO AND ADDITIONALITY

## 4.1 Procedure for Determining the Baseline Scenario

*Default Baseline Scenario:*

It is assumed that the Baseline Scenario for projects applying this Methodology consists of the combustion of all Feedstocks with energy capture (heat and/or electricity) in a bioenergy production facility. Bioenergy production has been identified as the most conservative Baseline Scenario for consideration under this Methodology as it represents the most conservative comparable alternative when considering the potential GHG reductions from the use of the Feedstock. Further, this considers the potential for these uses to generate other environmental credits. Citing bioenergy as the default Baseline Scenario results in the exclusion of all electricity, heat, bio-oil, and biogas production, as well as a negation of all benefits of methane generation avoidance. Other Baseline Scenarios may exist, however, adequate proof of alternative baseline Feedstock usage must be provided in order to justify using any non-bioenergy Baseline Scenario calculations.

Project Proponents must identify the bioenergy baseline for each individual Feedstock processed by their project for either of the following Feedstock end uses:

- The biomass residue is burned in a controlled manner to generate heat or electricity that is captured and used;
- The biomass residue is sold to other consumers in the market and the predominant use of the Biomass Residues in the region/country is for energy purposes (heat and/or power generation).

The Project Proponent shall establish a baseline condition for each Feedstock processed by the project. The Project Proponent has the option to assume that all Feedstocks would have been managed for bioenergy production, because this is the most conservative option. The table below outlines how the default baseline condition will be classified throughout the remainder of this Methodology.

**Table 4: Default baseline condition parameter**

| Default baseline condition | Baseline condition *i* | Parameter (FS$_i$) |
|---|---|---|
| The biomass residue is burnt in a controlled manner to generate heat or electricity that is captured and used.<br><br>OR<br><br>The biomass residue is sold to other consumers in the market and the predominant use of the Biomass Residues in the region/country is for energy purposes (heat and/or power generation). | Bioenergy production | FS $_B$ |

*Alternative Baseline Scenarios:*

Alternative Baseline Scenarios for projects applying this Methodology must be either 1) the decomposition of the Feedstock, under either aerobic or anaerobic conditions, or 2) the combustion of the Feedstock, without energy capture. In all these scenarios, carbon returns to the atmosphere as part of the biogenic carbon cycle. The combustion or decomposition processes may be controlled or uncontrolled. Appropriate evidence must be provided by Project Proponents in order to qualify for any alternative non-bioenergy-production Baseline Scenario.

In the agriculture sector, this could include the lagoon treatment or composting of agricultural residues and their re-application to the land. In the forestry sector, this could include the decomposition of forestry residues on the forest floor, lagoon treatment of mill residues, or the combustion of the material where there is no energy recovery. For other waste streams such as food waste or other Feedstocks collected from industrial, commercial, institutional and residential sources, these materials may either be disposed of in landfills (with or without gas capture), anaerobic lagoons, composted or incinerated.

If an alternative Baseline Scenario is used, Project Proponents must demonstrate that this is the most reasonable and credible baseline for each individual Feedstock processed by their project using the most recent version of the methodological tool "*Combined tool to identify the*

*Baseline Scenario and determine Additionality"* accessible through the UNFCC website (United Nations 2012d).

For each source of biomass residue, the Project Proponent shall use *Step 1: Identification of alternative scenarios to the proposed project activity that are consistent with current laws and regulations*, to identify alternative uses for the biomass residue. The alternatives to be analyzed for use of Biomass Residues include, *inter alia*:

- The biomass residue is dumped or left to decay under mainly aerobic conditions. This applies, for example, to dumping and decay of Biomass Residues on fields or the controlled composting of the residue;
- The biomass residue is dumped or left to decay under clearly anaerobic conditions at a Solid Waste Disposal Site(s) (SWDS);
- The biomass residue is managed under clearly anaerobic conditions in a wastewater lagoon.
- The biomass residue is burnt in an uncontrolled manner without utilizing it for energy purposes;
- The proposed project activity is undertaken with the biomass residue but without being registered as a Carbon Offset project (the Biomass Residues are pyrolyzed but no Carbon Offset payments are made);
- Any other use of the biomass residue (i.e. anaerobic digestion).

*Step 2: Barrier analysis to eliminate alternatives to the project activity that face prohibitive barriers:*

Establish a complete list of barriers that would prevent alternative scenarios for the use of Biomass Residues to occur in the absence of the Carbon Offset project. In doing so, relevant local regulations governing the use of different technologies and technical specifications of Biochar products should be taken into account.

*Step 3: Investment Analysis:*

This Step serves to determine which of the alternative scenarios in the short list remaining after Step 2 is the most economically or financially attractive. For this purpose, an investment comparison analysis is conducted for the remaining alternative scenarios after Step 2. If the investment analysis is conclusive, the economically or financially most attractive alternative scenario is considered as the Baseline Scenario.

*Step 4: Common Practice Analysis*

The previous Steps shall be complemented with an analysis of the extent to which the proposed project type (i.e. technology or practice) has already diffused in the relevant sector and geographical area. This test is a credibility check to demonstrate Additionality which complements the barrier analysis (Step 2) and, where applicable, the investment analysis (Step 3).

Based on these steps, the Project Proponent shall establish a baseline condition for each Feedstock processed by the project. The table below outlines how the most plausible baseline condition will be classified throughout the remainder of this Methodology.

**Table 5: Alternative baseline condition parameters**

| Most plausible alternative baseline condition | Baseline condition *i* | Parameter (FS$_i$) |
|---|---|---|
| The biomass residue is dumped or left to decay under mainly aerobic conditions. This applies, for example, to dumping and decay of Biomass Residues on fields. | Aerobic decomposition | FS$_A$ |
| The biomass residue is dumped or left to decay under clearly anaerobic conditions at a Solid Waste Disposal Sites (SWDS). | Anaerobic decomposition in SWDS | FS$_{An}$ |
| The biomass residue is managed under clearly anaerobic conditions in a wastewater lagoon. | Anaerobic decomposition in lagoon | FS$_L$ |
| The biomass residue is burnt in an uncontrolled manner without utilizing it for energy purposes; | Combustion | FS$_C$ |

If the most plausible baseline condition for biomass residue type *j* is not listed in the table above, the Project Proponent shall justify a conservative assumption for the baseline condition *i* of the Feedstock.

## 4.2 Procedure for Demonstrating Additionality

Additionality will be assessed and demonstrated using the most recent version of the methodological tool *"Combined tool to identify the Baseline Scenario and determine Additionality"* as published on the UNFCCC website (United Nations 2012e).

# 5 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

Note: values are given for each parameter in the parameter tables in 6.1 and 6.2.

## 5.1 Baseline Emissions

Baseline quantification in this Methodology is projection based, using projections of reductions or removals in the project to estimate the baseline emissions that would have occurred in the absence of the project. Emissions under the baseline condition are determined using the following equations:

**Default Baseline** (Feedstock would have been used only for bioenergy production)

$$BE_y = BE_{B,y} \qquad (1)$$

Where:

   $BE_y$ = the sum of the baseline emissions in year $y$

   $BE_{B,y}$ = emissions due to the combustion of Feedstock for bioenergy $B$ production in year $y$

OR, with appropriate evidence:

**Alternative Baseline**:

$$BE_y = BE_{A,y} + BE_{An,y} + BE_{L,y} + BE_{C,y} + BE_{E,y} + BE_{O,y} + BE_{G,y} + BE_{H,y}$$

$$(2)$$

Where:

   $BE_y$ = the sum of the baseline emissions in year $y$

   $BE_{A,y}$ = emissions due to the aerobic decomposition $A$ of Feedstock in year $y$

   $BE_{An,y}$ = emissions due to the anaerobic decomposition $An$ of Feedstock in an SWDS in year $y$

$BE_{L,y}$ = emissions due to the anaerobic decomposition of Feedstock in a lagoon $L$ in year $y$

$BE_{C,y}$ = emissions due to the combustion $C$ of Feedstock without bioenergy production in year $y$

$BE_{E,y}$ = auxiliary emissions due to the use of electricity $E$ in year $y$

$BE_{O,y}$ = auxiliary emissions due to the use of fossil oil $O$ in year $y$

$BE_{G,y}$ = auxiliary emissions due to the use of fossil gas $G$ in year $y$

$BE_{H,y}$ = auxiliary emissions due to the use of heat $H$ in year $y$

**Step 1: Identify the baseline condition**

Project Proponents shall use the steps outlined in Section 4.1 of this document to determine the Baseline condition $i$ for each Feedstock.

**Table 6: Baseline Conditions**

| Baseline condition $i$ | Parameter ($FS_i$) |
|---|---|
| Bioenergy production (default) | $FS_B$ |
| Aerobic decomposition | $FS_A$ |
| Anaerobic decomposition in a SWDS | $FS_{An}$ |
| Anaerobic decomposition in a lagoon | $FS_L$ |
| Combustion without bioenergy production | $FS_C$ |

Every stream of Feedstock that is processed into Biochar is assumed to be diverted from bioenergy production under the default calculations (Equation 1), unless otherwise justified by the procedure for determining the Baseline Scenario. Alternative Feedstock diversions may include those for aerobic decomposition, anaerobic decomposition in a Solid Waste Disposal Site (SWDS) or in a lagoon, or combustion without energy capture, and are addressed using the alternative calculations (Equation 2).

**Step 2: Identify the Feedstock composition**

The composition of Feedstock from Biomass Residues may vary and should be classified into the following categories:

**Table 7: Feedstock Categories**

| Feedstock type *j* | Parameter (p$_j$) |
|---|---|
| Wood and wood products | P$_W$ |
| Pulp, paper and cardboard (other than sludge) | P$_P$ |
| Food, food waste, beverages and tobacco (other than sludge) | P$_F$ |
| Textiles | P$_T$ |
| Garden, yard and park waste | P$_G$ |
| Glass, plastic, metal, other inert waste (non-biogenic) | P$_{NB}$ |

The amount of Feedstock type *j* prevented from baseline disposal *i* is calculated using sampling as follows:

$$FS_{i,j,y} = \sum_i FS_{i,y} \times \frac{\sum_{n=1}^z p_{n,j,y}}{z} \qquad (3)$$

Where:

FS$_{i,j,y}$ = the amount of Feedstock type *j* prevented from baseline disposal *i* in year *y* (t)

FS$_{i,y}$ = total amount of Feedstock  prevented from baseline disposal *i* in year *y* (t)

P$_{n,j,y}$ = weight fraction of the Feedstock type *j*  in the sample *n* collected during year *y* (t)

Z = number of samples collected during year *y*

Equation (3) determines the fraction of each individual Feedstock type used for one discreet Biochar production event (same Feedstock blend ratios and same production parameters). The mass of each Feedstock type (e.g. straw) is calculated by identifying the fraction it represents in the total mass of incoming Feedstock. Thus, if a Feedstock is a 60:35:5 blend of straw, wood chips, and non-biogenic material (as identified by following Feedstock determination and sampling procedures outlined in the *IBI Biochar Standards* (2013)), and the total volume of incoming Feedstock diverted from landfill disposal is 240 tonnes for year 1, the calculation is: 240t * 0.6 for straw, 240t * 0.35 for wood chips, and 240t * 0.05 for non-biogenic materials, resulting in 144, 84, and 12 tonnes for straw, wood chips and non-biogenic Feedstocks, respectively. This same procedure may be used to identify the total volume of each Feedstock

fraction, for each disposal type, including non-biogenic materials. These FS*i,j,y* values will be used in subsequent calculations to determine the total emission reduction.

### *Bioenergy Production (Default)*

The emissions due to the combustion of Feedstock for producing bioenergy (heat and/or electricity) are calculated as follows:

$$BE_{B,y} = \sum_i FS_{Bj,y} \times EF_{CH4,i} \; ; \sum_i FS_{Bj,y} \times EF_{N2O,i} \tag{4}$$

Where:

BE$_{B,y}$ = Baseline emissions due to the combustion of Feedstock for bioenergy *B* production in year *y*

FS $_{B,j,y}$ = the amount of Feedstock type *j* prevented from baseline condition *bioenergy production B* in year *y* (t)

EF$_{CH4,i}$ = the CH$_4$ emission factor for the Feedstock type *j* prevented from the baseline condition *i* (kg CH$_4$/kg)

EF$_{N2O,i}$ = the N$_2$O emission factor for the Feedstock type *j* prevented from the baseline condition *i* (kg N$_2$O/kg)

### *Aerobic Decomposition (Alternative)*

The emissions due to the aerobic decomposition of Feedstock are calculated as follows:

$$BE_{A,y} = \sum \left( FS_{A,j,y} \times EF_{ACH4,y} \times GWP_{CH4} \right) \; ; \left( FS_{A,j,y} \times EF_{AN2O,y} \times GWP_{N2O} \right) \tag{5}$$

Where:

BE$_{A,y}$ = Baseline emissions due to the aerobic decomposition *A* of Feedstock in year *y*

FS $_{A,j,y}$ = the fraction of Feedstock type *j* diverted from aerobic decomposition *A* in year *y* (t)

EF$_{ACH4,y}$ = the emission factor for methane *CH$_4$* per tonne of waste diverted from aerobic decomposition *A* valid in year *y* (t CH$_4$/t)

GWP$_{CH4}$ = Global Warming Potential of *CH$_4$* (t CO$_2$e/t CH$_4$); 21

EF$_{AN2O,y}$ = the emission factor for nitrous oxide $N_2O$ per tonne of waste diverted from aerobic decomposition $A$, valid in year $y$ (t $N_2O$/t)

GWP$_{N2O}$ = Global Warming Potential of $N_2O$ (t $CO_2$e/t $N_2O$); 310[3]

### *Anaerobic Decomposition in a SWDS (Alternative)*

The emissions due to the anaerobic decomposition of Feedstock in an SWDS are calculated as follows:

$$BE_{An,y} = \varphi \times \left(1 - f_y\right) \times GWP_{CH4} \times (1 - OX) \times \frac{16}{12} \times F \times DOC_{f,y} \times MCF_y$$

$$\times \sum_{y=1}^{10} \sum_{i} FS_{an,j,y} \times \left[e^{-k_j \cdot (y-1)} \times \left(1 - e^{-k_j}\right)\right] \times DOC_j \tag{6}$$

Where:

BE$_{An,y}$ = Baseline emissions due to the anaerobic decomposition $An$ of Feedstock in an SWDS in year $y$

$\varphi$ = Model correction factor to account for model uncertainties for year $y$

$f_y$ = the recovered methane at the landfill in year $y$ (%)

GWP$_{CH4}$ = the Global Warming Potential of methane $CH_4$ (t $CO_2$e/t $CH_4$); 21

OX = the oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil or other material covering the waste)

16/12 = Ratio of molecular weights of Methane (16) to Carbon (12)

F = the fraction of methane in the SWDS gas (%)

DOC$_{f,y}$= the fraction $f$ of degradable organic carbon that decomposes under the specific conditions occurring in the SWDS for year $y$

MCF$_y$ = Methane conversion factor for year $y$

FS$_{an,j,y}$ = the amount of Feedstock type $j$ prevented from baseline condition anaerobic decomposition $AN$ in an SWDS in year $y$ (t)

DOC$_j$ = the degradable organic carbon in the Feedstock type $j$

k$_j$ = the decay rate for the Feedstock type $j$ (l/yr)

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[3] SAR-100 GWP values for $CH_4$ and $N_2O$, from the IPCC Fourth Assessment Report (AR4), Working Group 1, Chapter 2, Table 2.14 (page 212) at http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch02.pdf.

### Anaerobic Decomposition in a Wastewater Lagoon (Alternative)

The emissions due to the anaerobic decomposition of Feedstock in a wastewater lagoon are calculated as follows:

$$BE_{Ly} = BE_{LCH4,MCFy} + BE_{LN2O,y} \qquad (7)$$

Where:

> $BE_{Ly}$ = Baseline methane emissions from the anaerobic treatment of wastewater in open anaerobic lagoons $L$, or of sludge in sludge pits in the absence of the project activity in year $y$ (tCO$_2$e)
>
> $BE_{LCH4, MCFy}$ = Baseline lagoon $L$ methane $CH_4$ emissions (tCO$_2$e) determined using the Methane Conversion Factor (MCF$_y$)
>
> $BE_{LN2O, y}$ = Annual baseline of lagoon $L$ N$_2$O emissions in (tCO$_2$e/yr)

The methane emissions due to the anaerobic decomposition of Feedstock in a wastewater lagoon are calculated as follows:

$$BE_{LCH4,MCFy} = GWP_{CH4} \times MCF_{BLy} \times B_o \times COD_{BLy} \qquad (8)$$

Where:

> $BE_{LCH4, MCFy}$ = Baseline lagoon $L$ methane $CH_4$ emissions (tCO$_2$e) determined using the Methane Conversion Factor (MCF$_y$)
>
> $GWP_{CH4}$ = the Global Warming Potential of methane $CH_4$ (t CO$_2$e/t CH$_4$); 21
>
> $MCF_{BLy}$ = Average baseline $B$ lagoon $L$ methane conversion factor (fraction) in year $y$, representing the fraction of (COD$_{BLy}$ x B$_o$) that would be degraded to CH$_4$ in the absence of the project activity
>
> $B_o$ = Maximum methane production capacity, expressing the maximum amount of CH$_4$ that can be produced from a given quantity of chemical oxygen $O$ demand (tCH$_4$/tCOD)
>
> $COD_{BLy}$ = Baseline $B$ quantity of chemical oxygen demand that would be treated in anaerobic lagoons $L$ or sludge pits in the absence of the project activity in year $y$ (tCOD)

$$(9)$$
$$MCF_{BLy} = f_d \times f_{Ty} \times 0.89$$

Where:

$MCF_{BLy}$ = Average baseline *B* lagoon L methane conversion factor (fraction) in year y, representing the fraction of ($COD_{BLy}$ x $B_o$) that would be degraded to $CH_4$ in the absence of the project activity.

$f_d$ = Factor expressing the influence of the depth *d* of the anaerobic lagoon or sludge pit on methane generation

$f_{Ty}$ = Factor expressing the influence of the temperature T on the methane generation in year *y*

0.89 = Conservativeness factor

The monthly value of $f_{Ty}$ is calculated as follows, using the "van't Hoff-Arrhenius" approach:

$$f_{Ty} = 0.104; \text{ if } T_{2,m} < 278K \qquad (10)$$

$$= e^{\left(\frac{E*(T_{2,m}-T_l)}{R*T_l*T_{2,m}}\right)}; \text{ if } 278K \leq T_{2,m} \leq 302.5K$$

$$= 0.95; \text{ if } T_{2,m} > 302.5K$$

Where:

$f_{Ty}$ = Factor expressing the influence of the temperature *T* on the methane generation in year *y.*

*e* = Activation energy constant (15,175 cal/mol)

$T_{2,m}$ = Average temperature T at the project site in month *m* (K)

$T_l$ = 303.15 K (273.15 K + 30 K)

R = Ideal Gas Constant (1.986 cal/K mol)

*m* = Months of year *y* of the crediting period.

The annual value of $f_{Ty}$ is calculated as follows:

$$(11)$$

$$f_{Ty} = \frac{\sum_{m=1}^{12} f_{Tm} \times COD_{available,m}}{\sum_{m=1}^{12} COD_{BL,m}}$$

Where:

$f_{Ty}$ = Factor expressing the influence of the temperature *T* on the methane generation in year *y.*

$f_{Tm}$ = Factor expressing the influence of the temperature *T* on the methane generation in month *m.*

COD$_{available,m}$ = Quantity of chemical oxygen demand available for degradation in the anaerobic lagoon or sludge pit in month $m$ (tCOD)

COD$_{BL,m}$ = Baseline $B$ quantity of chemical oxygen demand that would be treated in anaerobic lagoon $L$ or sludge pits in the absence of the project activity in month $m$ (tCOD)

$m$ = months of the year $y$ of the crediting period.

