Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil

Type of Document:	Product Definition and Specification Standards
Status of Document:	Final
Version Number:	2.1
Version Date:	23 November 2015
Document Reference Code:	IBI-STD-2.1

NOTE TO USERS:
The International Biochar Initiative may update this manual as necessary. Please make sure you are using the latest version available at http://www.biochar-international.org/characterizationstandard.

OWNERSHIP AND COPYRIGHT NOTICE

This work is licensed under the terms of the Creative Commons Attribution-Non Commercial-No Derivs 3.0 Unported License attached in Appendix 9. Under this license, you are free:

to **Share** — to copy, distribute and transmit the work

Under the following conditions:

Attribution — You must attribute the work to the International Biochar Initiative (IBI) (but not in any way that suggests that IBI endorses you or your use of the work).

Non-commercial — You may not use this work for commercial purposes.

No Derivative Works — You may not alter, transform, or build upon this work.

With the understanding that:

Waiver— Any of the above conditions can be waived if you get permission from the copyright holder.

Public Domain— Where the work or any of its elements is in the public domain under applicable law, that status is in no way affected by the license.

Other Rights— In no way are any of the following rights affected by the license:

- Your fair dealing or fair use rights, or other applicable copyright exceptions and limitations;
- The author's moral rights;
- Rights other persons may have either in the work itself or in how the work is used, such as publicity or privacy rights.

DISCLAIMER

The International Biochar Initiative (IBI) *Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil* (hereinafter referred to as the *IBI Biochar Standards*) have been prepared with the intent of providing stakeholders and commercial entities with standards to identify certain qualities and characteristics of biochar materials according to relevant, reliable, and measurable characteristics. Manufacturers who follow these *IBI Biochar Standards* do so voluntarily. In no way shall the IBI or its associates be responsible for the use or misuse of information and guidance provided in this document. Anyone making use of this document assumes all liability arising from such use.

IBI does not make, and hereby specifically disclaims, any representation, warranty, claim, or guarantee regarding biochar tested and characterized according to this document, including but not limited to any representation, warranty, claim, or guarantee relating to the safety or fitness of such biochar for a particular purpose. Independent professional judgment must be exercised when producing and using biochar and, IBI makes no representation or warranty as to the safety or quality of biochar tested and characterized according to this document. This document does not purport to address all of the safety concerns, if any, associated with the use of this document or the use or production of biochar tested and characterized according to this document. It is the responsibility of the user of this document, and the manufacturers and users or consumers of biochar, to establish appropriate safety and health practices and determine the applicability of any national, state or provincial, and local regulatory limitations prior to use.

IBI does not make, and hereby specifically disclaims, any representation, warranty, claim, or guarantee regarding biochar that has not been tested and characterized according to this document, including but not limited to any representation, warranty, claim, or guarantee relating to the safety or fitness of such biochar for a particular purpose.

IBI is not a seller of biochar and does not make, and hereby specifically disclaims, any and all representations, endorsements, guarantees, and warranties, express or implied, regarding the use of this document or biochar tested and characterized according to this document, including, without limitation, the implied warranties of merchantability and fitness for a particular purpose, title and non-infringement of third-party rights. IBI advises consumers of biochar that, from IBI's perspective, all biochar tested and characterized according to this document is purchased as is and with all faults from the biochar manufacturer.

IBI expressly disclaims any grant of apparent or actual authority from IBI to manufacturers of biochar tested and characterized according to this document.

No portion of this document is intended for use as a sustainability or production process guideline. Further documentation and guidance is necessary to identify appropriate sustainability practices and/or safe and effective production processes.

The benefits of a given biochar material vary widely with the material and with crop, soil, and climate factors. This document makes no representations, claims, guarantees, or warranties regarding the potential benefits of any given biochar material in any particular application.

The *IBI Biochar Standards* are intended to be revised and updated as the science and body of knowledge surrounding biochar continues to evolve, and, if necessary, to provide technical or other corrections or changes to the *IBI Biochar Standards* and/or this document. Please ensure that you are using the most up-to-date version found on the website of the International Biochar Initiative: http://www.biochar-international.org/characterizationstandard.