For each month m, the quantity of wastewater directed to the anaerobic lagoon, the quantity of organic compounds that decay and the quantity of any effluent from the lagoon is balanced, giving the quantity of COD that is available for degradation in the next month. The amount of organic matter available for degradation to methane (COD$_{available,m}$) is assumed to be equal to the amount of organic matter directed to the anaerobic lagoon or sludge pit, less any effluent, plus the COD that may have remained in the lagoon or sludge pit from the previous months as follows:

$$COD_{available,m} = COD_{BL,m} + \left(1 - f_{T,m-1}\right) \times COD_{available,m-1}$$

with

$$COD_{BLm} = \left(1 - \frac{COD_{out,x}}{COD_{in,x}}\right) \times COD_{PJm} \qquad (12)$$

and

$$COD_{PJ,m} = F_{PJ,AD,m} \times COD_{AD,m}$$

Where:

COD$_{available,m}$ = Quantity of chemical oxygen demand available for degradation in the anaerobic lagoon or sludge pit in month $m$ (tCOD)

$m$ = months of the year $y$ of the crediting period

COD$_{BL,m}$ = Baseline $B$ quantity of chemical oxygen demand that would be treated in anaerobic lagoons or sludge pits in the absence of the project activity in month $m$ (tCOD)

$f_{T,m-1}$ = Factor expressing the influence of the temperature $T$ on the methane generation in month $m$-1

COD$_{out,x}$ = COD of the effluent $out$ in period $x$ (tCOD)

COD$_{in,x}$ = COD directed to *in* open lagoons or in sludge pits in the period *x* (tCOD)

*x* = representative historical reference period

COD$_{PJm}$ = Quantity of chemical oxygen demand of the waste stream *J* that is treated in the Pyrolysis *P* unit or under clearly aerobic conditions in the project activity in month *m* (tCOD)

F$_{PJ,AD,m}$ = Quantity of wastewater or sludge that is treated in the Pyrolysis *P* unit or under clearly aerobic conditions (aerobic decomposition) *AD* in the project activity in month *m* (m$^3$)

COD$_{AD,m}$ = Chemical oxygen demand in the wastewater or sludge that is treated in the Pyrolysis unit or under clearly aerobic conditions *AD* in the project activity in month *m* (tCOD/m$^3$)

$$COD_{BLy} = \rho \times \left( 1 - \frac{COD_{out,x}}{COD_{in,x}} \right) \times COD_{PJy} \qquad (13)$$

Where:

COD$_{BLy}$ = Baseline *B* quantity of chemical oxygen demand that would be treated in anaerobic lagoon or sludge pits in the absence of the project activity in year *y* (tCOD)

COD$_{PJy}$ = Quantity of chemical oxygen demand of the waste stream *J* that is treated in the Pyrolysis *P* unit or under clearly anaerobic conditions in the project activity in year *y* (tCOD)

COD$_{out,x}$ = COD of the effluent *out* in the period *x* (tCOD)

COD$_{in,x}$ = COD directed to *in* the anaerobic lagoons or sludge pits in the period *x* (tCOD)

*x* = Representative historical reference period

$\rho$ = Discount factor to account for the uncertainty of the use of historical data to determine COD$_{BLy}$

$$COD_{PJy} = \sum_{m=1}^{12} F_{PJ,AD,m} \times COD_{AD,m} \qquad (14)$$

Where:

COD$_{PJy}$ = Quantity of chemical oxygen demand that is treated in the Pyrolysis *P* unit or under clearly aerobic conditions in the project activity in year *y* (tCOD)

F$_{PJ,AD,m}$ = Quantity of wastewater or sludge that is treated in the Pyrolysis *P* unit or under clearly aerobic conditions *AD* in the project activity in month *m* (m$^3$)

$COD_{AD,m}$ = Chemical oxygen demand in the wastewater or sludge that is treated in the Pyrolysis unit or under clearly aerobic conditions $AD$ in the project activity in month $m$ (tCOD/m$^3$)

$m$ = months of year $y$ of the crediting period

The nitrous oxide emissions due to the nitrification/denitirification of manure Feedstocks in a wastewater lagoon are calculated as follows:

$$BE_{LN2O,y} = GWP_{N2O} \times CF_{N2O-N,N} \times \frac{1}{1000} \times (E_{LN2O,D,y} + E_{LN2O,ID,y}) \qquad (15)$$

Where:

$BE_{LN2O,y}$ = Baseline emissions of lagoon $L$ N$_2$O due to the nitrification/denitirification of manure Feedstocks (tCO$_2$e)

$GWP_{N2O}$ = Global Warming Potential (GWP) for $N_2O$ (tCO$_2$e/tN$_2$O); 310

$CF_{N2O-N, N}$ = Conversion factor N$_2$O-N to N$_2$O (44/28)

$E_{LN2O, D, y}$ = Direct $D$ N$_2$O emission in year $y$ (t N$_2$O-N/year)

$E_{LN2O, ID, y}$ = Indirect $ID$ N$_2$O emission in year $y$ (t N$_2$O-N/year)

$$E_{LN2O,D,y} = \sum_{j} EF_{N2O,D,j} \times \sum_{m=1}^{12} (Q_{EM,m} \times [N]_{EM,m}) \qquad (16)$$

$$E_{LN2O,ID,y} = EF_{LN2O,ID} \times \sum_{j,LT} F_{gasMS,j,LT} \times \sum_{m=1}^{12} (Q_{EM,m} \times [N]_{EM,m}) \qquad (17)$$

Where:

$E_{LN2O, D, y}$ = Direct $D$ lagoon $L$ $N_2O$ emission in year $y$ (t N$_2$O-N/year)

$E_{LN2O, ID, y}$ = Indirect $ID$ lagoon $L$ $N_2O$ emission in year $y$ (t N$_2$O-N/year)

$EF_{LN2O, D, j}$ = Direct $D$ lagoon $L$ $N_2O$ emission factor for the treatment system $j$ of the manure management system (t N$_2$O-N/t N)

$Q_{EM, m}$ = Monthly volume of the effluent mix $EM$ entering the manure management system (m$^3$/month) month $m$

$[N]_{EM, m}$ = Monthly total nitrogen concentration in the effluent mix $EM$ entering the manure management system (t N/m$^3$) month $m$

$EF_{LN2O, ID}$ = Indirect *ID* lagoon *L* $N_2O$ emission factor for $N_2O$ emissions from atmospheric deposition of nitrogen on soils and water surfaces (t $N_2O$-N/t $NH_3$-N and NOx-N)

$F_{gasMS, j, LT}$ = Default values for nitrogen loss due to volatilization of $NH_3$ and NOx from manure management (fraction)

## *Combustion (Alternative)*

The emissions due to the combustion of Feedstock without bioenergy production are calculated as follows:

$$BE_{C,y} = \sum_i FS_{C,j,y} \times EF_{CH4,i} \times GWP_{CH4}; \sum_i FS_{C,j,y} \times EF_{N2O,i} \times GWP_{N2O} \qquad (18)$$

Where:

$BE_{C,y}$ = baseline emissions due to the combustion *C* of Feedstock without bioenergy production (t$CO_2$e) in year *y*

$FS_{C,j,y}$ = the amount of Feedstock type *j* prevented from baseline condition combustion *C* in year *y* (t)

$EF_{CH4,i}$ = the *CH₄* emission factor for combustion of the Feedstock type *j* baseline condition (pathways *i*) (kg $CH_4$/kg)

$GWP_{CH4}$ = Global Warming Potential of *CH₄* (t $CO_2$e/t $CH_4$); 21

$EF_{N2O,i}$ = the $N_2O$ emission factor for combustion of the Feedstock type *j* (kg $N_2O$/kg)

$GWP_{N2O}$ = Global Warming Potential of *N₂O* (t $CO_2$e/t $N_2O$); 310

## *Electricity Production*

The emissions due to the production of electricity that would have been required to compensate for the renewable electricity produced in the project condition are calculated as follows:

$$BE_{E,y} = E_{R,y} \times EF_{Grid} \qquad (19)$$

Where:

$BE_{E,y}$ = baseline emissions due to the production of electricity $E$ that would have been required to compensate for the renewable electricity produced in the project condition ($tCO_2e$)

$E_{R,y}$ = the net quantity of renewable electricity $R$ generated in the project condition and used off-site in year $y$ (kWh)

$EF_{Grid}$ = the regional electricity *grid* emission factor (kg $CO_2e$/kWh)

These baseline emissions $BE_{E,y}$, however, cannot be accounted for in the following scenarios:

1. The DEFAULT baseline bioenergy production has been indicated for the project. If any portion of the Feedstock used by the project would have been used for bioenergy production in the baseline, the Project Proponent cannot account for $BE_{E,y}$

2. If electricity emissions are covered by an existing regulatory framework (like a cap-and-trade program, a requirement to report GHG emissions, or any other tracking and regulation of GHGGHGGHG emissions) in the jurisdiction of the Biochar production, the Project Proponent cannot account for $BE_{E,y}$.

3. If the project occurs in an Annex 1 county, the Project Proponent cannot account for $BE_{E,y}$ because the emission reductions are indirect.

4. If the project is generating, claiming and selling Renewable Energy Certificates (RECs) or other environmental credits, the Project Proponent cannot account for $BE_{E,y}$. If RECs have been issued, the Project Proponent shall either not include this emission source or provide evidence that the RECs have not been used and have been cancelled from the environmental credit program.

### *Oil*

The emissions due to the use of fossil oil that would have been required to compensate for the bio-oil produced in the project condition are calculated as follows:

$$BE_{O,y} = \sum \left( Fuel_{i,y} \times EF\ Fuel_{CO2} \right); \sum \left( Fuel_{i,y} \times EF\ Fuel_{CH4} \right.$$
$$\left. \times GWP_{CH4} \right); \sum \left( Fuel_{i,y} \times EF\ Fuel_{N2O} \times GWP_{N2O} \right) \qquad (20)$$
$$Fuel_i = O_y \times \%_i$$

Where:

$BE_{O,y}$ = baseline emissions due to the use of fossil oil $O$ that would have been required to compensate for the bio-oil produced in the project condition (tCO$_2$e)

$Fuel_{i,y}$ = the volume of each type of liquid fuel $i$ to generate an equivalent amount of bio-oil on an energy basis in year $y$ (L, m$^3$ or other)

$O_y$ = the volume of bio-oil produced in the project condition in year $y$ (L, m$^3$ or other)

$\%_i$ = the percentage of each type of fuel offset (%)

$EF_{CO2.}$ = the $CO_2$ emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)

$EF_{CH4.}$ = the $CH_4$ emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of $CH_4$ (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the $N_2O$ emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of $N_2O$ (t CO$_2$e/t N$_2$O); 310

These baseline emissions $BE_{O,y}$ however, cannot be accounted for in the following scenarios:

1. The DEFAULT baseline bioenergy production has been indicated for the project. If any portion of the Feedstock used by the project would have been used for bioenergy production in the baseline, the Project Proponent cannot account for $BE_{O,y}$.

2. If fossil oil is covered by an existing regulatory framework (like a cap-and-trade program, a requirement to report GHG emissions, or any other tracking and regulation of Greenhouse Gas emissions) in the jurisdiction of the Biochar production, the Project Proponent cannot account for $BE_{O,y}$.

*Gas*

The emissions due to the use of fossil gas that would have been required to compensate for the syngas produced in the project condition are calculated as follows:

$$BE_{G,y} = \sum \left(Fuel_{i,y} \times EF\ Fuel_{CO2}\right); \sum \left(Fuel_{i,y} \times EF\ Fuel_{CH4}\right.$$
$$\left. \times GWP_{CH4}\right); \sum \left(Fuel_{i,y} \times EF\ Fuel_{N2O} \times GWP_{N2O}\right) \qquad (21)$$
$$Fuel_i = G_y \times \%_i$$

Where:

$BE_{G,y}$ = baseline emissions due to the use of fossil gas $G$ that would have been required to compensate for the syngas produced in the project condition (tCO$_2$e)

$Fuel_{i,y}$ = the volume of each type of gaseous fuel $i$ to generate an equivalent amount of syngas on an energy basis in year $y$ (L, m$^3$ or other)

$G_y$ = the volume of syngas produced in the project condition in year $y$ (L, m$^3$ or other)

$\%_i$ = the percentage of each type of fuel $i$ offset (%)

$EF_{CO2.}$ = the $CO_2$ emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)

$EF_{CH4.}$ = the $CH_4$ emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of $CH_4$ (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the $N_2O$ emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of $N_2O$ (t CO$_2$e/t N$_2$O); 310

These baseline emissions $BE_{G,y}$ however, cannot be accounted for in the following scenarios:

1. The DEFAULT baseline bioenergy production has been indicated for the project. If any portion of the Feedstock used by the project would have been used for bioenergy production in the baseline, the Project Proponent cannot account for $BE_{G,y}$.
2. If fossil gas is covered by an existing regulatory framework (like a cap-and-trade program, a requirement to report GHG emissions, or any other tracking and regulation of GHG emissions) in the jurisdiction of the Biochar production, the Project Proponent cannot account for $BE_{G,y}$.

*Heat*

The emissions due to the production of heat that would have been required to compensate for the heat produced in the project condition are calculated as follows:

$$BE_{H,y} = \sum \left( Fuel_{i,y} \times EF\ Fuel_{CO2} \right); \sum \left( Fuel_{i,y} \times EF\ Fuel_{CH4} \right.$$
$$\left. \times GWP_{CH4} \right); \sum \left( Fuel_{i,y} \times EF\ Fuel_{N2O} \times GWP_{N2O} \right) \tag{22}$$

$$Fuel_i = \left( H_y \times \%_i \right) / \left( NCV\ Fuel_i \times \%_{eff} \right)$$

Where:

$BE_{H,y}$ = baseline emissions due to the production of heat $H$ that would have been required to compensate for the heat produced in the project condition (tCO$_2$e)

$Fuel_{i,y}$ = the volume of fuel (fuel type $i$) to generate equivalent heat on an energy basis in year $y$ (L, m$^3$ or other)

$H_y$ = the heat load produced under the project condition in year $y$ (GJ)

$\%_i$ = the percentage of each type of fuel offset (%)

NCV Fuel$_i$ = the net calorific value of each type of fuel $i$ offset by the project (GJ/L, m$^3$ or other)

$\%_{eff}$ = the percentage of Efficiency $eff$ of the thermal energy heating system (%)

$EF_{CO2.}$ = the $CO_2$ emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)

$EF_{CH4.}$ = the $CH_4$ emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of $CH_4$ (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the $N_2O$ emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of $N_2O$ (t CO$_2$e/t N$_2$O); 310

These baseline emissions $BE_{H,y}$ however, cannot be accounted for in the following scenarios:

1. The DEFAULT baseline bioenergy production has been indicated for the project. If any portion of the Feedstock used by the project would have been used for bioenergy production in the baseline, the Project Proponent cannot account for $BE_{H,y}$.

2. If fuel$_i$ is covered by an existing regulatory framework (like a cap-and-trade program, a requirement to report GHG emissions, or any other tracking and regulation of GHG emissions) in the jurisdiction of the Biochar production, the Project Proponent cannot account for $BE_{H,y}$.

## 5.2 Project Emissions

Emissions under the project condition (in tonnes CO$_2$e) are determined using the following equation:

$$PE_y = PE_{TR,y} + PE_{P,y} + PE_{Py,y} + PE_{E,y} + PE_{PNB,y} + PE_{B,y} + PE_{OP,y} + PE_{GP,y} \\ + PE_{OU,y} + PE_{GU,y} - C_{BS,y} \tag{23}$$

Where:

$PE_y$ = the sum of the project emissions in year $y$ (t $CO_2e$)

$PE_{TR,y}$ = emissions due to the transportation $T$ of Feedstocks in year $y$ (t $CO_2$).

$PE_{P,y}$ = emissions associated with the processing $P$ and drying of Feedstock in year $y$ (t $CO_2e$)

$PE_{Py,y}$ = emissions due to the combustion of auxiliary fuel for the purpose of Pyrolysis $Py$, or thermal conversion of Feedstock in year $y$ (t $CO_2e$)

$PE_{E,y}$ = auxiliary emissions from the net consumption of electricity $E$ under the project condition in year $y$ (t $CO_2e$)

$PE_{PNB,y}$ = emissions due to the Pyrolysis $P$ of non-biogenic $NB$ Feedstock materials in year $y$ (t $CO_2e$)

$PE_{B,y}$ = auxiliary emissions due to the blending of Biochar $B$ in year $y$ (t $CO_2e$)

$PE_{OP,y.}$ = auxiliary emissions due to the processing of bio-oil $OP$ in year $y$ (t $CO_2e$)

$PE_{GP,y}$ = auxiliary emissions due to the processing of syngas $GP$ in year $y$ (t $CO_2e$)

$PE_{OU,y}$ = auxiliary emissions due to the use of bio-oil $OU$ in year $y$ (t $CO_2e$)

$PE_{GU,y}$ = auxiliary emissions due to the use of syngas $GU$ in the year $y$ (t $CO_2e$)

$C_{BS,y}$ = carbon sequestration $S$ associated with the appropriate end use and/or in-situ application of Biochar $B$ in year $y$ (t $CO_2e$)

### Feedstock Transportation

In cases where the Biomass Residues are not generated directly at the project site, Project Proponents shall determine $CO_2$ emissions resulting from transportation of the Biomass Residues to the project plant using the latest version of the tool "Project and Leakage emissions from road transportation of freight" from the Clean Development Mechanism. $PE_{TR,m}$ in the tool corresponds to the parameter $PE_{TR,y}$ in this Methodology and the monitoring period $m$ is one year.

### Processing and Drying Feedstock

The emissions associated with the processing and drying of Feedstock are calculated as follows:

$$PE_{P,y} = \sum \left( Fuel_{P,i,y} \times EF\ Fuel_{CO2} \right); \sum \left( Fuel_{P,i,y} \times EF\ Fuel_{CH4} \right.$$
$$\left. \times GWP_{CH4} \right); \sum \left( Fuel_{P,i,y} \times EF\ Fuel_{N2O} \times GWP_{N2O} \right) \tag{24}$$

Where:

> PE$_{P,y}$ = project emissions associated with the processing $P$ and drying of Feedstock in year $y$ (tCO$_2$e)
>
> Fuel$_{P,i,y}$ = the volume of each type of fuel used for drying in year $y$ (L, m$^3$ or other)
>
> EF$_{CO2.}$ = the CO$_2$ emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)
>
> EF$_{CH4.}$ = the CH$_4$ emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)
>
> GWP$_{CH4}$ = Global Warming Potential of CH$_4$ (t CO$_2$e/t CH$_4$); 21
>
> EF$_{N2O.}$ = the N$_2$O emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)
>
> GWP$_{N2O}$ = Global Warming Potential of N$_2$O (t CO$_2$e/t N$_2$O); 310

## *Auxiliary Fuel Combustion*

The emissions due to the combustion of auxiliary fuel for the purpose of Pyrolysis or thermal conversion of Feedstock are calculated as follows:

$$PE_{PY.y} = \sum \left( Fuel_{PY,i,y} \times EF\ Fuel_{CO2} \right); \sum \left( Fuel_{PY,i,y} \times EF\ Fuel_{CH4} \right. \\ \left. \times GWP_{CH4} \right); \sum \left( Fuel_{PY,i,y} \times EF\ Fuel_{N2O} \times GWP_{N2O} \right)$$

$$(25)$$

Where:

> PE$_{PY,y}$ = project emissions due to the combustion of auxiliary fuel for the purpose of Pyrolysis PY or thermal conversion in year $y$ of Feedstock (tCO$_2$e)
>
> Fuel$_{PY,i,y}$ = the volume of each type of Pyrolysis $PY$ or thermal conversion fuel (fuel type $i$) used in year $y$ (L, m$^3$ or other)
>
> EF$_{CO2.}$ = the *CO$_2$* emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)
>
> EF$_{CH4.}$ = the *CH$_4$* emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)
>
> GWP$_{CH4}$ = Global Warming Potential of *CH$_4$* (t CO$_2$e/t CH$_4$); 21
>
> EF$_{N2O.}$ = the *N$_2$O* emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)
>
> GWP$_{N2O}$ = Global Warming Potential of *N$_2$O* (t CO$_2$e/t N$_2$O); 310

## *Electricity Consumption*

The emissions due to the consumption of electricity in the project condition are calculated as follows:

$$PE_{E,y} = E_{G,y} \times EF_{Grid} \qquad (26)$$

Where:

> $PE_{E,y}$ = project emissions due to the consumption of electricity $E$ in the project condition ($tCO_2e$)
>
> $E_{G,y}$ = the quantity of grid $G$ electricity consumed in the project condition in year $y$ (kWh)
>
> $EF_{Grid}$ = the regional electricity *grid* emission factor (kg $CO_2e$/kWh)

If the project occurs in a country or region in which there is an operational cap-and-trade system, requirement to report Greenhouse Gas emissions, or any other tracking and regulation of GHG emissions that covers this electricity, these emissions still need to be accounted for. If, in the baseline, auxiliary emissions due to the use of electricity ($BE_{E,y}$) are not accounted for and total electricity being generated by the project activities in year $y$ is greater than or equal to the project's electricity consumption in year $y$, then the quantity of electricity consumed by the project does not need to be accounted for and $PE_{E,y}$ shall be 0.

### *Non-Biogenic Pyrolysis*

The emissions due to the Pyrolysis of non-biogenic Feedstock materials are calculated as follows:

$$PE_{NB,y} = \sum_i FS_{PNB,y} \times EF_{CO2,i} ; \sum_i FS_{NBy} \times EF_{CH4,i} \times GWP_{CH4} ; \sum_i FS_{PNB\,y} \qquad (27)$$
$$\times EF_{N2O,i} \times GWP_{N2O}$$

Where:

> $PE_{PNB,y}$ = project emissions due to the Pyrolysis of non-biogenic *PNB* Feedstock materials in year $y$ ($tCO_2e$)
>
> $FS_{PNBi,y}$ = the amount of non-biogenic Feedstock (feedstock type *i*) Pyrolyzed *PNB* in year $y$ (t)
>
> $EF_{CO2,}$ = the $CO_2$ emission factor for the *non-biogenic Feedstock* (kg $CO_2$/kg)
>
> $EF_{CH4,NB}$ = the $CH_4$ emission factor for the non-biogenic *NB* Feedstock (kg $CH_4$/kg)
>
> $GWP_{CH4}$ = Global Warming Potential of $CH_4$ (t $CO_2e$/t $CH_4$); 21
>
> $EF_{N2O,NB}$ = the $N_2O$ emission factor for the non-biogenic *NB* Feedstock (kg $N_2O$/kg)
>
> $GWP_{N2O}$ = Global Warming Potential of $N_2O$ (t $CO_2e$/t $N_2O$); 310

### Fuel for Processing Bio-Oil

The auxiliary emissions due to the processing of bio-oil are calculated as follows:

$$PE_{OP,y} = \sum \left(Fuel_{OP\,i,y} \times EF\,Fuel_{CO2}\right); \sum \left(Fuel_{OP\,i,y} \times EF\,Fuel_{CH4} \right.$$
$$\left. \times GWP_{CH4}\right); \sum \left(Fuel_{OP\,i,y} \times EF\,Fuel_{N2O} \times GWP_{N2O}\right) \tag{28}$$

Where:

$PE_{OP,y}$ = project emissions due to the processing of bio-oil $OP$ in year $y$ (tCO$_2$e)

$Fuel_{OPi,y}$ = the volume of each type of (oil processing $OP$) fuel $i$ used in year $y$ (L, m$^3$ or other)

$EF_{CO2.}$ = the $CO_2$ emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)

$EF_{CH4.}$ = the $CH_4$ emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of $CH_4$ (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the $N_2O$ emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of $N_2O$ (t CO$_2$e/t N$_2$O); 310

### Fuel for Processing Syngas

The auxiliary emissions due to the processing of syngas are calculated as follows:

$$PE_{GP,y} = \sum \left(Fuel_{GP\,i,y} \times EF\,Fuel_{CO2}\right); \sum \left(Fuel_{GP\,i,y} \times EF\,Fuel_{CH4} \right.$$
$$\left. \times GWP_{CH4}\right); \sum \left(Fuel_{GP\,i,y} \times EF\,Fuel_{N2O} \times GWP_{N2O}\right) \tag{29}$$

Where:

$PE_{GP,y}$ = project emissions due to the processing of syngas $GP$ (tCO$_2$e)

$Fuel_{GPi,y}$ = the volume of each type of syngas $GP$ fuel $i$ used in year $y$ (L, m$^3$ or other)

$EF_{CO2.}$ = the $CO_2$ emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)

$EF_{CH4.}$ = the $CH_4$ emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of $CH_4$ (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the $N_2O$ emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of $N_2O$ (t CO$_2$e/t N$_2$O); 310

### Fuel for Blending Biochar

The auxiliary emissions due to the blending of Biochar are calculated as follows:

$$PE_{Bl,y} = \sum \left( Fuel_{BL\ i,y} \times EF\ Fuel_{CO2} \right); \sum \left( Fuel_{BL\ i,y} \times EF\ Fuel_{CH4} \right. $$
$$\left. \times GWP_{CH4} \right); \sum \left( Fuel_{BL\ i,y} \times EF\ Fuel_{N2O} \times GWP_{N2O} \right) \tag{30}$$

Where:

$PE_{Bl,y}$ = project emissions due to the blending of Biochar *BI* (tCO$_2$e)

$Fuel_{BLi,y}$ = the volume of each type of fuel *i* used in year *y* (L, m$^3$ or other)

$EF_{CO2.}$ = the *CO$_2$* emission factor for each type of fuel (kg CO$_2$/L, m$^3$ or other)

$EF_{CH4.}$ = the *CH$_4$* emission factor for each type of fuel (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of *CH$_4$* (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the *N$_2$O* emission factor for each type of fuel (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of *N$_2$O* (t CO$_2$e/t N$_2$O); 310

### Bio-Oil Use

The auxiliary emissions due to the use of bio-oil are calculated as follows:

$$PE_{OU,y} = \sum \left( Fuel_{OU\ i,y} \times EF\ Fuel_{CH4} \times GWP_{CH4} \right); \sum \left( Fuel_{OU\ i,y} \right.$$
$$\left. \times EF\ Fuel_{N2O} \times GWP_{N2O} \right) \tag{31}$$

Where:

$PE_{OU,y}$ = project emissions due to the use of bio-oil *OU* in year *y* (tCO$_2$e)

$Fuel_{OUi,y}$ = the volume of each type of fuel *i* used in year *y* (L, m$^3$ or other)

$EF_{CH4.}$ = the *CH$_4$* emission factor for bio-oil used (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of *CH$_4$* (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the *N$_2$O* emission factor for bio-oil used (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of *N$_2$O* (t CO$_2$e/t N$_2$O); 310

### Syngas Use

The auxiliary emissions due to the use of syngas are calculated as follows:

$$PE_{GU,y} = \sum \left(Fuel_{GU\,i,y} \times EF\,Fuel_{CH4} \times GWP_{CH4}\right); \sum \left(Fuel_{GU\,i,y} \times EF\,Fuel_{N2O} \times GWP_{N2O}\right) \tag{32}$$

Where:

$PE_{GU,y}$ = project emissions due to the use of syngas $GU$ in year $y$ (tCO$_2$e)

$Fuel_{GUi,y}$ = the volume of each type of fuel $i$ used in year $y$ (L, m$^3$ or other)

$EF_{CH4.}$ = the $CH_4$ emission factor for syngas used (kg CH$_4$/L, m$^3$ or other)

$GWP_{CH4}$ = Global Warming Potential of $CH_4$ (t CO$_2$e/t CH$_4$); 21

$EF_{N2O.}$ = the $N_2O$ emission factor for syngas used (kg N$_2$O/L, m$^3$ or other)

$GWP_{N2O}$ = Global Warming Potential of $N_2O$ (t CO$_2$e/t N$_2$O); 310

### Biochar in Situ

The sequestration associated with the appropriate end use and/or application of Biochar in situ is calculated following procedures and measurements outlined in the "Standard Test Method for Estimating Biochar Carbon Stability" by the International Biochar Initiative (2013), which is Appendix 1 in this Methodology. The stability of carbon in Biochar is calculated first by determining the ratio of hydrogen to organic carbon within the Biochar, and then through comparing that ratio to a series of 100+ year stability values that were determined through extensive consultation with soil scientists, Biochar scientists and Biochar producers as part of the development of the Biochar carbon stability documentation. The organic carbon ratio and the 100+ year stability value are then inserted into the following formula to calculate the mass of sequestered carbon in Biochar. (Appendix 1 is the test method and Appendix 2 is the justification for this method.)

$$C_{BS,j,y} = BC_{j,y} \times C_{org,j,y} \times BC_{+100} \times [(100 - M_{j,y})/100] \times \frac{44}{12} \times 0.95 \tag{33}$$

Where:

$C_{BS,y}$ = Stable 100-year sequestration $BS$ associated with the appropriate end use and/or in-situ application of Biochar type $j$ (which was produced with a consistent Feedstock

type under uniform production parameters, following the *IBI Biochar Standards* (International Biochar Initiative 2013)) in year *y* (t CO$_2$e)

BC$_{j,y}$ = Mass of Biochar type *j* in year y (metric tonnes)

C$_{org,j,y}$ = Organic Carbon ratio as a percentage of Biochar *j* in year *y*

BC$_{+100}$ = percentage of Biochar carbon that is stable for at least 100 years in situ

M$_{j,y}$ = moisture content % of Biochar type *j* in year *y*

44/12 = molar ratio of carbon dioxide to carbon

0.95 = correction factor used to account for any possible positive priming effect of adding Biochar to soil (For more information, please refer to the Biochar carbon stability documentation in Appendix 3 (International Biochar Initiative 2013a).

These measurements and calculations must be repeated for each subsequent year of production or after any Material Change in Feedstock or process activity as outlined in the "Standard Test Method for Estimating Biochar Carbon Stability" document (International Biochar Initiative 2013a).

## 5.3 Leakage

Restricting Biochar production to non-purpose-grown Feedstocks will prevent Leakage from upstream sources. Further, Leakage due to the depletion of soil organic Carbon Stocks and the potential for overharvesting organic agricultural residue is addressed in Appendix 2. The provisions of this Methodology require documentation supporting the end use of Biochar, limiting the risk of Leakage by providing tangible, substantive evidence of stable sequestration.

Leakage could occur if, in the absence of the project, the Biomass Residues would have been used to generate renewable energy. When a Pyrolysis unit is optimized to make both energy and Biochar, it will make less energy than a biomass facility which is optimized to make energy alone, due to Efficiency reductions. Fossil fuels could therefore be used to compensate for the loss of energy associated with diverting some energy production into the production of Biochar instead.

If Feedstock type *j* was used for bioenergy production, as in the default Baseline Scenario, the Project Proponent must account for the increase in emissions needed to compensate for the

renewable energy that would have been produced in the Baseline Scenario. The Leakage emissions resulting from a loss in Efficiency of the biomass facility are calculated as follows:

$$Leakage_y = LE_{\eta loss}$$
$$LE_{\eta loss} = \sum(FS_{B,j,y} \times NCV_{j,y}) \times (\eta_B - \eta_P) \times EF_{Leakage} \tag{34}$$

Where:

$Leakage_y$ = Leakage that occurs in year $y$ (t $CO_2e$)

$LE_{\eta loss}$ = Leakage due to Pyrolysis of Feedstocks that otherwise would have been used purely for the generation of energy (t $CO_2e$)

$FS_{B,j,y}$ = the amount of Feedstock type $j$ diverted from baseline condition *bioenergy production* B in year $y$ (t)

$NCV_{j,y}$ = net calorific value of the Feedstock type $j$ processed at the Biochar facility in year $y$ (GJ/t of dry matter)

$\eta_B$ = the baseline $B$ Efficiency of the biomass facility where the Biomass Residues would have been combusted before the implementation of the project (kWh/GJ or GJ/GJ)

$\eta_P$ = the Efficiency of the Pyrolysis facility in the project $P$ condition (kWh/GJ or GJ/GJ)

$EF_{Leakage}$= Emission factor for reduced energy production. If the Feedstock would have produced electricity in the baseline condition, use the regional electricity grid emission factor (t $CO_2e$/kWh). If thermal heat would have been produced in the baseline, use the emission factor associated with the most carbon intensive fuel that could reasonably be used to replace this biomass heat (t $CO_2e$/GJ)

## 5.4 Summary of GHG Emission Reduction and/or Removals

The emission reductions for this project activity are calculated as follows:

$$ER_y = BE_y - PE_y - Leakage_y \tag{35}$$

Where:

$ER_Y$             = Net GHG emissions reductions and/or removals in year $y$

Y = year, where the baseline year is 0 and the first year of production is 1

$BE_Y$ = Baseline emissions in year $y$

$PE_y$ = Project emissions in year $y$

$Leakage_y$ = Leakage that occurs in year $y$

# 6 MONITORING

## 6.1 Data and Parameters Available at Validation

The following data will be made available at Validation by the Project Proponent. Default values may vary according to the physical location of the project activity. The Project Proponent must provide evidence and justification that the values presented here are applicable to their project activity, or provide and justify project specific values as needed.

Should the data parameters listed below not be available at the time of Validation, the Project Proponent must provide a plan for determination and/or monitoring the data during the project. All parameters used must be reviewed on an annual basis to ensure the most current value is used in calculations. A project proponent has flexibility to balance the cost of verification against accrued ERTs.

| Equation # | Equation 4 | |
|---|---|---|
| Data Unit / Parameter: | $EF_{ACH4}$ | |
| Data unit: | g $CH_4$/kg waste (wet basis) | |
| Description: | Emission factor for $CH_4$ associated with waste treatment practices. | |
| Source of data: | Table 4.1, Chapter 4, Volume 5 of IPCC 2006 Guidelines | |
| Value to be applied: | If country-specific data is available, then this shall be applied, and the method used to derive the value, as well as the data sources, need to be documented in the GHG Project Plan. If country-specific data are not available, then apply the default values listed in Table 8 below. **Table 8: Default emission factors for $CH_4$ emissions from the aerobic treatment of waste.** | |
| | | $CH_4$ emission factors (g $CH_4$/kg waste treated) |
| | On a dry weight basis | 10 (0.08 – 20) |
| | On a wet weight basis | 4 |

| | |
|---|---|
| | (0.03 – 8) |
| | Assumptions on the waste treated: 25-50% DOC in the dry matter, 2% N in dry matter, moisture content 60%. The emission factor for dry waste are estimated from those for wet waste assuming moisture content of 60% in wet waste. |
| Any comment: | Please note that emission factors will need to be converted to the proper units for inclusion in the baseline calculations, from g $CH_4$/kg waste to t $CH_4$/t waste. 100-yr conversion multiplier for $CH_4$ = 310, source: SAR-100 GWP values from the IPCC Fourth Assessment Report (AR4), Working Group 1, Chapter 2, Table 2.14 (page 212) at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html<br><br>http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch02.pdf |

| | |
|---|---|
| Equation # | Equation 5 |
| Data Unit / Parameter: | $EF_{AN2O}$ |
| Data unit: | g $N_2O$/kg waste (wet basis) |
| Description: | Emission factor for N2O associated with waste treatment practices. |
| Source of data: | Table 4.1, Chapter 4, Volume 5 of IPCC 2006 Guidelines |
| Value to be applied: | If country-specific data is available, then this shall be applied, and the method used to derive the value, as well as the data sources, need to be documented in the GHG Project Plan. If country-specific data are not available, then apply the default values listed in Table 9 below.<br><br>**Table 9: Default emission factors for $N_2O$ emissions from aerobic waste treatment.**<br><br>{table: | | $N_2O$ emission factors (g $N_2O$ /kg waste treated) |} |

| | | |
|---|---|---|
| | On a dry weight basis | 0.6 (0.2 – 1.6) |
| | On a wet weight basis | 0.3 (0.06 – 0.6) |
| | Assumptions on the waste treated: 25-50% DOC in the dry matter, 2% N in dry matter, moisture content 60%. The emission factor for dry waste are estimated from those for wet waste assuming moisture content of 60% in wet waste. | |
| Any comment: | Please note that emission factors will need to be converted to the proper units for inclusion in the baseline calculations, from g $N_2O$ /kg waste to t $N_2O$ /t waste. 100-yr conversion multiplier for $N_2O$ = 21 , source: SAR-100 GWP values from the IPCC Fourth Assessment Report (AR4), Working Group 1, Chapter 2, Table 2.14 (page 212) at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html | |

| | |
|---|---|
| Equation # | Equation 6 |
| Data Unit / Parameter: | $\varphi$ |
| Data unit: | - |
| Description: | Model correction factor to account for model uncertainties in calculating emissions due to the anaerobic decomposition of Feedstock in an SWDS |
| Source of data: | - |
| Value to be applied: | 0.9 |
| Any comment: | Oonk et el. (1994) have validated several landfill gas models based on 17 realized landfill gas projects.  The mean relative error of multi-phase models was assessed to be 18%.  Given the uncertainties associated with the model and in order to estimate emission reductions in a conservative manner, a discount of 10% (10% is used, rather than 18%, because it is conservative to underestimate the baseline emissions) is |

| | |
|---|---|
| | applied to the model results. |

| | |
|---|---|
| Equation # | Equation 6 |
| Data Unit / Parameter: | OX |
| Data unit: | Fraction |
| Description: | Oxidation factor (reflecting the amount of methane from the SWDS that is oxidized in the soil or other material covering the waste) |
| Source of data: | CDM Annex 10 – Tool for determining methane emissions avoided from dumping waste at SWDS (V4.0). |
| Value to be applied: | Default: 0.1

Project Proponent can alternatively conduct a site visit at the SWDS where Feedstocks would have been disposed. If the SWDS is covered with oxidizing material such as soil or compost, use the default value of 0.1. Use 0 for other types of Solid Waste Disposal Sites. |
| Any comment: | |

| | |
|---|---|
| Equation # | Equation 6 |
| Data Unit / Parameter: | F |
| Data unit: | - |
| Description: | Fraction of methane in the SWDS gas (volume fraction) |
| Source of data: | IPCC 2006 Guidelines for National Greenhouse Inventories |
| Value to be applied: | 0.5 |
| Any comment: | This factor reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS. A default value of 0.5 is recommended by IPCC. |

| | |
|---|---|
| Equation # | Equation 6 |

| Data Unit / Parameter: | $DOC_f$ |
|---|---|
| Data unit: | - |
| Description: | Fraction of degradable organic carbon (DOC) that can decompose |
| Source of data: | IPCC 2006 Guidelines for National Greenhouse Gas Inventories |
| Value to be applied: | 0.5 |
| Any comment: | |

| Equation # | Equation 6 |
|---|---|
| Data Unit / Parameter: | $DOC_j$ |
| Data unit: | - |
| Description: | Fraction of degradable organic carbon in the Feedstock type $j$ diverted (weight fraction) |
| Source of data: | IPCC 2006 Guidelines for National Greenhouse Gas Inventories (adapted from Volumes 5, Tables 2.4 and 2.5) |
| Value to be applied: | Apply the following values for different Feedstock types $j$: **Table 10: Default values for $DOC_i$** |

| Feedstock type $j$ | $DOC_j$ (% wet waste) | $DOC_j$ (% dry waste) |
|---|---|---|
| Wood and wood products | 43 | 50 |
| Pulp, paper and cardboard (other than sludge) | 40 | 44 |
| Food, food waste, beverages and tobacco (other than sludge) | 15 | 38 |
| Textiles | 24 | 30 |
| Garden, yard and park waste | 20 | 49 |
| Glass, plastic, | 0 | 0 |

| | metal, other inert waste | | |
|---|---|---|---|
| | If a Feedstock type, prevented from disposal by the project activity, cannot clearly be attributed to one of the Feedstock types in the table above, Project Proponents should choose among the Feedstock types that have similar characteristics to that Feedstock type where the values of $DOC_j$ and $k_j$ result in a conservative estimate (lowest emissions). | | |
| Any comment: | | | |

| Equation # | Equation 6 |
|---|---|
| Data Unit / Parameter: | $k_j$ |
| Data unit: | l/yr |
| Description: | Decay rate for the Feedstock type $j$ |
| Source of data: | IPCC 2006 Guidelines for National Greenhouse Gas Inventories (adapted from Volume 5, Table 3.3) |
| Value to be applied: | Apply the following default values for different Feedstock type $j$ **Table 11: Default values for the decay rate $k_j$** |

| | Boreal and Temperate (MAT≤20°C) | | Tropical (MAT>20°C) | |
|---|---|---|---|---|
| **Feedstock type $j$** | Dry (MAP/PET <1) | Wet (MAP/PET >1) | Dry (MAP<1000mm) | Wet (MAP>1000mm) |

| | | | | | |
|---|---|---|---|---|---|
| Slowly degrading | Pulp, paper, cardboard (other than sludge), textiles | 0.04 | 0.06 | 0.045 | 0.07 |
| | Wood, wood products and straw | 0.02 | 0.03 | 0.025 | 0.035 |
| Moderately degrading | Other (non-food) organic putrescible garden and park waste | 0.05 | 0.1 | 0.065 | 0.17 |
| Rapidly degrading | Food, food waste, sewage, sludge, beverages and tobacco | 0.06 | 0.185 | 0.085 | 0.4 |

NB: MAT – mean annual temperature, MAP – mean annual precipitation, PET – potential evapotranspiration. MAP/PET is the ratio between the mean annual precipitation and the potential evapotranspiration

If a Feedstock type disposed in a SWDS cannot clearly be attributed to one of the types in the above table, project participants should choose, among the Feedstock types that have similar characteristics, the type where the values of $DOC_j$ and $k_j$ result in a conservative estimate.