LIMITATION OF LIABILITY

Under no circumstances will IBI be liable for any loss or damage caused by your reliance on the information obtained from the *IBI Biochar Standards*. It is your responsibility to evaluate the accuracy, completeness, and usefulness of this document. In no event shall IBI be liable for any direct, indirect, punitive, incidental, special, or consequential damages arising out of or relating to the *IBI Biochar Standards,* whether based on warranty, contract, tort, strict liability, or any other legal theory. Because some jurisdictions do not allow the exclusion or limitation of liability for negligence, consequential, incidental, or other damages, in such jurisdictions IBI's liability is limited to the greatest extent permitted by law. If you are dissatisfied with any portion of the *IBI Biochar Standards*, your sole and exclusive remedy is to stop using the *IBI Biochar Standards*.

INDEMNITY

By using the *IBI Biochar Standards,* you hereby agree to defend and hold IBI harmless from and against any and all claims, actions, demands, liabilities, losses, settlements, costs, and fees (including, without limitation, reasonable attorneys' fees and court costs), arising from or allegedly arising from your use or misuse of this document.

Foreword

The *IBI Biochar Standards* provide a standardized definition of biochar and biochar characteristics related to the use of biochar as a soil amendment. They have been developed by the International Biochar Initiative (IBI) in collaboration with a wide variety of industry and academic experts and through public input on an international level. The *IBI Biochar Standards* were created to encourage further development of the biochar industry by providing standardized information regarding the characterization of biochar materials to assist in achieving more consistent levels of product quality. In addition to providing product definition and qualitative specification standards, this document has been developed to assist biochar manufacturers in providing consumers with consistent access to credible information regarding qualitative and physicochemical properties of biochar.

The *IBI Biochar Standards* are designed to support the *IBI Biochar Certification Program*. Separately, the *IBI Biochar Standards* are also intended for use by various national and regional product standards bodies, and national and regional biochar groups for their own local adaptation and use, and as a reference in regulatory situations, as may be appropriate.

The *IBI Biochar Standards* were developed as a means of providing information and market certainty about the attributes of biochars for use in soil applications. Ultimately, the use and promotion of these *IBI Biochar Standards* will build consumer and regulatory confidence about biochar, through the provision of consistent and reliable information regarding biochar properties. Biochar can be made from a variety of feedstocks, using a variety of different production processes, and can possess many different attributes. The consistent reporting of biochar properties will ensure that pertinent information about biochars for use in soil applications is systematically communicated, regardless of feedstock type, production process, or final properties.

IBI developed the *IBI Biochar Standards* in a transparent process open to public participation, review, and input. Throughout the development process IBI relied upon the drafting, review, and guidance of experts in the field, ensuring an efficient path from concept to final product, and addressing the needs of a broad range of commercial biochar manufacturers and end users. As the document was developed, public input from the larger international biochar community was continuously sought to provide a wider perspective on the use and functionality of this tool.

The design of the *IBI Biochar Standards* follows current best practices and available science. As biochar science continues to improve, the *IBI Biochar Standards* will be updated in an iterative process in order to remain current. Therefore these *IBI Biochar Standards* and this document will be periodically revised through further consultation with the international biochar community.

The *IBI Biochar Standards* document development process is based on the following guiding principles:

- Maintain congruence with best practice guidance for standards development such as International Standards Organization (ISO), ASTM International (ASTM), and Institute of Electrical and Electronics Engineers (IEEE);
- Strictly adhere to process, ensuring efficient and effective collaboration;

- Engage the knowledgeable and diverse stakeholder groups active in the biochar industry;
- Organize independent working groups with broad stakeholder representation, and,
- Rely on IBI infrastructure and capacity for leadership and administration of the initiative.

The complete record of process documentation, including the list of working group members, can be found on the IBI website at: http://www.biochar-international.org/characterizationstandard.

Table of Contents

1 Scope

Issued by the International Biochar Initiative (IBI) and based on international consultation, this *IBI Biochar Standards* document is intended to establish a common definition for biochar, and standardized testing and measurement methods for selected physicochemical properties of biochar materials.

Biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. Biochar can be used as a product itself or as an ingredient within a blended product, with a range of applications as an agent for soil improvement, improved resource use efficiency, remediation and/or protection against particular environmental pollution, and as an avenue for greenhouse gas (GHG) mitigation.