| Any comment: | Document in the ACR GHG Project Plan the climatic conditions at the SWDS site (temperature, precipitation and, where applicable, evapotranspiration). Use long term averages based on statistical data, where available. Provide references |
|---|---|

| Equation # | Equation 6 |
|---|---|
| Data Unit / Parameter: | GWP $_{CH4}$ |

| Data unit: | t $CO_2$e / t $CH_4$ |
|---|---|
| Description: | Global Warming Potential of methane |
| Source of data: | SAR-100 GWP values from the IPCC Fourth Assessment Report (AR4), Working Group 1, Chapter 2, Table 2.14 (page 212) at http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch02.pdf |
| Any comment: | Conversion Multiplier = 21 |

| Equation # | Equations 6, 7, 8, and 9 |
|---|---|
| Data Unit / Parameter: | MCF |
| Data unit: | - |
| Description: | Methane conversion factor |
| Source of data: | IPCC 2006 Guidelines for National Greenhouse Gas Inventories |
| Value to be applied: | <ul><li>for anaerobic managed Solid Waste Disposal Sites. These must have controlled placement of waste (i.e. waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; (iii) leveling of the waste;</li><li>0.5 for semi-aerobic managed Solid Waste Disposal Sites. These must have controlled placement of waste and will include all of the following structures for introducing air to the waste layers: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system;</li><li>0.8 for unmanaged Solid Waste Disposal Sites – deep. This comprises all SWDS not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 meters;</li><li>0.4 for unmanaged-shallow Solid Waste Disposal Sites or stockpiles that are considered SWDS. This</li></ul> |

| | comprises all SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 meters. This includes stockpiles of solid waste that are considered SWDS (according to the definition given for a SWDS) |
|---|---|
| Any comment: | The Methane conversion factor (MCF) accounts for the fact that unmanaged SWDS produce less methane from a given amount of waste than managed SWDS, because a larger fraction of waste decomposes aerobically in the top layers of unmanaged SWDS. |

| Equation # | Equation 8 |
|---|---|
| Data Unit / Parameter: | $B_o$ |
| Data unit: | tCH4/tCOD |
| Description: | Maximum methane producing capacity, expressing the maximum amount of $CH_4$ that can be produced from a given quantity of chemical oxygen demand (tCH4/tCOD) |
| Source of data: | UNFCCC, CDM ACM0022; Section 6.2.3.2, chapter 6, volume 5 of IPCC 2006 guidelines |
| Value to be Applied: | The default IPCC value for $B_o$ is 0.25 kg CH4/kg COD, and shall be used. |
| Any comment: | Applicable to the baseline emissions from wastewater treatment. |

| Equation # | Equation 9 |
|---|---|
| Data Unit / Parameter: | $f_d$ |
| Data unit: | Numerical value |
| Description: | The influence of the average depth of the anaerobic lagoons or sludge pits on methane generation. |
| Source of data: | UNFCCC, CDM ACM0022 |
| Value to be Applied: | As described below: |

| Any comment: | $f_d$ = 0; if D <1m |
| --- | --- |
| | 0.5; if 1m ≤ D ≤ 2m |
| | 0.7; if D ≥ 2m |
| | |
| | Where: |
| | $f_d$ = Factor expressing the influence of the depth of the anaerobic lagoon or sludge pit on methane generation |
| | D = Average depth of the anaerobic lagoons or sludge pits used in the Baseline Scenario (m). |

| Equation # | Equation 9 |
| --- | --- |
| Data Unit / Parameter: | D |
| Data unit: | m |
| Description: | Average depth of the lagoons or sludge pits |
| Source of data: | For existing plants: conduct measurements. |
| Measurement Procedures (if any): | Determine the average depths of the whole lagoon/sludge pit under normal operating conditions. |
| Any comment: | - |

| Equation # | Equation 10 |
| --- | --- |
| Data Unit / Parameter: | $T_{2,m}$ |
| Data unit: | K |
| Description: | Average temperature at the baseline lagoon site in month _m_ |
| Source of data: | Measurement in the project site, or national regional weather statistics. |
| Measurement Procedures (if any): | In the case that Project Proponents decide to measure temperature in the project site: <br> • The temperature sensor must be housed in a ventilated radiation shield to protect the sensor from thermal radiation. <br><br> Measurements should be continuously aggregated into |

| | monthly average values. |
|---|---|
| | Uncertainty of the measurements provided by the temperature sensor supplier should be discounted from the readings IF the Project Proponent decides to measure temperature at the project site. |
| Any comment: | - |


| Equation # | Equations 12 and 13 |
|---|---|
| Data Unit / Parameter: | $COD_{out,x}$ <br> $COD_{in,x}$ |
| Data unit: | t COD |
| Description: | COD of the effluent in the period $x$ <br> COD directed to the anaerobic lagoons or sludge pits in the period x (tCOD). |
| Source of data: | For existing plants: <br>     a) If there is no effluent: $COD_{out,x} = 0$; <br>     b) If there is effluent: <br>         • One year of historical data should be used, or <br>         • If one year data is not available, then x represents a measurement campaign of at least 10 days to the COD inflow ($COD_{in,x}$) and COD outflow ($COD_{out,x}$) from the lagoon or sludge pit. |
| Value to be Applied: | For the measurement campaign of at least 10 days: <br> The measurements should be undertaken during a period that is representative of the typical operation conditions of the plant and ambient conditions of the site (temperature). |
| Any comment: | - |


| Equation # | Equations 12 and 13 |
|---|---|
| Data Unit / Parameter: | x |
| Data unit: | Time |
| Description: | Representative historical reference period |
| Source of data: | For existing plants: |

|  | a) x should represent one year of historical data |
|---|---|
|  | b) If one year data is not available, then x represents a measurement campaign of at least 10 days. |
| Value to be Applied: | - |
| Any comment: | - |

| Equation # | Equations 12 and 14 |
|---|---|
| Data Unit / Parameter: | $F_{PJ,AD,m}$ |
| Data unit: | $m^3$ |
| Description: | Quantity of wastewater or sludge that is treated in the Pyrolysis unit or under clearly aerobic conditions in the project activity in month $m$ ($m^3$) |
| Source of data: | Measured |
| Measurement Procedures (if any): | The volume of wastewater or sludge that is treated is determined by calibrated meters or following industry best management practices. |
| Any comment: | Parameter monitored continuously, but aggregated monthly and annually for calculations. |

| Equation # | Equations 12 and 14 |
|---|---|
| Data Unit / Parameter: | $COD_{AD,m}$ |
| Data unit: | $T\ COD/m^3$ |
| Description: | Chemical oxygen demand in the wastewater or sludge that is treated in the Pyrolysis unit or under clearly aerobic conditions in the project activity in month $m$. |
| Source of data: | Measurements. |
| Measurement Procedures (if any): | Measure the COD according to national or international Standards. If COD is measured more than once per month, the average value of the measurements should be used. Measurements should be conducted frequently to calculate average monthly and annual values. |
| Any comment: | - |

| Equation # | Equation 13 |
|---|---|
| Data Unit / Parameter: | $\rho$ |
| Data unit: | - |
| Description: | Discount factor to account for the uncertainty of the use of historical data to determine $COD_{BL,y}$ |
| Source of data: | For existing plants:<br>a) If one year of historical data is available, $\rho$=1<br>**b)** If a measurement campaign of at least 10 days is available, $\rho$=0.89 |
| Measurement Procedures (if any): | The value of 0.89 for the case where there is no one year historical data to account for the uncertainty rate (of 30% to 50%) associated with this approach, as compared to one-year historical data. |
| Any comment: | - |

| Equation # | Equation 15 |
|---|---|
| Data Unit / Parameter: | $GWP_{N2O}$ |
| Data unit: | T $CO_2e$ / t $N_2O$ |
| Description: | Global Warming Potential of methane |
| Source of data: | SAR-100 GWP values from the IPCC Fourth Assessment Report (AR4), Working Group 1, Chapter 2, Table 2.14 (page 212) at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html |
| Any comment: | Conversion multiplier = 310 |

| Equation # | Equation 16 |
|---|---|
| Data Unit / Parameter: | $EF_{N2O, D, j}$ |
| Data unit: | t $N_2O$-N / t N |

| | |
|---|---|
| Description: | Direct $N_2O$ emission factor for the treatment system j of the manure management system |
| Source of data: | Estimated with site-specific, regional or national data if such is available. Otherwise use default $EF_3$ from table 10.21, chapter 10, volume 4, in the IPCC 2006 Guidelines for National Greenhouse Gas Inventories |
| Any comment: | |

| Equation # | Equation 17 |
|---|---|
| Data Unit / Parameter: | $EF_{LN2O, ID}$ |
| Data unit: | t $N_2O$-N/t $NH_3$-N and $NO_x$-N |
| Description: | Indirect $N_2O$ emission factor for $N_2O$ emissions from atmospheric deposition of nitrogen on soils and water surfaces |
| Source of data: | Estimated with site-specific, regional or national data if such is available. Otherwise use default $EF_4$ from table 11.3, chapter 11, volume 4, in the IPCC 2006 Guidelines for National Greenhouse Gas Inventories. |
| Any comment: | |

| Equation # | Equation 17 |
|---|---|
| Data Unit / Parameter: | $F_{gasMS, j, LT}$ |
| Data unit: | Fraction |
| Description: | Default values for nitrogen loss due to volatilization of $NH_3$ and $NO_x$ from manure management |
| Source of data: | IPCC 2006 Guidelines, Volume 4, Chapter 10, Table 10.22. |
| Any comment: | |

| Equation # | Equation 19 |
|---|---|
| Data Unit / Parameter: | $EF_{Grid}$ |
| Data unit: | kg GHG ($CO_2$, $CH_4$, $N_2O$) per kWh |

| Description: | Emission factor describing the GHG emissions from the regional electricity grid |
|---|---|
| Source of data: | Projects in the United States must use the latest version of the United States Environmental Protection Agency eGRID factors for the appropriate eGRID Subregion where the project is located. <br><br> See http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. <br><br> Projects outside of the United States must identify the most appropriate emission factor for the electricity grid for the region of interest. Project Proponents can also refer to the CDM's "Tool to calculate the emission factor for an electricity system (Version 01.1)". (CDM 2011) |
| Any comment: | If the grid emission factor is not already available for the region, the CDM's guidance is the most appropriate tool for calculating emissions associated with an electricity grid. |

| Equation # | Equations 20 and 21 |
|---|---|
| Data Unit / Parameter: | $EF_{GHG, i}$ |
| Data unit: | kg GHG ($CO_2$, $CH_4$, $N_2O$) per kg |
| Description: | Emission factor for Feedstock type $i$ for $CO_2$, $CH_4$, and $N_2O$ |
| Source of data: | Reference values may be obtained from national and international GHG inventories. In the absence of local or regional data, IPCC defaults can be used from the most recent version of the *IPCC Guidelines for National Greenhouse Gas Inventories* providing they are deemed to reasonably represent local circumstances. The Project Proponent must choose the values in a conservative manner and justify the choice. |
| Any comment: | This is one of the most comprehensive emission factor databases available. Note: $CH_4$ and $N_2O$ must be multiplied by their GWP conversions: 21 and 310, respectively. |

| Equation # | Equations 20 and 21 |
|---|---|
| Data Unit / Parameter: | EF Fuel $_{GHG}$ |
| Data unit: | kg GHG ($CO_2$, $CH_4$, $N_2O$) per L, $m^3$ or other |
| Description: | Emission factor describing the GHG emissions from each type of fuel |
| Source of data: | The Project Proponent must identify the most appropriate emission factor for the combustion of liquid or gaseous fossil oil or gas for the Territory of interest. In the absence of local or regional data, IPCC defaults can be used from the most recent version of the *IPCC Guidelines for National Greenhouse Gas Inventories* providing they are deemed to reasonably represent local circumstances. The Project Proponent must choose the values in a conservative manner and justify the choice. |
| Any comment: | This is one of the most comprehensive fuel emission factor databases available. |

| Equation # | Equation 22 |
|---|---|
| Data Unit / Parameter: | %$_{eff}$ |
| Data unit: | % |
| Description: | Percentage Efficiency of the thermal energy heating system |
| Source of data: | Manufacturer's specifications |
| Any comment: | Represents the most reasonable means of estimation. |

| Equation # | Equation 34 |
|---|---|
| Data Unit / Parameter: | EF$_{Leakage}$ |
| Data unit: | $CO_2e$/kWh or $CO_2e$/GJ |
| Description: | Emission factor for reduced energy production due to Pyrolysis rather than exclusive energy generation. If the Feedstock would have produced electricity in the baseline condition, use the regional electricity grid emission factor. |

| Source of data: | If the Feedstock would have produced electricity in the baseline condition, use the regional electricity grid emission factor. Projects in the United States must use the latest version of the United States Environmental Protection Agency eGRID factors for the appropriate eGRID Subregion where the project is located. See http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html. |
|---|---|
| | Projects outside of the United States must identify the most appropriate emission factor for the electricity grid for the region of interest. Project Proponents can also refer to the CDM's "Tool to calculate the emission factor for an electricity system (Version 01.1)". (CDM 2011) |
| | If thermal heat would have been produced in the baseline, use the emission factor associated with the most carbon intensive fuel that could reasonably be used to replace this biomass heat. In the absence of local or regional data, IPCC defaults can be used from the most recent version of the *IPCC Guidelines for National Greenhouse Gas Inventories* providing they are deemed to reasonably represent local circumstances. The Project Proponent must choose the values in a conservative manner and justify the choice. |
| Any comment: | Verifier will confirm the conservativeness of the assumptions of the Project Proponent. |

| Equation # | Equation 34 |
|---|---|
| Data Unit / Parameter: | $\eta_B$ |
| Data unit: | For electricity production: kWh/GJ<br>For thermal energy production: GJ/GJ |
| Description: | The baseline Efficiency of the biomass facility where the Biomass Residues would have been combusted before the |

| | |
|---|---|
| | implementation of the project |
| Default value to be applied | For electricity production: 111.11 kWh/GJ<br>For thermal energy production: 0.85 GJ/GJ |
| Source of data: | International Energy Agency's Handbook of Biomass Combustion and Co-Firing. Van Loo and Koppenan et al 2002. |
| Any comment: | Justification of choice of data or description of measurement methods and procedures applied:<br><br>Default values are taken from the International Energy Agency's Handbook of Biomass Combustion and Co-Firing. The highest possible efficiencies based on net calorific value (or lower heating value) were used to be conservative. For electricity, the International Energy Agency estimates the most efficient use is to co-fire the biomass in a power plant that produces .4 GJ of electricity for each GJ of energy in the Feedstock. This is equivalent to 111.11 kWh/GJ of energy in the Feedstock. For thermal energy production, the International Energy Agency estimates the most efficient use is in a stove boiler with efficiencies of .85 GJ of thermal energy per GJ of Feedstock.<br><br>If the Project Proponent determines that these values are overly conservative, they can define a regional specific value by assessing the Efficiency of three biomass plants in the project's region that could have been recipients of the Feedstock using either measured Efficiency or manufacturer's information on Efficiency. Project Proponents shall use the highest value found in this survey.<br><br>QA/QC procedures: Reasonableness review during Verification |

| | |
|---|---|
| Equation # | See Appendix 1 |

| Data Unit / Parameter: | BC$_{+100}$ |
|---|---|
| Data unit: | % |
| Description: | In situ 100+ year carbon stability value for Biochar that is applied to soil or is employed in another appropriate end use and/or in-situ application of Biochar. |
| Source of data: | International Biochar Initiative 2013a |
| Value to be applied: | As described below |
| Any comment: | Biochar 100+ year stability conversion values, in correlation to H:Corg ratios. |

| H:C$_{org}$ | BC$_{+100}$ |
|---|---|
| < 0.4 | 70% |
| 0.4 - 0.7 | 50% |
| > 0.7 | 0 |

BC+100 is determined following the calculation of H:Corg ratios, as indicated in the Standard Test Method for Estimating Biochar Carbon Stability (International Biochar Initiative 2013a).

## 6.2 Data and Parameters Monitored

The following data parameters will be monitored during the project.

| Equation # | Equation 3 |
|---|---|
| Data Unit / Parameter: | FS $_{i,j,y}$ |
| Data unit: | T |
| Description: | Total amount of Feedstock type *j* diverted from baseline condition *i* in year *y*. (dry weight) |
| Source of data: | Sample measurements conducted by Project Proponent, following guidance outlined in the most recent version of the *IBI Biochar Standards*, as produced by the International Biochar Initiative. |

| Measurement procedures: | *Sample the Feedstock composition, using the Feedstock categories j, as provided in* Table 4 *and weigh each Feedstock fraction* |
|---|---|
| Monitoring frequency: | Continuously, aggregated monthly or annually. |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | See the most recent version of the *IBI Biochar Standards* (International Biochar Initiative 2013), with specific attention to sections addressing general Feedstock material requirements and Material Changes in Feedstocks. The *IBI Biochar Standards* Appendix 4 addresses Feedstock criteria in more detail. |

| Equation # | Equation 3 |
|---|---|
| Data Unit / Parameter: | p $_{n,j,y}$ |
| Data unit: | T |
| Description: | Weight fraction of the Feedstock type *j* in the sample *n* collected during year y (dry weight) |
| Source of data: | Sample measurements conducted by Project Proponent, following guidance outlined in the most recent version of the Biochar Standards, provided by the International Biochar Initiative. |
| Measurement procedures: | *Sample the Feedstock composition, using the Feedstock categories j, as provided in* Table 4 *and weigh each Feedstock fraction* |
| Monitoring frequency: | Minimum of three samples every three months |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | See the most recent version of the *IBI Biochar Standards* (International Biochar Initiative 2013), with specific attention to sections addressing general Feedstock material requirements and Material Changes in Feedstocks. |

| Equation # | Equation 3 |
|---|---|

| Data Unit / Parameter: | Z |
|---|---|
| Data unit: | - |
| Description: | Number of samples collected during year y |
| Source of data: | Project Proponent |
| Measurement procedures: | Minimum of three samples every three months |
| Monitoring frequency: | Continuously, aggregated annually |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | |
| Equation # | Equations 4-5, 17-32, and 34 |
| Data Unit / Parameter: | $EF_H$ (Where H = GHG) |
| Data unit: | kg GHG ($CO_2$, $CH_4$, $N_2O$) per GJ |
| Description: | Emission factor associated with the fuel that is used instead of biomass due to the project |
| Source of data: | Either conduct measurements or use accurate and reliable local or national data where available. Where such data is not available, use IPCC default emission factors (country specific, if available) if they are deemed to reasonably represent local circumstances. Choose the value in a conservative manner and justify the choice. |
| Measurement procedures: | Measurements shall be carried out at reputed laboratories and according to relevant international Standards. |
| Monitoring frequency: | In case of measurements: At least every six months, taking at least three samples for each measurement<br>In case of other data sources: Review the appropriateness of the annual data. |
| QA/QC procedures: | Check consistency of measurements and local/national data with default values by the IPCC. If the values differ significantly from IPCC default values, collect additional information or conduct additional measurements. |
| Any comment: | To conservatively determine which fuel is used instead of biomass due to the project, the Project Proponent should select the most carbon intensive fuel type used among the |

| | |
|---|---|
| | fossil fuel types used at the project site during year x. |

| | |
|---|---|
| Equation # | Equation 6 |
| Data Unit / Parameter: | $f_y$ |
| Data unit: | % |
| Description: | Fraction of methane capture at the SWDS and flared, combusted or used in another manner that prevents the emissions of methane to the atmosphere in year y |
| Source of data: | Select the maximum value from the following: (a) contract of regulation requirements specifying the amount of methane that must be destroyed /used (if available) and (b) historic data on the amount captured |
| Measurement procedures: | - |
| Monitoring frequency: | Annual |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | n/a |

| | |
|---|---|
| Equation # | Equation 17 |
| Data Unit / Parameter: | $Q_{EM, m}$ |
| Data unit: | m3/month |
| Description: | Monthly volume of the manure effluent mix entering the manure management system |
| Source of data: | Project Proponents, manure suppliers |
| Measurement procedures: | Using flow meters |
| Monitoring frequency: | This parameter shall be continuously monitored |
| QA/QC procedures: | Flow meters will undergo maintenance/calibration subject to appropriate industry Standards. This maintenance/ calibration practice should be clearly stated in the GHG Project Plan |

| | |
|---|---|
| Any comment: | This parameter shall be monitored by continuous flow meters installed after the effluent admittance point or after the equalization tanks (if existent) |

| | |
|---|---|
| Equation # | Equation 17 |
| Data Unit / Parameter: | $[N]_{EM, m}$ |
| Data unit: | t N/m$^3$ |
| Description: | Monthly total nitrogen concentration in the manure effluent mix entering the manure management system |
| Source of data: | Project Proponents |
| Measurement procedures: | |
| Monitoring frequency: | Aggregated weekly for monthly average |
| QA/QC procedures: | Sample collection procedures shall be performed as described in appendix 5 of United Nations 2012i: CDM ACM0010 Version 07.0.0 Approved consolidated baseline Methodology ACM0010 "Consolidated baseline Methodology for GHG emission reductions from manure management systems." Total nitrogen determination should be performed according to the guidance provided in appendix 4 of CDM ACM0010 Version 07.0.0 |
| Any comment: | The effluent mix shall be collected after the effluent admittance point or after the equalization tanks (if existent). |

| | |
|---|---|
| Equation # | Equation 19 |
| Data Unit / Parameter: | $E_{R,y}$ |
| Data unit: | kWh |
| Description: | Electricity will be produced at off-site grid connected generation facilities in the baseline to cover the amount of |

| | renewable electricity being generated from the Biochar output in the project condition. |
|---|---|
| Source of data: | Measurement by Project Proponent |
| Measurement procedures: | Direct metering of the net quantity of renewable electricity generated in the project condition and used off-site in year y. |
| Monitoring frequency: | Continuous metering |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | n/a |

| Equation # | Equation 20 |
|---|---|
| Data Unit / Parameter: | $O_y$ |
| Data unit: | L, m3, or other |
| Description: | Volume of bio-oil produced in the project condition in year y. This parameter is used to calculate the baseline emissions due to the use of fossil oil that would have been required to compensate for the bio-oil produced in the project condition. |
| Source of data: | The volume of bio-oil produced is determined by calibrated meters or following industry best management practices. |
| Measurement procedures: | Direct metering or reconciliation of volume in storage (including volumes received), or monthly invoices filed for Verification. |
| Monitoring frequency: | Continuous metering or monthly reconciliation. |
| QA/QC procedures: | Industry best practice |
| Any comment: | n/a |

| Equation # | Equation 20 |
|---|---|
| Data Unit / Parameter: | $G_y$ |
| Data unit: | L, m3, or other |
| Description: | Volume of syngas produced in the project condition in year y. This parameter is used to calculate the baseline emissions |

| | |
|---|---|
| | due to the use of fossil gas that would have been required to compensate for the syngas produced in the project condition. |
| Source of data: | The volume of gas produced is determined by calibrated meters or following industry best management practices. |
| Measurement procedures: | Direct metering or reconciliation of volume in storage (including volumes received), or monthly invoices filed for Verification. |
| Monitoring frequency: | Continuous metering or monthly reconciliation. |
| QA/QC procedures: | Industry best practice |
| Any comment: | n/a |

| Equation # | Equations 20, 21, and 22 |
|---|---|
| Data Unit / Parameter: | $\%_i$ |
| Data unit: | % |
| Description: | Percentage of each type of fuel offset from either the production of bio-oil, syngas or heat in the project condition. |
| Source of data: | Based on monthly recorded fossil fuel consumption in one or more years prior to the implementation of the project. |
| Measurement procedures: | Represents most reasonable means of estimation. |
| Monitoring frequency: | Once |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | n/a |

| Equation # | Equation 22 |
|---|---|
| Data Unit / Parameter: | $H_y$ |
| Data unit: | GJ |
| Description: | Heat load produced under the project condition in year y. This parameter is used to calculate the baseline emissions |

| | |
|---|---|
| | due to the production of heat that would have been required to compensate for the heat produced in the project condition. |
| Source of data: | Facility records |
| Measurement procedures: | Direct metering of thermal energy delivered to the end user in the project condition. |
| Monitoring frequency: | Monthly |
| QA/QC procedures: | Industry best practice |
| Any comment: | n/a |

| | |
|---|---|
| Equation # | Equations 25, 28, 29, 30, 31, and 32 |
| Data Unit / Parameter: | $Fuel_P$, $Fuel_{PY}$, $Fuel_{OP}$, $Fuel_{GP}$, $Fuel_{BL}$, $Fuel_{OU,}$ and $Fuel_{GU}$ |
| Data unit: | L, $m^3$, or other |
| Description: | Volume of each type of fuel consumed in year y. This volume of fuel is adjusted for both functional equivalence and units of productivity. |
| Source of data: | Measurement by Project Proponent or third party custody invoices, consolidated monthly. |
| Measurement procedures: | Direct metering or reconciliation of volume in storage (including volumes received), or monthly invoices filed for Verification. |
| Monitoring frequency: | Continuous metering or monthly reconciliation. |
| QA/QC procedures: | Industry best practice. Meters should be calibrated according to manufacturer's specifications. |
| Any comment: | n/a |

| | |
|---|---|
| Equation # | Equation 26 |
| Data Unit / Parameter: | $E_{G,y}$ |
| Data unit: | kWh |
| Description: | The quantity of grid electricity consumed in the project condition in year *y* |

| Source of data: | Utility invoices |
|---|---|
| Measurement procedures: | Direct metering, aggregated monthly. |
| Monitoring frequency: | Continuous metering |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | n/a |

| Equation # | Equation 33 |
|---|---|
| Data Unit / Parameter: | $BC_{j,y}$ |
| Data unit: | Tonne or kg |
| Description: | Mass of Biochar type $j$ produced from the facility in year $y$ |
| Source of data: | Facility records |
| Measurement procedures: | Direct measurement of mass of Biochar produced |
| Monitoring frequency: | Continuous, aggregated monthly or annually |
| QA/QC procedures: | Industry best practice |
| Any comment: | Biochar type $j$ has been produced with a consistent Feedstock type and under uniform parameters in year $y$, following the guidance outlined in the Biochar Standard (International Biochar Initiative 2013) |

| Equation # | Equation 33 |
|---|---|
| Data Unit / Parameter: | $M_{j,y}$ |
| Data unit: | % |
| Description: | Moisture content of Biochar $j$ in year $y$ |
| Source of data: | Measurements by analytical laboratory |
| Measurement procedures: | Measurement of materials conducted as prescribed by the Standard Test Method for Estimating Biochar Carbon Stability (International Biochar Initiative 2013a). |
| Monitoring frequency: | Annually, or with any Material Change of Feedstock type or production process |
| QA/QC procedures: | Reasonableness review during Verification |

| Any comment: | |
|---|---|

| Equation # | Equation 33 and 37 |
|---|---|
| Data Unit / Parameter: | $C_{org}$ |
| Data unit: | % or x/100 |
| Description: | Percent organic carbon of Biochar $j$ in year $y$ |
| Source of data: | Measurements by analytical laboratory |
| Measurement procedures: | Measurement of materials conducted as prescribed by the Standard Test Method for Estimating Biochar Carbon Stability (International Biochar Initiative 2013a) |
| Monitoring frequency: | Annually, or with any Material Change of Feedstock type or production process |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | |

| Equation # | Equation 34 |
|---|---|
| Data Unit / Parameter: | $NCV_j$ |
| Data unit: | GJ/t |
| Description: | Net calorific value of the Feedstock type $j$ being diverted from bioenergy production in the baseline condition |
| Source of data: | Third party laboratory report |
| Measurement procedures: | Measurements shall be carried out at reputed laboratories and according to relevant international Standards. Measure/calculate the NCV based on dry biomass. |
| Monitoring frequency: | At least every six months, taking at least three samples for each measurement. |
| QA/QC procedures: | Check the consistency of the measurements by comparing the measurement results with measurements from previous years, relevant data sources (e.g. values in the literature, values used in the national GHG inventory) and default values by the IPCC. If the measurement results differ significantly from previous measurements or other relevant |

| | data sources, conduct additional measurements. Ensure that the NCV is determined on the basis of dry biomass. |
|---|---|
| Any comment: | n/a |

| Equation # | Equation 34 |
|---|---|
| Data Unit / Parameter: | $\eta_P$ |
| Data unit: | For electricity production: kWh/GJ<br>For thermal energy production: GJ/GJ |
| Description: | The Efficiency of the biomass facility after the implementation of the project |
| Source of data: | Use either (a) the measured Efficiency or (b) the manufacturer's information on the Efficiency. |
| Measurement procedures: | Use recognized Standards for the measurement of the Efficiency, such as the *British Standard Methods for Assessing the thermal performance of boilers for steam, hot water and high temperature heat transfer fluids*. (BS845). Where possible, use preferably the direct method (dividing the net heat generation by the energy content of the fuels fired during a representative time period), as it is better able to reflect average efficiencies during a representative time period compared to the indirect method (determination of fuel supply or heat generation and estimation of the losses). Document measurement procedures and results and manufacturers information transparently in the GHG Project Plan. |
| Monitoring frequency: | Annual |
| QA/QC procedures: | Industry best practice |
| Any comment: | n/a |

| Equation # | Equation 38 |
|---|---|
| Data Unit / Parameter: | H/C$_{org}$ |
| Data unit: | Molar ratio |

| Description: | Hydrogen to organic carbon molar ratio |
|---|---|
| Source of data: | Measurements by analytical laboratory |
| Measurement procedures: | Measurement of materials conducted as prescribed by the Standard Test Method for Estimating Biochar Carbon Stability (International Biochar Initiative 2013a) |
| Monitoring frequency: | Annually, or with any Material Change of Feedstock type or production process parameters |
| QA/QC procedures: | Reasonableness review during Verification |
| Any comment: | |

## 6.3 Description of the Monitoring Plan

The Project Proponent must develop a monitoring plan detailing the procedures for data capture, measurement and reporting of the data parameters listed in Section 6.2. In general, data quality management must include sufficient data capture such that the mass and energy balances may be easily performed with the need for minimal assumptions and use of contingency procedures. The data shall be of sufficient quality to fulfill the quantification requirement and be substantiated by company records for the purpose of Verification.

The Project Proponent shall establish and apply quality management procedures to manage data and information. Written procedures should be established for each measurement task outlining responsibility, timing and record location requirements. The greater the rigor of the management system for the data, the more easily an audit will be conducted for the project.

Record keeping practices shall be established that include:

- Electronic recording of values of logged primary parameters for each measurement interval;
- Offsite electronic back-up of all logged data;
- Written logs of operations and maintenance of the project system including notation of all shut-downs, start-ups and process adjustments;
- Storage of all documents and records in a secure and retrievable manner for at least two years after the end of the project Crediting Period.

The Project Proponent must also develop a QA/QC plan to add confidence that all measurements and calculations have been made correctly. QA/QC measures that may be implemented include, but are not limited to:

- Protecting monitoring equipment (sealed meters and data loggers);
- Protecting records of monitored data (hard copy and electronic storage);
- Checking data integrity on a regular and periodic basis (manual assessment, comparing redundant metered data, and detection of outstanding data/records);
- Comparing current estimates with previous estimates as a 'reality check';
- Provide sufficient training to operators to perform maintenance and calibration of monitoring devices;
- Establish minimum experience and requirements for operators in charge of project and monitoring; and
- Performing recalculations to ensure no mathematical errors have been made.

# 7 REFERENCES AND OTHER INFORMATION

**7.1 Sources**

The protocols, methodologies and tools used to develop the quantification Methodology are presented in the Table below.

**Table 12: Protocols, methodologies and tools referenced in the Methodology (IPCC Good Practice Guidance)**

| Document Title | Publishing Body / Date | Description |
|---|---|---|
| **General Methodology Guidance** | | |
| Canada's National Inventory Report: Greenhouse Gas Sources and Sinks in Canada, 1990-2010 | Government of Canada (2012) | On behalf of the Government of Canada, Environment Canada releases a national inventory of Greenhouse Gases annually in accordance with international UNFCCC reporting Standards. |
| Alberta Offset System Offset Credit Project Guidance Document | Alberta Environment (February 2008) | A draft guidance document outlining how to develop offset projects under the Alberta Offset System. |
| ISO 14064-2 | International Organization for Standardization (2006) | Provides guidance at the project level for quantification, monitoring and reporting of Greenhouse Gas emission reductions or removal enhancements. |
| ISO 14064-3 | International Organization for Standardization (2006) | Provides guidance for the Validation and Verification of GHG assertions. |

**Methodologies Reviewed**

| | | |
|---|---|---|
| AMS – III.E. Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment --- Version 16.0 | Clean Development Mechanism – Executive Board | Approved baseline and monitoring Methodology from the decay of biomass through controlled combustion, gasification or mechanical/thermal treatment |
| AMS – III.L. Avoidance of methane production from biomass decay through controlled Pyrolysis --- Version 2.0 | Clean Development Mechanism – Executive Board | Approved baseline and monitoring Methodology from the decay of biomass through controlled Pyrolysis |
| Tool to determine methane emissions avoided from disposal of waste at a Solid Waste Disposal Site. | Clean Development Mechanism – Executive Board | Provides guidance and procedures to calculate baseline, project, or Leakage emissions of methane from solid waste disposed or prevented from disposal at Solid Waste Disposal Sites. |
| ACM0010 Consolidated baseline Methodology for GHG emission reduction from | Clean Development Mechanism – Executive Board | Approved baseline and monitoring Methodology for the anaerobic treatment of livestock manure. |

| manure management systems. | | |
|---|---|---|
| ACM0022 Consolidated baseline and monitoring Methodology for alternative waste treatment processes | Clean Development Mechanism – Executive Board | Approved baseline and monitoring Methodology consolidating a number of waste treatment process methodologies including composting, aerobic thermal treatment, methane emission reduction and energy production from organic waste treatment. |
| OWD Organic Waste Digestion Project Protocol – Version 2.0 | Climate Action Reserve | Approved GHG accounting Methodology for projects that divert anaerobic- digestion-eligible organic wastes and/or wastewater streams that would otherwise have gone to uncontrolled anaerobic storage, treatment and disposal systems. |
| OWC Organic Waste Composting Project Protocol – Version 2.0 | Climate Action Reserve | Approved GHG accounting Methodology for projects that divert compost-eligible organic wastes and/or wastewater streams that would otherwise have gone to uncontrolled anaerobic storage, treatment and disposal systems. |
| US Landfill Project Protocol | Climate Action Reserve | Approved GHG accounting Methodology for the direct avoidance of methane emissions through the installation of a landfill gas collection and destruction system at landfill operations. |
| Quantification Protocol for Aerobic Composting Projects | Alberta Offset System; Specified Gas Emitters Regulation | Approved baseline and monitoring Methodology for the direct avoidance of methane emissions from anaerobically decomposed materials in landfills through the diversion of organic residues from landfill for |

| | | |
|---|---|---|
| | | biological decomposition. |
| Quantification Protocol for Innovative feeding of swine and storing and spreading of swine manure. | Alberta Offset System; Specified Gas Emitters Regulation | Approved baseline and monitoring Methodology for the reduction and avoidance of methane and nitrous oxide emissions from swine operations. |
| Quantification Protocol for Reducing beef age at harvest. | Alberta Offset System; Specified Gas Emitters Regulation | Approved baseline and monitoring Methodology for the reduction and avoidance of methane and nitrous oxide emissions from beef cattle operations. |

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Alberta Environment and Sustainable Resource Development, Alberta Offset System, Specified Gas Emitters Regulation. 2008. Quantification protocol for aerobic composting projects. http://environment.gov.ab.ca/info/library/7905.pdf (Accessed September 2012)

Alberta Environment and Sustainable Resource Development, Alberta Offset System, Specified Gas Emitters Regulation. 2011. Quantification protocol for reducing the age at harvest of beef cattle. http://environment.gov.ab.ca/info/library/7916.pdf (Accessed November 2012)

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# APPENDIX 1: STANDARD TEST METHOD FOR ESTIMATING BIOCHAR CARBON STABILITY (BC$_{+100}$)

## 1 Scope

This test method provides the calculations needed to estimate the amount of carbon that is expected to remain in Biochar after a period of 100 years (BC$_{+100}$), which is considered "stable" for the purpose of determining a GHG emissions reduction value. This stable portion of the carbon sequestered in Biochar is deducted from Project Emissions in Equation 23. As part of that method, this covers the determination of hydrogen, total carbon and organic carbon in a sample of Biochar.

This document builds upon previous work coordinated by The International Biochar Initiative (IBI) to develop the "***Standardized Product Definition and Product Testing Guidelines for Biochar that Is Used in Soil***" (International Biochar Initiative 2012). This document constrains its scope to materials with properties that satisfy the criteria for Biochar as defined by the IBI Standards (International Biochar Initiative 2012).

This Standard test method does not purport to address all of the safety concerns, if any, associated with use of Biochar. It is the responsibility of the user of this Standard test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. The minimum safety equipment should include protective gloves and sturdy eye and face protection.

## 2 Terminology

Biochar – A solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment (International Biochar Initiative 2012) that complies with the definition in the *IBI Biochar Standards* 2012.

BC$_{+100}$ – The fraction of carbon present in Biochar that is expected to remain in soil for at least 100 years (Kyoto Protocol 1998) when added to soil.

Total carbon – The total amount of carbon in a sample, both organic and inorganic.

Organic carbon – The fraction of carbon in the sample that is derived from biogenic material.

Inorganic carbon – The fraction of material derived from geologic or soil parent material (Schumacher, 2002), which is mineral. Carbon Dioxide, salts of carbonates and soluble carbonates are the most common forms of inorganic carbon.

## 3    Summary of Test Method

The sample is prepared in a specified manner (see section 6). An elemental analyzer is used to determine hydrogen and total carbon in the Biochar sample. Inorganic carbon is measured and subtracted from total carbon to estimate the organic carbon ($C_{org}$) content, which allows the calculation of the molar ratio of hydrogen to organic carbon ($H/C_{org}$). Finally, the calculated $H/C_{org}$ value is converted into its equivalent $BC_{+100}$ value – based on the report Biochar Carbon Stability Test Method: An Assessment of Methods to Determine Biochar Carbon Stability – needed to calculate the amount of stable (+100) Biochar carbon sequestration ($C_{BS,y}$) as used in equations (23) and (33) GHG.

## 4    Significance and Use

The production of Biochar can qualify as a carbon sequestration strategy because of the increased stability of Biochar carbon that is obtained through Pyrolysis. This test method allows for the determination of the GHG emission reduction that could be claimed through the production of Biochar, based on the carbon estimated to remain stable in Biochar after 100 years.

## 5    Apparatus and Reagents

Use only reagents of recognized analytical grade.

- 105°C ±2 drying oven
- 200°C heat resistant drying vessel (high silica or porcelain evaporating dish)
- Balance (0.01 g capacity)
- Mortar and Pestle
- #10 (2 mm) Sieve
- Elemental analyzer for Hydrogen and Carbon
- Rapid Carbonate Analyzer (ASTM D4373 fig.2)
- 1 N HCl
- Reagent Grade Calcium Carbonate ($CaCO_3$)

- 20mL Graduated Cylinder

## 6    Sample Collection and Handling

### 6.1 Development of appropriate sampling plans

As mentioned in the United States Environmental Protection Agency (EPA) Manual SW-846 (US Environmental Protection Agency 2006), which addresses the development and implementation of a scientifically credible sampling plan and the documentation of the chain of custody for such a plan, the initial, and perhaps most critical, element in a program designed to evaluate the physical and chemical properties of a sample (in this case, of Biochar), is the sampling plan.

A sampling plan is usually a written document that describes objectives and tasks and identifies how the individual tasks will be performed. The SW-846 Manual (US Environmental Protection Agency 2006) suggests that a sampling plan should be designed with input from the various sectors involved in the project, which include: regulatory sampling, end-users, field team members, analytical chemists, process engineers or equivalent, statisticians and quality assurance representatives.

The referenced manual describes a number of sampling procedures (simple, stratified, systematic random, composite), of which one must be selected which is most appropriate, according to the characteristics of the sampled object. The team involved in the elaboration of the sampling plan must therefore consult the SW-846 Manual during the development of a sampling plan. This test method proposes the use of composite sampling, as it will help reduce the physical/chemical heterogeneity of a sample.

### 6.2 Sample selection and frequency

The sample shall be selected so as to be representative of all the material contained in a production lot. This is achieved by employing a composite sampling procedure (US Environmental Protection Agency 2006), which requires the collection of multiple random sub-samples from the final volume of produced Biochar, and mixing them together to obtain a homogeneous sample of no less than 500 g. It needs to be demonstrated that the sample size is representative of the whole production lot, via statistical analysis. Samples must be taken:

- Annually; or
- After a material change in Feedstock; or
- After a material change in thermochemical production parameters;

Whichever is more frequent.

Material changes (International Biochar Initiative 2012, section 6.2) in Feedstock reflect shifts in Feedstock type from one source of biomass to a distinctly different source of biomass. See Appendix 4 of the IBI Standards (International Biochar Initiative 2012) for more information on how to determine Feedstock types that constitute a "material change". In mixed Feedstocks, whether processed or unprocessed, a 10% or greater shift in total Feedstock composition shall constitute a material change in Feedstock.

Material changes in production processes reflect increases or decreases in process temperature or residence time. A material change in thermochemical production parameters has occurred if process temperature (also known as Heat Treatment Temperature) changes by +/- 50˚C, or if the thermochemical processing time (residence time) changes by more than 10% of the initial processing time.

Testing of Biochar materials should occur after thermochemical processing is complete and before final shipment. If the material is intended to be mixed with another material, testing of the Biochar material must occur before mixing or blending with any other product.

### 6.3 Additional Considerations for Sampling

Sampling practices should follow a composite sampling procedure (well-mixed batch), where a single sample (or group of samples) is taken to represent a specific period of production time. Frequency of sampling depends on the appropriate number of samples needed to achieve the necessary precision (at least 95% confidence level). Precision is improved by increasing the number of samples while maintaining a sampling pattern to guarantee a spatially uniform distribution. The number of samples required is the least amount to generate a sufficiently precise estimate of the true mean concentration. The number of samples required must also demonstrate that the upper limit of the confidence interval of the true mean is less than applicable regulatory threshold value. Detailed calculations for the number of samples required can be found within the US EPA SW-846 manual (US Environmental Protection Agency 2006) and within the US Composting Council TMECC composting methods manual (US Composting Council 2001).

### 6.4 Chain of Custody form

Chain of custody forms and procedures should be used with all environmental or regulatory samples. These forms are used to track sampling and handling from the time of collection through laboratory analysis and data reporting. The form should include, at a minimum:

collector's name, signature of collector, date and time of collection, location (place and address) of collection, identification of sample to be used in all reporting, requested analysis (code number) and signature of people involved in the chain of possession (a sample form is included at the end of this document).

### 6.5 Sample preparation

The sample must leave the production facility in a sealed, moisture-proof container for transport to the analyzing facility, to prevent moisture loss/gain before it is to be analyzed.

## 7        Sample Analysis Procedures

### 7.1 Materials

Make replicate determinations and run appropriate Standard reference materials (SRM) with each analysis to ensure quality.

### 7.2 Moisture

Zero the balance. Place a 200°C heat resilient vessel (high silica or porcelain evaporating dish) on the balance, and record the mass to the nearest 0.01g ($m_v$).

Working quickly so as to not lose or gain moisture during preparation, mix the sample and place no less than 5 g in the vessel. Record the mass of the vessel and as-received sample ($m_{sr}$) to the nearest 0.01 g. Immediately place the vessel containing the sample in a 105°C oven until a constant mass is reached.

Remove the vessel and sample from the oven and let cool in a desiccator until it reaches room temperature. Record the mass of the vessel and dried sample ($m_{sd}$) to the nearest 0.01g.