These *IBI Biochar Standards* provide a standardized definition of biochar and biochar characteristics related to the use of biochar as a soil amendment. They serve as the basis for the *IBI Biochar Certification Program*, and are intended for use and adaptation to local conditions and regulations by any nation or region. These *IBI Biochar Standards* support not only baseline safety considerations but also the evolving understanding of the positive functions of biochar in soil. This document does not prescribe appropriate uses for biochar materials, nor provide guidance on what biochar can or should be used for.

These *IBI Biochar Standards* relate to the physicochemical properties of biochar only, and do not prescribe production methods or specific feedstocks, nor do they provide limits or terms for defining the sustainability and/or GHG mitigation potential of a biochar material, for the *IBI Biochar Certification Program* or otherwise.

Different feedstock types, and hence differentiated testing requirements of biochar, are defined in this guidance document as means for the identification and classification of a range of biochar materials. The testing categories are based upon increasing levels of physicochemical property reporting and not necessarily on increasing levels of biochar performance or quality. The intended audiences for these *IBI Biochar Standards* include commercial biochar manufacturers, users, regulators, researchers and marketers, as well as the many national and regional biochar affiliates of the IBI. However, the commercial biochar manufacturer is the entity most likely to apply the *IBI Biochar Standards*, as a label (of differentiation) on its biochar material or product.

2 Terms and Definitions

A complete list of terms and definitions is found, along with a list of acronyms, in Appendix 8 *Glossary*. A clear understanding of the defined terms is essential to the proper use of these *IBI Biochar Standards*. Defined terms are indicated with a double underline in the text on the first instance of the use of that term in the following sections.

3 Biomass Feedstock Material and Biochar Production

3.1 General Feedstock Material Requirements

The materials used as feedstocks for biochar production have direct impacts on the nature and quality of the resulting biochar. Although the focus of this document is on the biochar material, some restrictions have been applied to feedstock contents and quality. To qualify as biochar feedstock under these standards, the feedstock may be a combination of biomass and diluents, but may not contain more than 2% by dry weight of contaminants (following Brinton 2000). Any diluents that constitute 10% or more by dry weight of the feedstock material must be reported as a feedstock component. Feedstocks are differentiated into two types: unprocessed feedstocks and processed feedstocks, with different requirements for sampling and analysis of potential toxic substances. Suitable feedstocks include but are not limited to biomass residues, which may contain a minimal quantity of contaminants (see above) as part of the feedstock.

Feedstock that may have been grown on contaminated soils is considered to be a processed feedstock and must meet the toxicant assessment testing frequency requirements for processed feedstocks given in Section 5.5 *Category B Testing Frequency*.

Municipal Solid Waste (MSW) containing hazardous materials or wastes may not be included as eligible feedstock under these standards. It is the manufacturer's responsibility to ensure that biochar feedstock materials are free of hazardous materials.

NB: Issues of feedstock sustainability are not addressed in this document.

3.2 Best Management Practices for Biochar Production, Material Handling and Storage

The *IBI Biochar Standards* do not prescribe production and handling parameters for biochar, but do include recommended best management practices (BMPs) for safe production and handling. It is the responsibility of the biochar manufacturer to create biochar in a safe manner. IBI recommends that current industry BMPs be followed throughout the production and handling process.

Local requirements and regulations for the operation of biochar production facilities should be followed. Where applicable, biochar production must comply with local and international regulatory requirements and treaties that govern thermal processes, the production of volatile and particulate emissions, and the transport of goods. Relevant to local and international regulatory compliance, biochar manufacturers should adhere to the following recommended BMPs:

1) A biochar manufacturer should provide a relevant material safety data sheet (MSDS) for the final output of its biochar production process. Brief outlines of MSDS document creation are available from numerous online sources, including MSDS Search, the Canadian Center for Occupational Health and Safety, and the US Department of Labor Occupational Safety and Health Administration (OSHA).

2) Biochar should be tested to address the potential for self-heating and flammability during storage and transport. Documentation of the results of this testing should be appended to the MSDS.

3) To minimize the effects of weathering which can significantly alter the material properties of biochar after it has been tested (see Section 5.6), biochar should be stored indoors in a protected location. If stored outdoors, biochar should be covered with a tarpaulin or other material to protect it from precipitation events.

While the IBI does not require these practices as part of its definition and certification of biochar (under the *IBI Biochar Certification Program*) since they do not relate directly to product quality, they are important considerations in good business practices and responsible industrial production. The majority of industrialized nations provide detailed standards, expectations, and regulations governing the manufacturing sector and will have relevant information available to industrial operators.

4 Biochar Material Test Categories and Characteristics

As described in this section, biochar characteristics shall be assessed according to a defined set of test categories intended to provide increasing levels of physicochemical property reporting. Two sets of required test categories to measure basic biochar characteristics that impact soil functions are supplemented with an optional test category for advanced analysis and soil enhancement properties. Toxicant assessment testing is required for all biochars. Increasing levels of physicochemical property testing and reporting do not correspond to increasing levels of biochar performance or quality; rather, the categorization structure is designed to:

- provide a uniform presentation format by which a biochar user would be able to fairly compare and assess the reported properties of different biochar materials;
- provide a set of required tests for basic biochar utility and an optional set of additional tests for measuring advanced analysis and soil enhancement properties; and
- require toxicant reporting appropriate to the potential risks associated with both unprocessed and processed feedstocks. Increased testing frequency is required to attain quality assurance for processed feedstocks, which carry a higher potential risk of contamination.

Each test category was developed according to an assessment of the relevant parameters for biochar properties and safety, balanced against cost and accessibility.

These *IBI Biochar Standards* identify three categories of tests for biochar materials:

Test Category A – Basic Utility Properties: ***Required for all biochars***. This set of tests measures the most basic properties required to assess the utility of a biochar material for use in soil.

Test Category B – Toxicant Assessment: ***Required for all biochars***. Biochars made from processed feedstocks must be tested more frequently than biochars made from unprocessed feedstocks, as defined in Section 5 *General Protocols and Restrictions*.

Test Category C – Advanced Analysis and Soil Enhancement Properties: Optional for all biochars. Biochar may be tested for advanced analysis and enhancement properties in addition to meeting test requirements for Test Categories A and B. All tests in Test Category C are optional. Manufacturers may report on none, one, some or all of the properties.

Further details on each of the test categories are provided in Sections 4.1 through 4.3.

4.1 Test Category A: Basic Utility Properties

All biochars must be tested for basic utility properties and meet the criteria specified under Test Category A, as shown in Table 1 below. Basic biochar characteristics include the physical properties of particle size and moisture, as well as the chemical properties of elemental proportions [Hydrogen (H), Carbon (C), and Nitrogen (N)], ash proportion, Electrical Conductivity (EC) and pH/liming ability. Organic carbon (C_{org}) content is used to assign the biochar material to one of three classes depending on the percentage of C_{org} in the material and representing the range of C_{org} contents typical of biochar materials. Carbon stability is indicated by the molar ratio of hydrogen to organic carbon. Lower values of this ratio are correlated with greater carbon stability. See Appendix 7 *The Use of $H:C_{org}$ to Indicate C Stability* for more information on this analysis.

Table 1. Test Category A Parameters, Criteria, and Test Methods.