In a clean and dry mortar and pestle place your dried sample and grind it as many times as necessary until the material passes through a 2mm sieve.

The dried and ground sample will be separated into two sub-samples, with masses determined by the requirements of the specific equipment to be used for the measurement of H, $C_{tot}$ and $C_{org}$. Sample quantities must be large enough to complete all analyses. One sub-sample is used to determine the hydrogen and total carbon and the other to determine organic carbon content via inorganic carbon measurement and subtraction from measured total carbon.

### 7.3 Hydrogen and total carbon

One of the sub-samples is tested for hydrogen and total carbon using an elemental analyzer, employing a dry combustion method of molecular mass determination, according to the manufacturer's protocol.

Record the initial sample mass, as well as the hydrogen and total carbon percentages.

### 7.4 Inorganic carbon

The second sub-sample is used to determine the inorganic carbon content. It is treated with 1N HCl in a closed vessel. Carbon Dioxide gas is evolved during the reaction between the acid and carbonate fraction of the specimen. The resulting pressure is proportional to the carbonate content of the specimen. This pressure is measured using a pre-calibrated pressure gauge based on reagent grade calcium carbonate, according to (ASTM D4373).

Weigh and record the mass of the second sub-sample, which is then inserted into the reactor. Following insertion of a Biochar sub-sample into the reactor, lower the 20 mL filled acid container carefully into the reactor without spilling. Seal the reactor and close the pressure-release valve. Tilt the reactor to spill the acid onto the sample and swirl to mix until reaction is complete (~2 to 3 minutes). Monitor the pressure gauge to ensure that the reaction vessel is completely sealed. Record the pressure. Repeat this procedure using increasing masses of the reagent grade calcium carbonate Standard (0, 0.2, 0.4, 0.6, 0.8 and 1.0 g), register values and plot a graph of $CaCO_3$ mass versus reactor pressure. Calibrate the pressure dial directly in percent inorganic carbon along the following range: 0, 2.4, 4.8, 7.2, 9.6, and 12%. These inorganic carbon percentages correspond directly to the masses of $CaCO_3$ used in the Standard calibration, since pure calcium carbonate is 12% carbon (please refer to the chemical properties listed for this reagent to determine its specific carbon content, and specify the accuracy of the equipment). Remove acid with heat and/or vacuum.

Record the inorganic carbon content as interpreted from the pressure calibration curve.

## 8      Calculations

### 8.1  Moisture

Calculate the moisture content as follows:

$$M = \left[\frac{(m_{sr} - m_{sd})}{(m_{sr} - m_v)}\right] * 100 \tag{36}$$

Where:

M = Moisture content (%)

$m_{sr}$ = Mass of vessel and as received sample (g)

$m_{sd}$ = Mass of vessel and dried sample (g)

$m_v$ = Mass of vessel (g)

### 8.2 Hydrogen and total carbon

Simply record the results for H and $C_{tot}$ from the elemental analyzer in percent units.

### 8.3 Organic carbon

Calculate the organic carbon as follows:

$$C_{org} = (C_{tot} - C_{inorg}) \qquad (37)$$

Where:

$C_{org}$ = Percent organic carbon in the sample.

$C_{tot}$ = Percent total carbon (7.3)

$C_{inorg}$ = Percent inorganic carbon (7.4)

### 8.4 Hydrogen to Organic carbon molar ratio

Calculate the Hydrogen to Organic carbon molar ratio as follows:

$$H/C_{org} = \frac{(\%H/1)}{(\%C_{org}/12)} \qquad (38)$$

Where:

$H/C_{org}$ = Hydrogen to organic carbon molar ratio

%H = Hydrogen mass of the sample (in %) (8.2)

$\%C_{org}$ = Organic carbon mass of the sample (in %) (8.3)

### 8.5 Emissions reduction

Calculate the GHG emissions reduction (ER) to be claimed as follows:

8.5.1   Convert the calculated $H/C_{org}$ value to the equivalent $BC_{+100}$ value as follows:

| $H/C_{org}$ | $BC_{+100}$ |
|---|---|
| <0.4 | 70% |
| 0.4-0.7 | 50% |

8.5.2   Multiply the calculated $BC_{+100}$ value to calculate GHG emissions reduction as follows:

$$ER = W_{LOT} \times \frac{C_{org}}{100} \times \left(\frac{BC_{+100}}{100}\right) \times \left(\frac{(100 - M)}{100}\right) \times \frac{44}{12} \times 0.95 \qquad (39)$$

Where:

ER= Greenhouse Gas emissions reduction, expressed in tons of carbon dioxide equivalent (ton $CO_2$eq).

$W_{LOT}$ = Weight of the production lot from where the sample was taken (in metric tons)

$C_{org}$ = Organic carbon calculated from the sample (8.2)

$BC_{+100}$ = Biochar carbon stable for at least 100 years (8.5.1)

M = Moisture content (%) (8.1)

44/12 = Molar ratio of carbon dioxide to carbon.

0.95 = correction factor due to possible positive priming effect[4]

(Alternatively, use calculated values of $C_{org}$, $B_{+100}$, and M in Equation 33 to determine $C_{BS,j,y}$ for Equation 23.)

## 9      Precision and Bias for Hydrogen, Total carbon and Inorganic carbon methods

### 9.1 Precision and Bias

Precision: To date, no inter-laboratory testing program has been conducted using this method to determine multi-laboratory precision.

Bias: The bias of the procedure in this test method has not yet been conducted.

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[4] Support Information section 1 of the report "Biochar Carbon Stability Test Method: An assessment of methods to determine Biochar carbon stability"

The $BC_{+100}$ calculations are based on the lower limit of a 95% confidence interval of a regression performed to relate $H/C_{org}$ values registered from Biochar samples (n=37), based on a two-component double exponential model. They are therefore considered conservative estimations.

Maintaining a written and/or visual (photos, video, other) registry of the complete process, regarding the values obtained in each step for each variable is required in order to provide documented data for third-party Verification bodies.

## 10    Keywords

Biochar, $BC_{+100}$, hydrogen, total carbon, organic carbon, hydrogen-to-organic carbon molar ratio.

## 11    Documents Cited

(1) ASTM D4373 – 96 Standard test method for Calcium Carbonate Content in Soils.

(2) International Biochar Initiative (IBI) (2013). Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used In Soil. Version 1.1. April, 2013.

(3) Kyoto Protocol (1998) COP3 Decision 2/CP.3 Methodological issues related to the Kyoto Protocol, paragraph 3.

(4) Schumacher, B. (2002) Methods for determination of Total Organic carbon (TOC) in soils and sediments. US Environmental Protection Agency (EPA), Environmental Sciences Division National Exposure Research Laboratory, Office of Research and Development.

(5) US Composting Council (2001) Test Methods for the Examination of Composting and Compost (TMECC) Composting methods Manual, Field Sampling of Compost Material Section 02.01-C.

(6) US Environmental Protection Agency (2006), Test Methods for Evaluating Solid Waste, Physical/Chemical methods, Chapter 9.

# Chain of Custody

**Chain of Custody Sample Form**

| | | | | | | Lab Use Only |
|---|---|---|---|---|---|---|
| | | | | | | Cold Room |

Certified Lab:
 Contact:
 Address:
 City, St, Zip:

Tel: ( )
Fax: ( )
email:
Web Address: http://

**CLIENT:** Please fill out or staple business card

| | | Shelf # |
|---|---|---|

cc sent to:
 Company:
 Contact:
 Address 1:
 Address 2:
 City, St, Zip:
 Tel: ( )
 Fax: ( )
 email:

Company:
 Contact:
 Address 1:
 Address 2:
 City, St, Zip:
 Tel: ( ) email:
 Fax: ( )

| | | Group # |
| | | Account # |
| | | Client # |

| SAMPLE Identification | Date Sampled | Stable Carbon Package | Phytotoxicity Package | Worm Avoid. Package | IBI Char Package | tests required Other-1 | tests required Other-2 | tests required Other-3 | tests required Other-4 | tests required Other-5 | Sample Condition |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |

* call for information;  + copies of report sent into program manager;  check boxes above that apply

| RELEASING | Date | Time | RECEIVING | Date | Time |
|---|---|---|---|---|---|
| Releasing Signature 1 | | | Receiving Signature 1 | | |
| Releasing Signature 2 | | | Receiving Signature 2 | | |
| Releasing Signature 3 | | | Receiving Signature 3 | | |
| Releasing Signature 4 | | | Receiving Signature 4 | | |

Notes:

Special Instructions:
 1
 2
 3
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 5

# APPENDIX 2: JUSTIFICATION FOR THE "STANDARD TEST METHOD FOR ESTIMATING BIOCHAR CARBON STABILITY (BC$_{+100}$)"

A. Budai[5]; A. R. Zimmerman[6]; A.L. Cowie[7]; J.B.W. Webber[8]; B.P. Singh[9]; B. Glaser[10]; C. A. Masiello[11]; D. Andersson[12]; F. Shields[13]; J. Lehmann[14]; M. Camps Arbestain[15]; M. Williams[16]; S. Sohi[17]; S. Joseph[18], Miguel Rodriquez[19]

## Abstract

Twenty seven methods currently used to characterize Biochar were assessed in terms of their usefulness to determine the stability of Biochar carbon in the environment. The International Biochar Initiative (IBI), which led the effort, gathered fourteen experts in different fields of Biochar relevant to stability, who guided the process for obtaining a simple, yet reliable, measure for Biochar stability. Important requisites were defined for the test, including cost, repeatability and availability. Identification of a cost-effective, scientifically valid test to measure the stable carbon component of Biochar is imperative to distinguish Biochar from non-Biochar (non-stable) materials, and to develop a Biochar offset Methodology for carbon markets. The stability of Biochar carbon in soils makes it a highly promising product for consideration as a strategy for climate change mitigation. The definition of the variable BC+100, which represents the amount of Biochar carbon that is expected to remain stable after 100

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years, along with predictions of stability based on simple (Alpha) and more sophisticated (Beta) methods, allowed to correlate a molar ratio (H/$C_{org}$) to the relative stability of Biochar. The process for identifying the Biochar Carbon Stability Test Method is summarized here, and the method itself is available as a separate, technical document (Appendix 1).

**Introduction**

The stability of Biochar is of fundamental importance in the context of Biochar use for environmental management for two primary reasons: first, stability determines how long carbon applied to soil, as Biochar, will remain in soil and contribute to the mitigation of climate change; second, stability will determine how long Biochar will continue to provide benefits to soil, plant, and water quality (Lehmann et al., 2006). Biochar production and application to soil can be, in many situations, a viable strategy for climate change mitigation. Conversion of biomass carbon (C) to Biochar C via Pyrolysis can lead to sequestration of about 50% of the initial C compared to the low amounts retained after burning (3%) and biological decomposition (<10–20% after 5–10 years) (Lehmann et al, 2006, Figure A2-1), with the entirety of uncharred biomass being most likely decomposed after a century, which is a relevant time frame for the purpose of the stability test, as presented in subsequent sections.
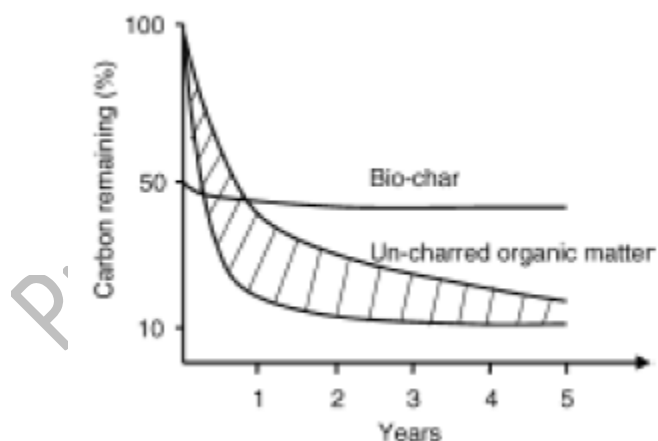


**Figure A2-1. Schematic of Biochar and biomass degradation patterns. Source:** Lehmann et al. (2006)

Biochar has been found to mineralize in soil much slower than the organic material it is produced from. The Mean Residence Time (MRT) of different Biochars has been found to fall mostly in the centennial to millennial scales, as shown in Table A2-1, with some studies showing estimations of decadal scales. The difference in these data is not the result of random variability

but to a large extent the product of different materials and to different environmental and experimental conditions.

**Table A2-1. Mean Residence Time (MRT) of Biochar across studies.**

| Publication | Scale of estimated MRT (years) |
|---|---|
| Masiello and Druffel, 1998 | Millennial (2,400 – 13,900) |
| Schmidt et al., 2002 | Millennial (1,160 – 5,040) |
| Cheng et al., 2006 | Millennial (1,000) |
| Laird, 2008 | Millennial (1,000's) |
| Cheng et al., 2008 | Millennial (1,335) |
| Kuzyakov et al., 2009 | Millennial (2,000) |
| Major et al., 2010 | Millennial (3,264) |
| Novak et al., 2010 | Millennial (1,400-51,000) |
| Liang et al., 2008 | Centennial to millennial (100-10,000's) |
| Zimmerman, 2010 | Centennial to millennial (100-100,000) |
| Baldock and Smernik, 2002 | Centennial (100-500) |
| Hammes et al., 2008 | Centennial (200-600) |
| Schneider et al., 2011 | Centennial (100's) |
| Hamer et al. 2004 | Decadal (10's) |
| Nguyen et al. 2008 | Decadal (10's) |

**Objective**

The goal of this effort was to develop a method for testing and quantifying the mineralization of carbon in Biochar, by specifying the amount of C that is predicted to remain present in soil 100 years[20] after land application, which for the purposes of the stability test is termed $BC_{+100}$. The fraction of carbon in Biochar that mineralizes during the same time period is termed $BC_{-100}$. Selection of methods was based on the following:

- Only analytical tests for Biochar stability that have been published in the peer-reviewed literature before the final issuance of this document were considered;
- Sampling procedures and test methods had to be considered cost-effective; and

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[20] Global Warming Potential (GWP) of Greenhouse gases (GHG) is assessed over a 100-year time horizon. One hundred years is commonly used to define permanence in carbon offset markets (e.g. Mechanisms under the Kyoto Protocol (Clean Development Mechanism - CDM, Joint Implementation - JI), Australia's Carbon Farming Initiative).

- All assumptions made during the development of this test method followed the principle of conservativeness, i.e. the Methodology should in every instance utilize conservative approaches in order to avoid over-estimating the stability of Biochar carbon.

**Scope of Work**

The effort was built upon previous work completed by The International Biochar Initiative (IBI) to develop "***Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used In Soil***" (***IBI Biochar Standards, 2012***). The present document constrains its scope to materials with properties that satisfy the criteria for Biochar as defined by the IBI Standards.

This test method considers only the carbon stabilized in Biochar via Pyrolysis. Neither Biochar impacts on plant productivity, nor any effects on native soil Carbon Stocks or vice-versa (i.e. positive or negative priming) are included (Figure A2-2), because scientific evidence is insufficient at this time to determine the direction and magnitude of these processes. Biochar may stabilize native soil organic carbon by sorbing organic compounds (Smernik, 2009). There are, however, cases where Biochar addition to soil can produce an undesirable "positive priming effect" (Hamer et al., 2004; Wardle et al., 2008; Kuzyakov et al., 2009; Zimmerman et al., 2011; Cross and Sohi, 2011; Woolf and Lehmann, 2012; Singh et al., 2012), causing the release of additional $CO_2$ from soil. However, Woolf and Lehmann (2012) estimated that no more than 3 to 4% of initial non-pyrogenic SOC might be mineralized due to priming by Biochar over 100 years. Even though this effect may be small compared to the possible increase in C sequestration from the negative priming effect, positive priming was conservatively taken into account with the 0.95 correction factor in equation (33) of the GHG Methodology.
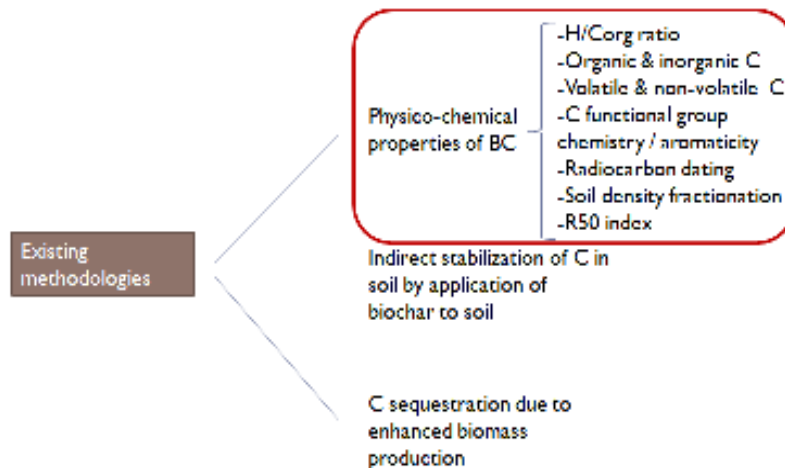
**Figure A2-2. Scope of work for the test method.**

Even though there is evidence of increased net primary productivity (NPP) of soils after Biochar addition (Lehman et al., 2006; Major et al., 2010), carbon sequestration due to enhanced biomass production was not included because insufficient data are available to quantify the effects of Biochar additions to soil on crop productivity, which is likely to vary widely between soil types, Feedstock and environments (Van Zwieten et al., 2010; Jeffery et al., 2011). Additionally, the longevity of the measured short-term impacts of Biochar on NPP is unknown. Furthermore, C sequestered in biomass of annual crops and pasture cannot be considered stable, mainly due to its fast turnover rate. The decision not to include these also reflects the conservative approach of this effort.

**Definitions**

**Types of methods**

Through a review made by the Expert Panel consisting of fourteen Biochar experts, test methods were categorized into three groups: (1) Alpha methods, which may allow routine estimation of the $BC_{+100}$ at minimal costs; (2) Beta methods, which directly quantify $BC_{+100}$ and may be used to calibrate Alpha methods; and (3) Gamma methods, which may provide the physiochemical underpinning for the Alpha and Beta methods. These categories of methods are justified and described below.

**Alpha methods**

Alpha methods are defined as those which provide a simple and reliable measure of the relative stability of carbon in Biochar, that are readily available, at a cost of less than 100 US dollars (USD) (defined as feasible by the Expert Panel) and within a timeframe of minutes or hours to, at maximum, a few days. Alpha methods are intended to be undertaken by a certified laboratory to be used by Biochar producers.

Alpha methods do not provide an absolute measure of stability; rather, they assess a property (usually chemical or physical) that is related to stability. Alpha methods must be calibrated through comparison with Beta and/or Gamma methods.

Some Alpha methods have already been developed ("Alpha-1") and were found to be strongly related to the properties determined by the Beta and Gamma methods. It is expected that more Alpha methods will emerge as Biochar stability research continues to develop, which could be placed in a category called "Alpha-2" methods.

The results of any Alpha method must correlate – ideally linearly – with results of at least one Beta (calibration) method, as well as those of the applicable Gamma methods. Some possible Alpha-1 methods are briefly described and discussed below.

*Hydrogen to Organic Carbon Molar Ratio (H:Corg) (Enders et al., 2012; IBI, 2012) and Oxygen to Carbon Molar Rratio (O:C) (Spokas, 2010):*

Both ratios reflect the physico-chemical properties of Biochar related to stability, as the proportion of elemental compounds (H and O) relative to carbon (C) present in Biochar. These elemental constituents of Biochar can be measured routinely, using an elemental analyzer, based on the manufacturer's protocol.

Increasing production temperatures lead to lower H/C and O/C ratios (Krull et al., 2009; Spokas, 2010), as the abundance of C relative to H and O increases during the Pyrolysis process (Figure A3-3).
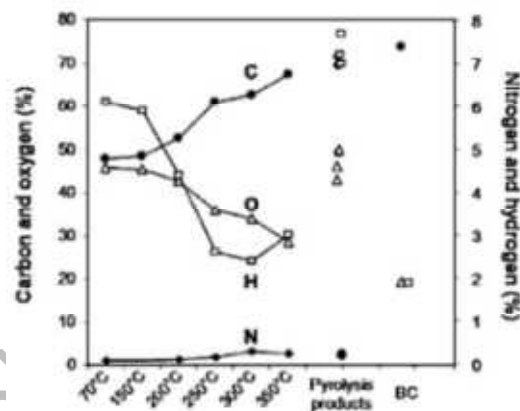


**Figure A3-3. Changes in Biochar elemental composition with varying Pyrolysis temperatures. Source:** Krull et al. (2009).