Test Category A: Basic Utility Properties (Required for All Biochars)			
Parameter	**Criteria[1]**	**Unit**	**Test Method[2]**
Moisture	Declaration	% of total mass, dry basis	ASTM D1762-84 Standard Test Method for Chemical Analysis of Wood Charcoal (specify measurement date with respect to time from production)
Organic Carbon (C_{org})	10% Minimum *Class 1*: ≥60% *Class 2*: ≥30% and <60% *Class 3*: ≥10% and <30%	% of total mass, dry basis	Total C and H analysis by dry combustion-elemental analyzer. Inorganic C analysis by determination of CO_2-C content with 1N HCl, as outlined in ASTM D4373 Standard Test Method for Rapid Determination of Carbonate Content of Soils. Organic C calculated as Total C – Inorganic C. See Appendix 7 for H:C_{org} discussion.
H:C_{org}	0.7 Maximum	Molar ratio	
Total Ash	Declaration	% of total mass, dry basis	ASTM D1762-84 Standard Test Method for Chemical Analysis of Wood Charcoal
Total Nitrogen	Declaration	% of total mass, dry basis	Dry combustion-elemental analyzer following the same procedure for total C and H above.
pH	Declaration	pH	pH analysis procedures as outlined in section 04.11 of TMECC (2001) using modified dilution of 1:20 biochar:deionized H_2O (w:v) and equilibration at 90 minutes on the shaker, according to Rajkovich et al. (2011). See Appendix 5 for further information.
Electrical Conductivity	Declaration	dS/m	EC analysis procedures as outlined in section 04.10 of TMECC (2001) using modified dilution of 1:20 biochar:deionized H_2O (w:v) and equilibration at 90 minutes on the shaker, according to Rajkovich et al. (2011). See Appendix 5 for further information.
Liming (if pH is above 7)	Declaration	% $CaCO_3$	AOAC 955.01 potentiometric titration on "as received" (i.e., wet) samples. Use dry weight to calculate % $CaCO_3$ and report "per dry sample weight".
Particle size distribution	Declaration	% <0.5 mm; % 0.5-1 mm; % 1-2 mm; % 2-4 mm; % 4-8 mm; % 8-16 mm; % 16-25 mm; % 25-50 mm; % >50 mm	Progressive dry sieving with 50 mm, 25 mm, 16 mm, 8mm, 4mm, 2 mm, 1 mm, and 0.5 mm sieves.

[1] All values will be reported to one decimal place significant digit (0.1), unless otherwise indicated within the criteria for any reporting requirement (e.g., if the analysis is 0.73, it can be reported as 0.7).
[2] See Section 8 – References for complete citations

4.2 Test Category B: Toxicant Assessment

In addition to Test Category A thresholds and declarations, all biochar materials must meet the soil toxicity assessment thresholds as outlined in Table 2 below. Toxicants may be divided into two categories: those that may be present in the feedstocks used (metals and polychlorinated biphenyls), and those that may be produced by the thermochemical conversion process used to make biochar (polycyclic aromatic hydrocarbons and dioxins/furans).

Biochar made from processed feedstocks may carry additional risks from the potential presence of toxicants in the feedstock and must meet the toxicant assessment testing frequency requirements of Section 5.3.

Biochar toxicity assessment reporting follows commonly identified soil toxicity and chemical content reporting requirements for soil amendments, composts and fertilizers. The threshold values in Table 2 are given as a range of values based on standards for soil amendments or fertilizers from a number of jurisdictions.[3] The Maximum Allowed Thresholds (MAT) indicate toxicant levels above which the material would not be considered acceptable. In order to meet the requirements of these *IBI Biochar Standards*, reported toxicant levels must be below the MAT that has been established in the area of jurisdiction where biochar is produced and/or intended for use. If the area of jurisdiction where the biochar will be used has no threshold for a particular toxicant, the biochar must be below the highest maximum value established by a different jurisdiction for that toxicant. See Appendix 1 *Expanded Information on Test Methods in Category B Toxicants Assessment*, Appendix 2 *PAH, PCDD/F and PCB Compounds to be Tested*, and Appendix 3 *Toxicant Assessment and Determination of Thresholds* for more information.

Table 2. Test Category B Parameters, Maximum Allowed Thresholds and Test Methods.

Test Category B: Toxicant Assessment (Required for All Biochars)		
Parameter	**Range of Maximum Allowed Thresholds**	**Test Method[4, 5, 6]**
Germination Inhibition Assay	Pass/Fail	OECD methodology (1984) using three test species, as described by Van Zwieten et al. (2010). See Appendix 5 for further information.

[3] The following jurisdictions were used to construct the range of values: Australia, Canada, EU, UK, and the USA. These entities were chosen as reference countries because they all have a long history of regulations addressing these toxicants in soils and other substrates.

[4] See Section 7 *References* for complete citations.

[5] For parameters using US Environmental Protection Agency (EPA) test methods, it is required to use the most recent EPA revision of the test method.

[6] For parameters using test methods described in the TMECC, please review Appendix 1 for descriptions of the test methods.