Materials with low H/C and O/C values are graphite-like materials (i.e. soot, black carbon, activated carbon), which exhibit high stability compared to uncharred biomass, which possesses high H/C and O/C values (Figure A2-4) and low resistance to degradation. Hence, as Biochars resemble graphite-like materials, characterized by low H/C and O/C ratios, they are expected to be more stable or inert, and less prone to mineralization than uncharred organic matter (Masiello, 2004).
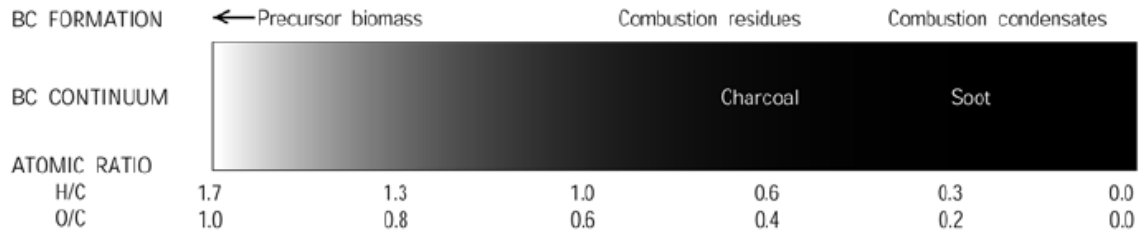
**Figure A2-4. Physical characteristics and ratios related to Biochar stability.** Source: Adjusted from Hammes et al. (2007)

These two ratios can be plotted in a two-dimensional Van Krevelen diagram, which is a graphical representation of Biochars, based on elemental composition. In a study by Schimmelpfenning and Glaser (2012), different Biochars are characterized based on the relation between the measured H/C and the O/C ratios, and compared to different types of coals (Figure A2-5).
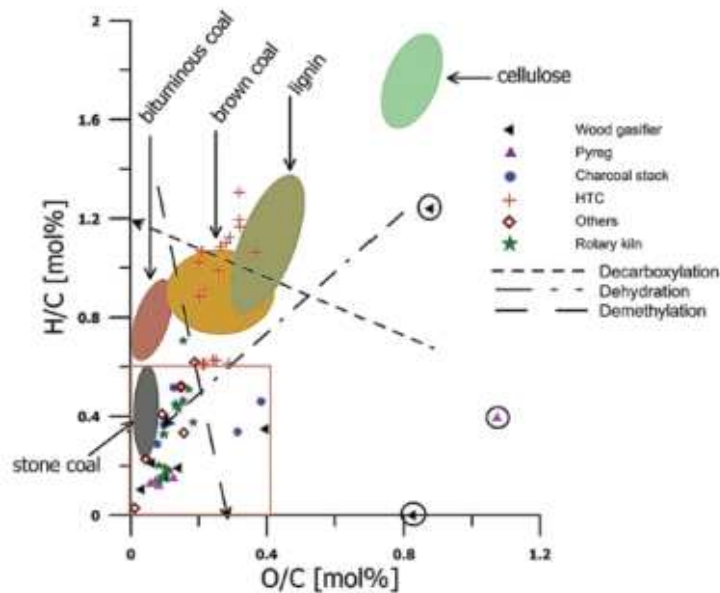


**Figure A2-5. Van Krevelen diagram.** Source: Schimmelpfennig and Glaser (2012)

The use of the molar $H/C_{org}$ ratio is proposed instead of the H/C ratio, as the former does not include inorganic C that may be 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 soil on a centennial scale.

*Volatile Matter Content:*

The content of volatile matter (VM) in Biochar has also been observed to be inversely related to Biochar stability, calculated as mean residence time or half-life (Enders et al., 2012; Zimmerman, 2010; Spokas, 2010). Volatile matter content can be measured through different paths, usually thermal treatment, (e.g. the ASTM method D1762-84[21] (2007) (CDM SSM AMS.III-L; DeGryze et al. 2010; Enders et al., 2012)), also termed Proximate Analysis, which covers the determination of moisture, volatile matter, and ash in a variety of materials.

VM is well correlated with elemental ratios (O/C and H/C), as shown in Figure A2-6 for O/C ratios. As a result, it could be expected to be a good predictor of Biochar carbon stability. However, Spokas (2010) found a weak correlation between VM content and the estimated Biochar half-life using data from 37 Biochar sample measurements from different studies (Figure A2-7). Therefore volatile matter is discarded as a well-suited predictor of stability.
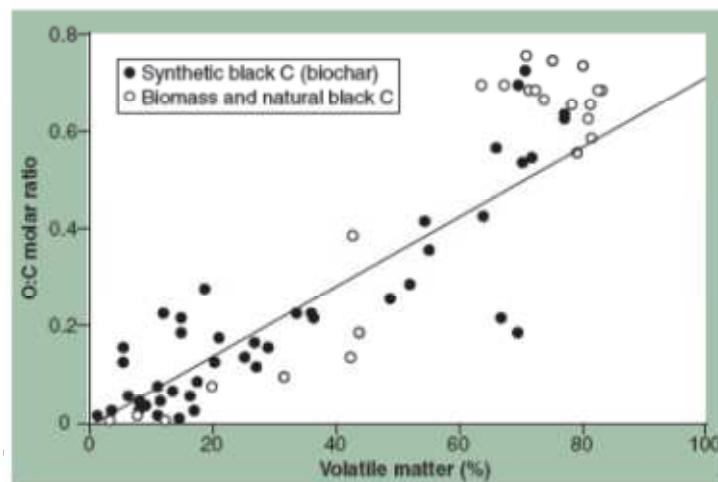


**Figure A2-6. Correlation of volatile matter and O/C molar ratio.** Source: Spokas (2010) ($R^2$ = 0.76)
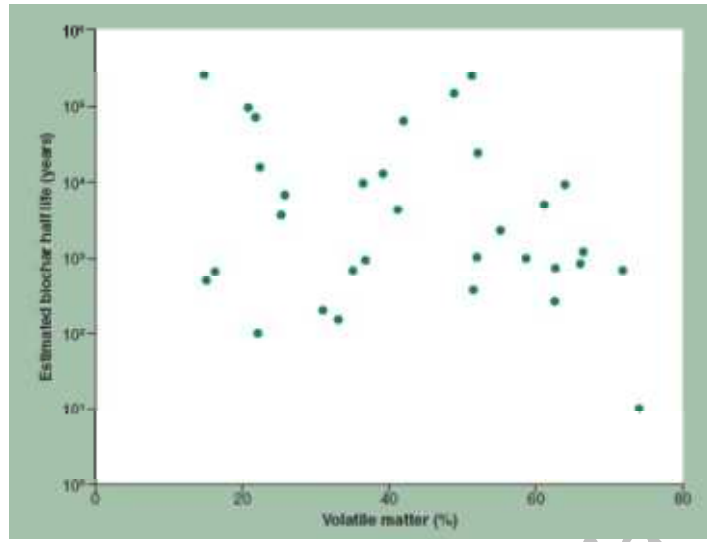
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[21] Chemical analysis of wood charcoal

**Figure A2-7. Comparison of volatile matter content with estimated Biochar half life.** Source: Spokas (2010) ($R^2$ not available)

**Beta methods**

Beta methods are those that (1) directly quantify BC loss over a period of time, and (2) demonstrate a relationship with results of an Alpha method (a more conveniently measured parameter) and Gamma values for a range of Biochar types. At present, the Beta methods in use are laboratory and field-based incubations as well as field chronosequence measurements, all of which must be combined with modeling to estimate Biochar C lost over the specific time interval of 100 years ($BC_{-100}$).

Beta methods provide an absolute measure for the carbon that will remain in Biochar for at least 100 years (at minimum, a conservative estimate of stability). Beta methods are not widely available or obtainable at a cost or within the timeframes specified for Alpha methods. It is also not feasible to have registry of direct observations of Biochar for 100 years, in order to demonstrate the suitability of a Beta method. Some Beta methods have been published and are presented below.

*Incubation and Field Studies:*

Incubation studies of Biochar under laboratory conditions (Zimmerman, 2010; Singh et al., 2012) and studies of Biochar in soils (Major et al., 2010b; Cheng et al., 2008; Liang et al., 2008; Kuzyakov et al., 2009) have recorded temporal Biochar decomposition patterns (see Figure A2-8). Observations derived from incubation experiments are critical to the understanding of Biochar behavior and, therefore, projected longevity in soils. The incubations (3-5 years of duration) were undertaken in controlled environmental conditions (e.g., moisture, temperature) and with the addition of microbial inoculations and nutrient solutions in order to promote mineralization. Because these are closed systems and non-variant conditions, estimates of stability based on these measurements can be considered conservative. Mineralization rates have been observed to decrease until reaching a constant rate at around 600-700 days, indicating that remaining Biochar carbon may exhibit a certain degree of stability. In order to quantify stability a very conservative approach must be used for extrapolating measurements from short- to medium-term studies to 100 years, which is done in this report, as explained in subsequent sections.
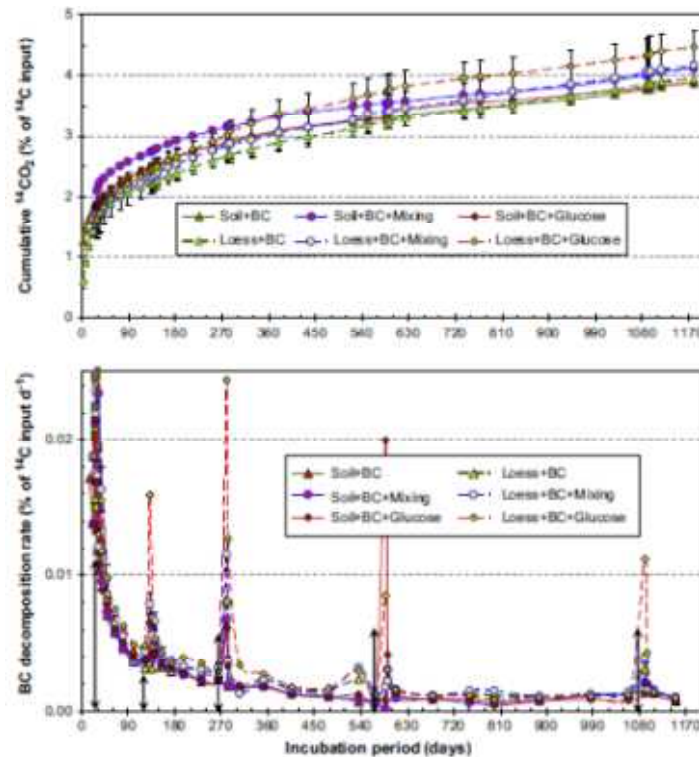
**Figure A2-8. Biochar mineralization rate.** Source: Kuzyakov et al., 2009 (3.2 year incubation)

Both two-component (double exponential) models (e.g. Cheng et al., 2008; Zimmerman et al., 2011; Singh et al., 2012) and power regression models (e.g. Zimmerman 2010) have been used to extrapolate measurements from incubations of freshly produced and aged Biochar to predict the longer-term stability of Biochar. The second model may better represent the physical characteristics of Biochar and assumes an exponentially decreasing degradation rate, whereas the first assumes Biochar is composed of only two fractions – labile and stable. Thus, the two-component model is likely to underestimate stability of Biochar C and will yield a more conservative estimate of C sequestration, since the greater the number of pools that are added, the larger predictions of stability will be.

*Chronosquences:*

A Biochar C loss rate can also be determined by using measurements of Biochar distribution from sites that vary in time interval since Biochar was applied (a chronosequence). However, results of these types of studies, thus far, range from no loss to complete C loss, and are likely affected by erosion or translocation (Nguyen et al. 2008; Major et al. 2010b; Foereid et al. 2011).

**Gamma methods**

Gamma methods measure molecular properties relevant to Biochar stability and can verify the legitimacy of the Alpha and Beta methods through establishing strong relationships between the properties measured by them. Thus, Gamma methods would provide safeguard against selection of Alpha or Beta methods based on empirical correlations that do not reflect a functional relationship. Some Gamma methods are briefly described below.

*NMR spectroscopy (Brewer et al., 2011; McBeath et al., 2011):*

Direct polarization $^{13}$C nuclear magnetic resonance spectroscopy with magic angle spinning (DP/MAS $^{13}$C NMR) is a well-established technique for measuring the aromaticity (fraction of total carbon that is aromatic) of Biochars. Aromaticity is strongly correlated to C stability (Singh et al., 2012) and aromaticity can be predicted by the H/$C_{org}$ values of Biochar (Wang et al., 2013). The $^{13}$C NMR spectrum of aryl carbon (i.e. derived from condensed aromatic carbon) is very characteristic, comprising a single resonance centered at approximately 130 ppm. Spinning side bands associated with the presence of aromatic carbon can be detected.

*Pyrolysis Gas Chromatography mass spectrometry (Py GC/MS) – analytical Pyrolysis (Kaal et al., 2008, 2009, 2012; Fabbri et al., 2012):*

Analytical Pyrolysis is a technique that uses controlled invasive thermal degradation to break down large molecules for identification. The resultant Pyrolysis products are separated and identified using gas chromatography and mass spectroscopy. The sum of the most abundant fingerprints of charred material in pyrograms (i.e., monoaromatic hydrocarbons, polyaromatic hydrocarbons, benzonitriles/total quantified peak area) is related to the proportion of condensed aromatic carbon present in Biochar.

*Ring Current NMR (McBeath and Smernik, 2009; McBeath et al., 2011):*

This method gauges the degree of aromatic condensation of Biochars. It involves sorbing $^{13}$C-labeled benzene to the Biochar structure. The $^{13}$C NMR chemical shift of the sorbed benzene (relative to straight $^{13}$C-benzene) is affected by diamagnetic ring currents that are induced in the conjugated aromatic structures when the Biochar is placed in a magnetic field. These ring currents increase in magnitude with the increasing extent of aromatic condensation.

*Benzene polycarboxylic acids (BPCA) (Glaser et al., 1998; Brodowski et al., 2005; Schneider et al., 2010):*

The BPCA are molecules formed during the nitric acid oxidation of Biochar. The maximum number of carboxylic groups reflects the number of quaternary C atoms initially present. Biochar with a higher degree of condensation should result in higher proportion of the penta

(B5CA) and hexacarboxylic (B6CA) benzoic acids relative to BPCAs with less quaternary carbon atoms (B3CA, B4CA). The ratio of B6CA-C/total BPCA-C thus is positively related to the degree of condensed aromatic C present in Biochar; the larger the ratio the greater the aromaticity. The concentration of the sum of BPCA can be used to quantify Biochar in the environment, e.g. in soil amended with pure Biochar or in mixture with other organic materials.

Gamma methods are not expected to be used by Biochar producers for determining Biochar C stability. This is mainly because of the high level of technical expertise required to perform these tests, specialized expensive instruments, high costs per analysis, and low availability. Instead, Gamma methods are intended to be used by scientists in order to calibrate Alpha and Beta methods for iterative improvement of a simple Biochar C stability test method.

**Material and methods: Biochar Carbon Stability Test Method selection process**

Twenty-eight test methodologies currently used to assess Biochar characteristics, mostly related to stability, were reviewed and evaluated by the Expert Panel. $H/C_{org}$ was selected as the preferred Alpha method for being cost-effective, simple, replicable, and published in peer-reviewed literature. Modeled data from observations of carbon degradation from 3- to 5-year incubation studies (Zimmerman, 2010 as extended in Zimmerman and Gao, 2013; and Singh et al., 2012) was used as the Beta method to calibrate the predictions and determine $BC_{+100}$.

**Results**

A strong relationship was found between the $H/C_{org}$ values of 31 Biochar samples from the two mentioned studies and the predicted $BC_{+100}$ values, based on the two-component model (Figure A2-9).

The observed behavior for carbon in each of the 31 samples followed a typical pattern as shown in Figure A2-8, where after some months, the turnover rate slowed, exhibiting little carbon loss. The two Q10 adjustments for harmonizing the data between both studies were not made. However, even if a low value were to be used, e.g. Q10 = 2 (compared to Cheng et al., 2008), harmonizing the data from 30°C that lack soil minerals (Zimmerman, 2010) to 22°C (Singh et al., 2012), would yield higher $BC_{+100}$ values than the ones reported in this Methodology, thus complying with the conservativeness principle. In addition, it is conservative to utilize the data with high incubation temperatures of 30°C and 22°C, given that the global mean temperature is less than 10°C (Rohde et al., 2013). With even a low Q10 of 2, a recaluculation of only 22°C to

10°C would make a large change to $BC_{+100}$. Grouping the predicted $BC_{+100}$ values, based on the two-component model, results in Figure A2-9.
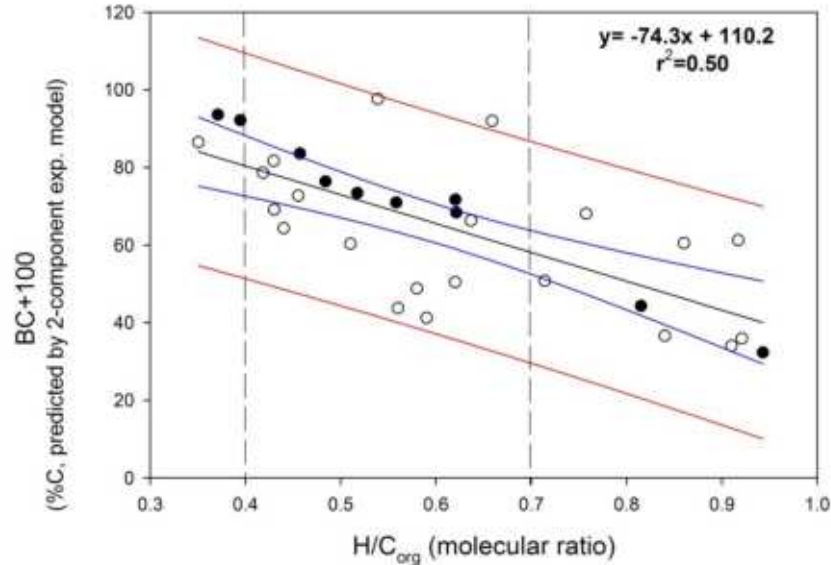
**Figure A2-9. The correlation between H/C$_{org}$ and Biochar C predicted to remain after 100 years as predicted by a two-component model (i.e. BC$_{+100}$) was produced using data and calculations from Singh et al., 2012 (closed circles) and Zimmerman, 2010 as extended in Zimmerman and Gao, 2013 (open circles).**

The vertical axis in Figure A2-9 represents the percentage of organic carbon present in Biochar that is expected to remain in soil after 100 years. Thus, a Biochar sample with a H/C$_{org}$ value of 0.6 would be predicted to have a BC$_{+100}$ of 65.6%, indicating that 65.6% of the organic carbon measured in Biochar will likely remain in soil for at least a century. The statistical basis for this inference is presented below.

The blue and red lines in the plot represent the 95% confidence upper and lower intervals, and the 95% prediction intervals, respectively. The correlation measure shows a modest value (R$^2$ = 0.5). As Biochar is composed of various constituents, it is notable that this one parameter (H/C$_{org}$) explains 50% of the variation in the carbon stability of the Biochar samples assessed. Furthermore, every individual sample but one falls within the 95% prediction interval, which predicts the range in which values of future samples will fall. Additionally, a p-value below 0.0001 indicates the strong statistical significance of the calculations. Thus, this regression model is judged adequate for determining BC$_{+100}$ based on H/C$_{org}$ measurements.

Defining cut-offs every 0.1 for H/C$_{org}$ values in the range of 0.4 to 0.7 for the Biochar samples, the equivalent mean, upper limit and lower limit BC$_{+100}$ values are obtained for analysis (Table A2-2). Two distinct levels can be evidenced: for an H/C$_{org}$ value of 0.4, the lower limit of the confidence interval of BC$_{+100}$ is above 70% (in a range of 88-72%). From this it is concluded that

at least 70% of the $C_{org}$ measured in Biochar is predicted to remain in soil for 100 years with 95% confidence, for an $H/C_{org}$ value lower or equal to 0.4. Confidence intervals are considered over prediction intervals, as they exhibit the probability that they will contain the true predicted parameter value, for the selected confidence level.

On the other hand, for an $H/C_{org}$ value of 0.7, a $BC_{+100}$ of 50% can be conservatively expected. If a cut-off of $BC_{+100}$ is defined at 50%, most (17 out of 19) of the observed values in the 0.4-0.7 $H/C_{org}$ range would fall above this point, therefore underestimating stability. Thus, cut-offs at values of $H/C_{org}$ of 0.4 and 0.7 are defined to characterize "highly stable" ($BC_{+100}$ of 70%) and "stable" ($BC_{+100}$ of 50%) $C_{org}$ in Biochars, respectively.

**Table A2-2. $H/C_{org}$ and $BC_{+100}$ equivalences at 95% confidence**

| $H/C_{org}$ | BC$_{+100}$ (%) | | | |
| | Mean | Lower Limit | Upper Limit | Chosen Value |
|---|---|---|---|---|
| **0.4** | **80.5** | **72.6** | **88.2** | **70** |
| 0.5 | 73.1 | 67.1 | 78.9 | 50 |
| 0.6 | 65.6 | 60.5 | 70.6 | 50 |
| **0.7** | **58.2** | **52.5** | **63.8** | **50** |

Biochar materials that obtain $H/C_{org}$ values higher than 0.7 are not considered to be Biochar, as these materials would not meet the definition of Biochar as defined by the IBI Standards.

**Discussion**

The comments in this section seek to provide guidance as to the possible next steps for the continuous improvement of the predictability of different Alpha, Beta and Gamma methods.