Table 2 (continued). Test Category B Parameters, Maximum Allowed Thresholds and Test Methods.

Parameter	Range of Maximum Allowed Thresholds		Test Method
Polycyclic Aromatic Hydrocarbons (PAHs), total (sum of 16 US EPA PAHs)[7]	6 – 300	mg/kg[8] dry wt	US EPA 8270 (2007) using Soxhlet extraction (US EPA 3540) and 100% toluene as the extracting solvent
Dioxins/Furans (PCDD/Fs)[9]	17	ng/kg WHO-TEQ[10] dry wt	US EPA 8290 (2007)
Polychlorinated Biphenyls (PCBs)[11]	0.2 – 1	mg/kg dry wt	US EPA 8082 (2007) or US EPA 8275 (1996)
Arsenic	13 – 100	mg/kg dry wt	TMECC (2001)
Cadmium	1.4 – 39	mg/kg dry wt	TMECC (2001)
Chromium	93 – 1200	mg/kg dry wt	TMECC (2001)
Cobalt	34 – 100	mg/kg dry wt	TMECC (2001)
Copper	143 – 6000	mg/kg dry wt	TMECC (2001)
Lead	121 – 300	mg/kg dry wt	TMECC (2001)
Mercury	1 – 17	mg/kg dry wt	US EPA 7471 (2007)
Molybdenum	5 – 75	mg/kg dry wt	TMECC (2001)
Nickel	47 – 420	mg/kg dry wt	TMECC (2001)
Selenium	2 – 200	mg/kg dry wt	TMECC (2001)
Zinc	416 – 7400	mg/kg dry wt	TMECC (2001)
Boron	Declaration	mg/kg dry wt	TMECC (2001)
Chlorine	Declaration	mg/kg dry wt	TMECC (2001)
Sodium	Declaration	mg/kg dry wt	TMECC (2001)

[7] For a list of the required PAH compounds to be tested see Appendix 2.
[8] PAHs must also be reported on a B(a)P toxic equivalency basis with a maximum level of 3 mg/kg B(a)P-TEQ dry weight. See Appendix 3 for further information on TEF values for PAHs.
[9] For a list of the required PCDD/F compounds to be tested see Appendix 2.
[10] See Appendix 3 for further information on the WHO 2005 TEF values for PCCD/Fs.
[11] For a list of the required PCB compounds to be tested see Appendix 2.

4.3 Test Category C: Advanced Analysis and Soil Enhancement Properties

Test Category C is optional for all biochar materials. Manufacturers may report on none, one, some, or all of the properties contained in the Test Category C set of advanced analysis and soil enhancement properties, using the prescribed test methods. Biochar advanced analysis characteristics include the volatile matter content and surface area of biochars. Biochar soil enhancement properties identify plant nutrients contained in the biochar.

Biochars tested under Test Category C may report on any or all of the properties presented in Table 3 below:

Table 3: Test Category C Parameters, Criteria, and Test Methods.

Test Category C: Advanced Analysis and Soil Enhancement Properties (Optional for All Biochars)			
Parameter	**Criteria**	**Unit**	**Test Method[12]**
Mineral (available) Nitrogen (ammonium and nitrate)	Declaration	mg/kg	2M KCl extraction followed by spectrophotometry (Rayment and Higginson 1992)
Total Phosphorus & Potassium*	Declaration	mg/kg	Modified dry ashing (Enders and Lehmann 2012). Elements in the digest determined by common analytical techniques.
Available Phosphorous	Declaration	mg/kg	2% formic acid followed by spectrophotometry (Wang et al. 2012)
Total Calcium, Magnesium and Sulfur	Declaration	mg/kg	Modified dry ashing (Enders and Lehmann 2012). Elements in the digest determined by common analytical techniques.
Available Calcium, Magnesium and Sulfate-S	Declaration	mg/kg	1M HCl extraction (Camps Arbestain et al. 2015). Elements in the digest determined by common analytical techniques.
Volatile Matter	Declaration	% of total mass, dry basis	ASTM D1762-84 Standard Test Method for Chemical Analysis of Wood Charcoal
Total Surface Area	Declaration	m^2/g	ASTM D6556 Standard Test Method for Carbon Black – Total and External Surface Area by Nitrogen Adsorption. See Appendix 5 for further information.
External Surface Area	Declaration	m^2/g	
* Total K is sufficiently equivalent to available K for the purpose of this characterization			

[12] See Section 7 *References* for complete citations.