The members of the Expert Panel agreed upon the necessity of continued collaboration to further refine the proposed method. Interest emerged to start the exchange of Biochar samples to run different laboratory tests in the form of a ring trial. Additional funding would be needed for this very desirable initiative to occur. As stated earlier in this document, as new findings emerge, they should be incorporated into the proposed Methodology, with the aim of obtaining the most precise and, at the same time, the most economically feasible method for determining $BC_{+100}$.

**Fate of Biochar**

*Biochar transport mechanisms*

The physical movement of Biochar away from the point of soil application appears to occur at a similar rate to or possibly faster than for other organic carbon in soil (Rumpel et al., 2005; Guggenberger et al., 2008; Major et al., 2010b). Eroded Biochar C is considered to remain sequestered as it is typically buried in lower horizons of soil or in lake or ocean sediments (France-Lanord and Derry, 1997; Galy et al., 2007; Van Oost et al., 2007).

Biochar can move from the topsoil into the subsoil i.e. translocation (Major et al., 2010b). It is not clear whether this transport occurs at the same rate as other organic matter in soil (Leifeld, 2007). It may be assumed that different pathways operate for particulate Biochars in comparison to dissolved organic C (Zhang et al., 2010). Biochar in subsoils can be considered stabilized to a greater degree than Biochar in topsoils, as evidenced by the great age of organic carbon found in subsoils in general, and because microbial activity sharply decreases with depth (Rumpel and Koegel-Knabner, 2011).

Some studies indicate that a significant fraction of land-applied Biochar can be exported within the first few years following amendment, even when Biochar is incorporated into soil (Rumpel et al., 2009; Major et al., 2010b). However, physical transport of Biochar offsite does not necessarily result in a $CO_2$ flux to the atmosphere, as the final fate of charcoal erosion from the land surface may be deposition in marine sediments. The intrinsic refractivity of charcoal in marine environments may lead to its long-term storage in sediments (Masiello, 2004). It is reasonable to assume that mobilized Biochar does not decompose, and remains a long-term carbon sink as it transits to the sea floor.

There is a small risk of losing C to the atmosphere from Biochar which has been exported through the mobilization of Biochar C into pyrogenic dissolved organic C (DOC). But studies show that this mechanism only accounts for the movement of a small fraction of the total carbon in Biochar. Over 2 years after field application, 1% of Biochar applied to an Oxisol was mobilized by percolating water, mostly in the form of DOC rather than particulate organic C (Major et al., 2010b). In a study simulating the geochemical weathering of Biochar, only 0.8% of the total organic C was released as DOC (Yao et al., 2010). And a maximum of 1.3% of the C was extracted from any of the Biochars tested using multiple sequential leaching experiments (Zimmerman and Gao, 2013). Because soluble C may represent the same portion of C that is mineralizable C (Leinweber, 1995; Zimmerman and Gao, 2013), the additional mineralization of Biochar C via DOC is assumed to be minor, even when translocation occurs. While further research pertaining to C mineralization of dissolved Biochar is crucial, existing field and

laboratory experiments show the loss of C to the atmosphere due to mobilized Biochar DOC mineralization to be minor.

*Combustion*

Biochar can be combusted, either unintentionally due to inappropriate handling during transport, storage or application, or intentionally, by diverting it from the intended land application to a use as fuel, since many Biochars can possess a significant energy value. Through Applicability Condition 4, the methodology assures that Biochar used only as a soil amendment qualifies therefore mitigating the risk that the Biochar will be combusted. Another theoretical oxidation by combustion is through vegetation fires. Re-burning of previously deposited pyrogenic carbon from vegetation fires has been observed in Mediterranean forests (Knicker et al., 2006). It is unlikely that vegetation fires will lead to a significant re-burning of applied Biochar that is incorporated into the soil. Temperatures during fires decrease dramatically with soil depth, and mixtures of Biochar and soil will exhibit no greater combustibility than that of other organic matter in soil.

**Resolution of information on carbon stability**

Although there is a clear correlation between the $H/C_{org}$ ratios and $BC_{+100}$ over a wide range of values at a 95% confidence level (Figure A2-9), variability will remain in the stability predictions. Future refinement and a greater data set with longer-term incubation experiments, including field data, will allow better constraint of the relationship. For the purpose of this first Methodology, as mentioned previously, a very conservative approach was chosen (e.g. via the selection of the model to obtain $BC_{+100}$ and the conditions of the incubation experiments) and thus predictability can be further improved over time.

The second analytical constraint stems from the quantification of inorganic and organic C (and H) in the Biochar (Wang et al., 2013). Some uncertainties in the Standard method using acidification and repeated determination of total C led to an initial recommendation of restricting the Methodology to class 1 Biochars (as defined in the *IBI Biochar Standards* under the criteria for Organic Carbon in Table 1). For these Biochars, which by definition contain more than 60% organic carbon, the proportion of inorganic carbon is likely negligible and organic carbon is roughly equivalent to total carbon. However, data analysis determined that this restriction yielded no change in the prediction results. Nevertheless, a method for calculating inorganic carbon in the sample was included, allowing the calculation of organic carbon by difference to total carbon. This exemplifies how the conservative approach mentioned was operationalized in the decisions made to arrive at a test method.

**Future improvements to Alpha, Beta and Gamma methods**

*Alpha:*

The choice amongst routine analytical procedures that would reflect a robust, repeatable, and analytically sound result was limited to those that had been used in the peer-reviewed literature. These included the Standard Test Method for Chemical Analysis of Wood Charcoal, so-called Proximate Analysis (ASTM-D1762-84, 2007) and elemental ratios of O, H and C. Structural information beyond stoichiometric relationships between elements may provide better estimates of stability and may be attainable through spectroscopy or automated thermogravimetry. However, these have not been sufficiently developed or are not available at a sufficiently low cost or time requirement to be included at present, or both.

*Beta:*

Longer periods of observation will likely provide evidence to improve precision of predictions of $BC_{+100}$ (Lehmann et al., 2009; Zimmerman et al., 2012), likely increasing the stable carbon component calculated, since the current proposed method is highly conservative. The known long-term incubations experiments will continue and a revised future Methodology will reflect improvements based on longer periods of observation. Only a few long-term field experiments have been published beyond a few years (Major et al., 2010), but are expected to be available for up to 10 year-periods in the coming years. However, pitfalls of field experiments are that these often do not distinguish between mineralization and physical loss by erosion and leaching, and the capabilities to estimate these differential losses over long periods of time are typically low. Therefore, these experiments often give, at best, a minimum mean residence time. A third approach is the use of aged Biochars as proxies for Biochar that has weathered in soil for long periods of time. Examples are Biochar-type materials from Terra Preta (Liang et al., 2008), from charcoal storage sites (Cheng et al., 2010) or possibly archaeological deposits. The challenge using this approach is to develop adequate proxies for the starting material to assess its properties.

*Gamma:*

Great progress has been made over the past years in understanding the change in the chemical form of fused aromatic carbons beyond aromaticity. Advancement in this area may come from NMR studies (Mao et al., 2012), measurements of adsorbed C-13-benzene (McBeath et al., 2012) and wet chemical methods such as BPCA (Glaser et al., 1998; Brodowski et al., 2005; Schneider et al., 2010). To improve predictability of Biochar decomposition, next steps may

include systematically relating structural information to improved Alpha-type methods, as defined in this document

**Conclusions**

One of the most important properties of Biochar – if not the most important one – is its stability, as it allows all other ancillary environmental benefits, especially as they pertain to agronomic properties (i.e., soil amelioration and enhancement), to persist in time. Mainly, the stability of the carbon component in Biochar makes it particularly useful as a long-term climate change mitigation strategy, and thus having a scientifically valid Methodology for the quantification of stable carbon will allow unlocking the potential benefits of Biochar. That is what makes this effort, oriented by an Expert Panel, ground-breaking, and as such can contribute to the development of policies and programs that promote the deployment of Biochar systems.

Given that this is the first such Methodology to be developed, and that the science is rapidly evolving, the Panel necessarily devised a conservative Methodology that is likely to underestimate the amount of stable carbon in Biochar to a period of 100 years. But with continued research and development, some of which is described herein, we are confident that the test Methodology will grow more robust and more rigorous over time, allowing for a more complete and precise estimation of stable carbon in Biochar.

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# APPENDIX 3: PRIMING OF SOC MINERALIZATION BY BLACK CARBON

Priming can be defined as any change (positive or negative, persistent or ephemeral) in the turnover rate of soil organic matter caused by the addition of a new substrate (Woolf and Lehmann 2012). Increased or decreased turnover rates are defined as positive or negative priming, respectively. Only positive priming is considered in this Methodology, because this is a risk factor that might reduce the net C sequestration of Biochar systems. Negative priming is not considered here due to application of the conservativeness principle, whereby detrimental feedbacks should be included in the Methodology if there exists a non-negligible probability that they may be realized, whereas beneficial feedbacks should not be included unless they are unequivocal.

Addition of Biochar to soils has been shown to alter the mineralization rate of non-pyrogenic SOC (npSOC). Positive priming of npSOC has been reported by Abiven and Andreoli (2010); Cross and Sohi (2011); Hamer et al. (2004); Jones et al. (2011); Keith et al. (2011); Liang et al. (2010); Luo et al. (2011); Novak et al. (2010); Spokas and Reicosky (2009); Wardle et al. (2008); Zimmerman et al. (2011). Negative priming of npSOC mineralization has been reported by Keith et al. (2011); Kuzyakov et al. (2009); Liang et al. (2010); Spokas and Reicosky (2009); and Zimmerman et al. (2011). Zimmerman et al. (2011) found that initial positive priming gave way to net negative priming over time. Where it has been possible to discriminate between labile- and stable-SOC decomposition, either no priming of stable SOC (Cross and Sohi 2011; Jones et al. 2011) or an increase in the stabilized SOC fraction (i.e. negative priming; Liang et al. 2010) was observed.

Only a few studies have allowed discrimination between priming of labile- or stable-npSOC decomposition. Where it has been possible to discriminate between labile- and stable-npSOC decomposition, either zero or negative priming of stable npSOC has been reported. Liang et al. (2010) added organic matter (AOM) with a distinct $^{13}$C isotopic signature (from a $C_4$ plant) to BC-rich Anthrosols and BC-poor adjacent soils. They found a 19–340% increase in AOM-carbon in the organo-mineral fraction (assumed to indicate an increase in C stabilized by mineral associations) after 1.5 yr in BC-rich relative to adjacent soils. Cross and Sohi (2011) compared the priming effect in a silty-clay loam from Rothamsted Research, U.K., where three different management practices had been maintained for >60 years: (1) bare fallow (soil kept completely bare, with regular cultivation), (2) continuous arable (wheat) and (3) managed grassland. The fallow soil was assumed to contain only stable npSOC due to the long period without organic

matter inputs. Slight (no p statistic given, may not be significant) negative priming was observed from additions of BC to the fallow soil. Jones et al. (2011) found negative priming of a $^{14}$C label that had been applied to the soil (Ah horizon, Typic Dystrochrept) 6 years prior to addition of BC in an incubation study. Due to the long interval between applying the radiocarbon label and the subsequent incubation trial, the $^{14}$C was assumed to be present only in stable npSOC.

Wardle et al. (2008) conducted a 10 year litterbag study with charcoal in a boreal-forest litter-layer in which positive priming was observed only during the first year. Other studies have observed positive priming over a period of a few weeks to months in short-term incubations (Luo et al. 2011; Keith et al. 2011; Zimmerman et al. 2011). Nonetheless, the precautionary principle suggests that one should consider the possibility that priming effects might persist long term. Woolf and Lehmann (2012) modeled the impact of Biochar on priming over 100 years in a system designed to probe the upper bounds of priming impacts on npSOC. Specifically, they assumed[22]:

1. priming effects up to and including the largest that have been measured in any published short-term study;

2. that priming effects persist long-term;

3. that BC stocks accumulate in soil at a high rate (because they are produced from the abundant residues from a high-NPP crop; the BC is produced in an engineered Pyrolysis system that gives high yields of BC per unit biomass Feedstock; and the BC is produced under controlled conditions which ensure that it decomposes only slowly).

Under this set of highly conservative assumptions, Woolf and Lehmann (2012) found that no more than 3 to 4% of initial npSOC might be mineralized due to priming by BC over 100 years. In absolute quantities, this loss of npSOC was greatest in soils with the highest initial stocks of npSOC. Biochar production was also positively correlated with initial npSOC, due to the greater production of crop residues for Feedstock on more fertile soils. Table A3-1 shows the initial npSOC (npSOC$_0$), potential loss of npSOC due to positive priming over 100 yrs (Δ npSOC$_{p+}$), BC remaining in soil after 100 years (BC$_{+100}$), and Δ npSOC$_{p+}$ expressed as a percentage of BC$_{+100}$, (denoted as RPL = Relative Priming Loss) for each of the locations studied in Woolf and Lehmann (2012).

**Table A3-1**. **Loss of soil carbon over 100 yr due to positive priming caused by BC at three study locations.** Source: Woolf and Lehmann, 2012

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[22] In this paper, Biochar is added gradually over 100 years and not in one large treatment in year zero. However, the model has been run using initial large application of Biochar to soil and priming results were similar in magnitude.

| Site | npSOC$_0$ (kg C m$^{-2}$, in top 0.15m of soil profile) | Δ npSOC$_{p+}$ (kg C m$^{-2}$) | BC$_{+100}$ (kg C m$^{-2}$) | RPL |
|------|------|------|------|------|
| Colombia | 0.94 | 0.037 | 3.31 | 1.1% |
| Kenya | 1.56 | 0.05 | 3.29 | 1.5% |
| Iowa | 6.29 | 0.26 | 5.95 | 4.4% |

A linear regression of RPL versus npSOC$_0$ yields the relationship

$$RPL = 0.0062 \ npSOC_0 + 0.0053 \qquad (R^2 = 0.99992)$$

From which it follows that the maximum npSOC$_0$ for which RPL is less than 5% is 7.2 kg C m$^{-2}$ in the top 0.15m of the soil profile. (i.e. For soils starting with less than 7.2 kg npSOC m$^{-2}$, cumulative priming losses will be less than 5% of the BC remaining after 100 years.) If a 5% threshold for positive priming enhancement due to the addition of Biochar to soil would be defined as a condition to disregard the effect of priming for Biochar carbon stability estimations, Biochar should not be applied to soils with more than 7.2 kg npSOC m$^{-2}$. However, soils with such concentrations are rarely found within agricultural soils, and are more frequent in forestland or peat soils (Davidson and Ackerman, 1993), where Biochar would not likely be applied. In the case that Biochar were applied to soils with concentrations higher than 7.2 kg npSOC m$^{-2}$, it could lead to positive priming, which is factored into the calculations of stable carbon, with a discount factor of 5%, although – as stated – it would be rare to find soils with organic carbon content higher than the stated limit, in order to maintain a conservative approach to stability estimations. Additionally, it would not make much sense to apply a carbonaceous-rich material to a carbon-rich soil, if agronomic and environmental benefits are sought from Biochar use.

See references in Appendix 2.

# APPENDIX 4: SUSTAINABLE FEEDSTOCK CRITERIA

**Overview**

Biochar has the potential to improve soil quality when used as a soil additive, especially when combined with nutrient-rich materials, such as compost. Biochar also has carbon sequestration potential, which means it reduces greenhouse gas emissions from avoided decomposition emissions of the biomass. It is necessary to ensure that these benefits are not offset by negative impacts elsewhere in the Biochar production cycle. The most common feedstock types, forest and agricultural feedstocks, will be addressed in more detail. This appendix provides feedstock requirements:

**General Requirements (Applicable to all Feedstocks)**

- Any Biomass Residue, as defined in 1.4 and meeting the Feedstock expectations of the IBI Biochar Standards (2013), is eligible for Biochar production under this methodology provided it meets the applicable Sustainable Feedstock criteria in this Appendix. Eligible Biomass Residues include, but are not limited to: insect/pathogen-killed wood (with precautions taken to avoid contamination of other sites), forest thinning for wildfire mitigation, any forest residue meeting the Forestry Feedstock criteria of this Appendix, any agricultural residue meeting the Agricultural Feedstock criteria of this Appendix, landscaping and clean construction residues, biomass cogeneration residues, and non-toxic biosolids.

- Project Proponent must provide evidence that no land use change (LUC) has taken place in the past 7 years.

- Evidence should be provided that no net negative impacts are likely from diverting residue from its alternative use based on most common alternative uses from the previous seven years. For instance, would diverting this residue have any broader impacts on the local community that used the residue for another purpose, such as heat generation, or create greater (indirect) Greenhouse Gas impacts?

- Project Proponent must ensure that carbon stocks and other critical soil and ecosystem attributes are not depleted or negatively impacted by residue harvests. Assessment of sustainable residue removal rates (for carbon and other critical nutrients) should be

conducted and a monitoring plan implemented. At least 25% of the residues must be left in place to replenish soil nutrients. This is relevant for both forestry and agriculture.

- There must be a management and monitoring plan in place for sustainable harvesting of biomass. At a minimum, this should address avoidance of:
    - o Overharvesting and thus reducing the Soil Carbon and other nutrients in the soil
    - o Causing soil erosion or soil compaction
    - o Water pollution

Other impacts that must be addressed include:

- Documentation of biomass treatment with pesticides, herbicides, or other chemicals (including date applied, frequency applied, type, brand, amount and concentration)
- If the feedstock is produced from Biosolids, it must be free of toxic materials, such as radioactive materials, carcinogens or heavy metals, as this is intended for agricultural soil application (refer to *IBI Biochar Standards* latest version).
- Chain of Custody documentation and site location (GIS Shapefile preferred) for the feedstock site must be collected and retained (for the 7 year term of the project) for each feedstock site by the Biochar producer.

Each Biochar producer will be initially evaluated for using qualified feedstock. The Crediting Period of the project is 7 years. If the Biochar producer would like to continue for additional terms, they must pass the evaluation of feedstock criteria again prior to the Crediting Period renewal.

It is the responsibility of the Biochar producer to collect necessary documentation from each feedstock: supplier, source, and site. The Biochar producer will submit the Feedstock Documentation form to an ACR-approved Validation/Verification Body (VVB) for review for each new feedstock prior to registering credits.

Biochar producers will be periodically and randomly evaluated for adhering to the document collection requirements and feedstock suppliers for meeting the qualification criteria. This will be performed by a VVB at least every 5 years and may be more frequent at the Project Proponent's discretion.

**Additional Requirements for Forestry and Agricultural Feedstocks**

Additional guidelines have been provided for forest and agricultural feedstocks. Projects using each type of feedstock must comply with the general criteria above, as well as the relevant criteria in this section.

*Forestry Feedstocks*

Forest residues may only be permitted as Feedstock sources if there is substantive proof that they were harvested in a sustainable manner that does not result in the depletion of soil organic Carbon Stocks or significantly impact soil, water, and biodiversity the harvested land area.

Substantive proof may be provided through the following attestations:

- Sustainable forest certified by the approved standard, Forestry Stewardship Council (FSC) – US national standard https://ic.fsc.org/national-standards.247.htm or if international, the local jurisdictional equivalent version of FSC.

  Each feedstock site must provide documentation that the feedstock has been certified by FSC. Included in the written attestation, the feedstock supplier confirms that at least 25% of the residue was left in the forest to replenish the Carbon Stocks. Chain of custody, feedstock harvesting method and location data will also be collected.

  OR

- Verification Statement by an independent third-party professional for each feedstock site. This professional must be forestry certified by a recognized provincial, state, or national body (e.g. professional forester, etc.), certifying the forestry feedstock criteria.

*Agricultural Feedstocks*

Agricultural residues may only be permitted as Feedstock sources if there is substantive proof that they were harvested in a sustainable manner that does not result in the depletion of soil organic Carbon Stocks or in significant compaction or erosion of soil on the harvested land area.

Substantive proof may be provided through the following attestations:

- Scientifically published, peer-reviewed studies; regional research station analysis; or soil carbon modeling that provide proof that the level of agricultural residue removal is sustainable for soil organic carbon stock maintenance under the regional conditions (crops, soil types, removal rates) of the affected area.

  OR

- Each feedstock site must provide documentation that the feedstock has been certified by an approved standard (Council on Sustainable Biomass Production or Roundtable on Sustainable Biomaterials or if international, the local jurisdictional equivalent). Included in the written attestation, the feedstock supplier confirms that at least 25% of the residue was left in the forest to replenish the Carbon Stocks. Chain of custody, feedstock harvesting method and location data will also be collected.
    o Council on Sustainable Biomass Production (CSBP), website: http://www.csbp.org/Portals/0/Documents/CSBP%20Standard%20For%20Sustainable%20Production%20of%20Agricultural%20Biomass%2006122012_1.pdf
    o Roundtable on Sustainable Biomaterials (RSB), website: Standard for certification of biofuels based on by-products and residues http://rsb.org/pdfs/standards/13-03-18%20RSB-STD-01-020%20RSB%20Standard%20on%20residues%20and%20by-products.pdf

  OR

- Verification Statement by an independent third-party professional for each feedstock site. This professional must be certified in agrology or agronomy by a recognized provincial, state, or national body (e.g. professional agronomist, certified crop advisors, agricultural extension agents, etc.), certifying the agricultural feedstock criteria, including that soil organic Carbon Stocks will not be depleted through the harvest of agricultural residues for the purpose of Biochar production.