5 General Protocols and Restrictions

Biochar manufacturers must follow the protocols described in this section that address biochar sampling procedures; the selection of testing laboratories; timing and frequency of testing; special testing requirements related to material changes in feedstocks or thermochemical production parameters, or to biochar processing after thermochemical conversion; and restrictions on biochar that has undergone weathering.

5.1 Biochar Sampling Procedures

Strict adherence to standardized biochar sampling procedures is critical to ensure reliable, representative, and replicable test results. Manufacturers should adhere to the sampling procedures outlined in Appendix 4 *Biochar Sampling Procedures*, drawn from established compost sampling procedures, but adapted specifically for biochar. Adherence to these biochar sampling procedures will ensure that the sample collected is representative of the entire biochar material being analyzed.

5.2 Laboratory Standards

Laboratory analysis of biochar shall be conducted by trained and accredited laboratory professionals following the appropriate procedures outlined for each test. [Please refer to Appendix 5 *Recommended General Sample Analysis Procedures and Protocols for Specific Tests* for further guidance on sample handling and processing prior to analysis.] Testing shall follow strict quality assurance and control (QA/QC) requirements according to standardized laboratory procedures. Laboratory professionals are expected to be trained in the relevant field of analytical chemistry and operate in professional laboratories that have received general laboratory accreditation. Such accreditation should be provided by a relevant governing body or an international standards body like the ISO. Examples of accreditation bodies and programs in the U.S. include: the National Environmental Laboratory Accreditation Program (NELAP; http://www.nelac-institute.org/newnelap.php) and the American Association for Laboratory Accreditation (A2LA; http://www.a2la.org/). Internationally, accreditation bodies include: ISO/IEC 17025:2005 "General Requirements for the Competence of Testing and Calibration Laboratories" (http://www.iso.org/iso/catalogue_detail.htm?csnumber=39883). While accreditation by these bodies (and others not listed above) does not directly assert biochar testing competency, adherence to protocols overseen by accreditation bodies and set forth in each individual laboratory's internal QA/QC programs do provide assurances that contributing laboratories will provide reliable and replicable results and that an appropriate standard of quality is met. Laboratories are expected to provide information describing their internal QA/QC programs as well as their participation in laboratory accreditation programs.

5.3 Timing and Frequency of Testing

Testing of biochar materials should occur after thermochemical processing is complete and before application to soils. Biochar testing and reporting of all Category A, B, and C tests according to the *IBI Biochar Standards* shall be performed:

- annually; or

- after a material change in feedstock; or,
- after a material change in thermochemical production parameters; or
- whichever is more frequent.

5.4 Material Changes in Feedstock and Thermochemical Production Parameters

Significant changes in feedstock composition may lead to materially different biochar products. For this reason, a 10% or greater change in total feedstock composition shall constitute a material change in feedstock, pursuant to these *IBI Biochar Standards*. See Appendix 6 *Determining a "Material Change" in Feedstock* for detailed information on how to determine a material change in feedstock composition.

Material changes in thermochemical production parameters 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%.

5.5 Category B Testing Frequency

Category B Toxicant Assessment tests shall follow the test frequency and reporting requirements outlined above, with *the following exception for unprocessed feedstocks*:

- Category B tests may be repeated every three years rather than annually, as long as there is no material change in the thermochemical production parameters or the feedstock composition. Figure 1 below depicts a set of two process flow charts that compare the initial testing requirements for all feedstock materials with the annual testing requirements, showing how the exception for unprocessed feedstocks is incorporated.

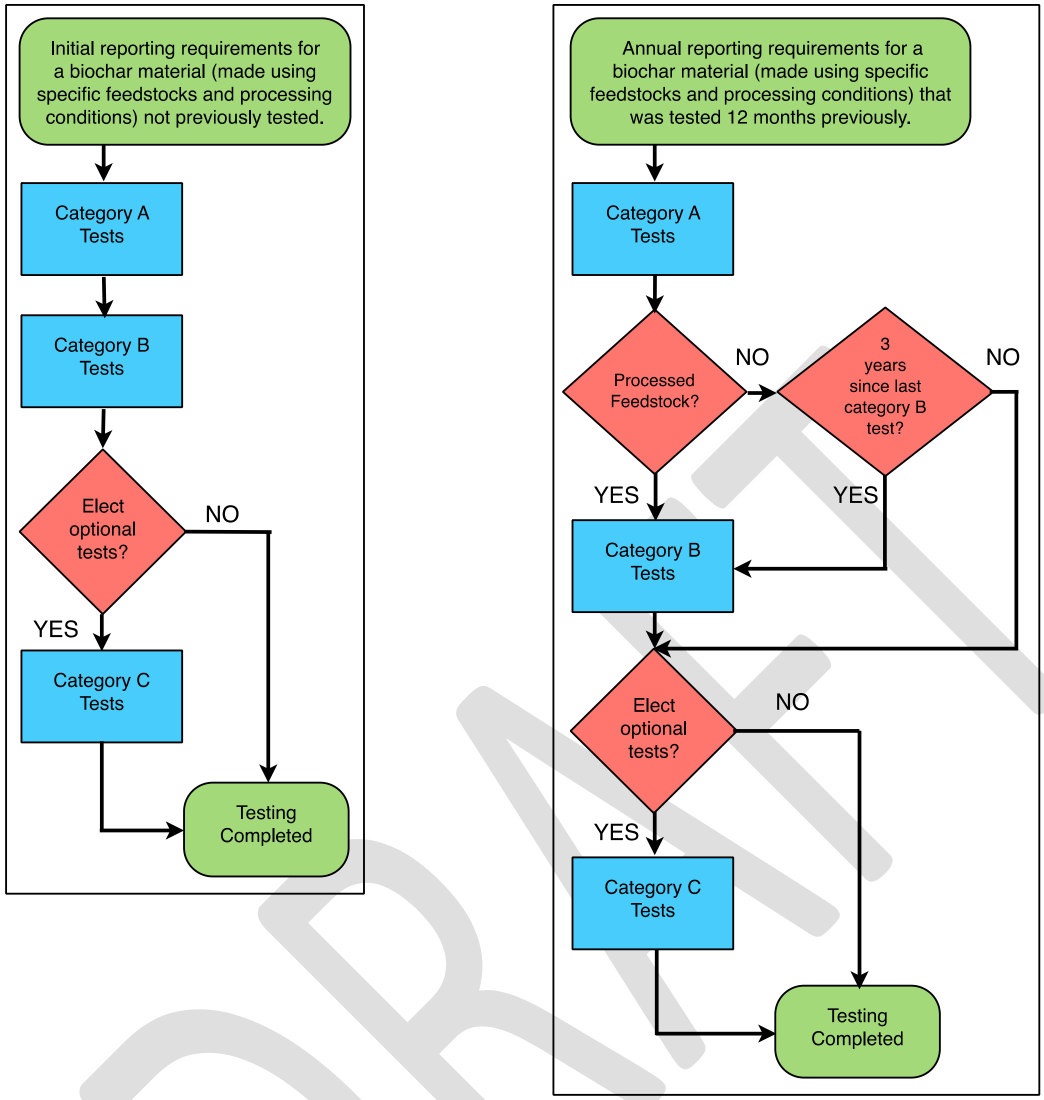

Figure 1. Process flow charts showing testing protocols for initial testing and annual retesting of biochar materials.

5.6 Testing Requirements for Weathered Biochar

Biochar weathering may occur when biochar is exposed to precipitation, ice, freeze-thaw cycles, fluctuations in temperature, deposition of atmospheric chemicals, and/or exposure to ambient air. All of these factors may alter the biochar and its physicochemical properties by changing its physical structure and/or its chemical properties through oxidation, hydration, leaching, or other processes. In many instances biochar weathering can be a beneficial process that enhances the material properties of the biochar.

Biochar that is stored uncovered outdoors is subject to the most extreme physical and chemical weathering. Furthermore, weathering affects biochar differentially depending on the type and extent of exposure, the properties of specific biochars, and biochar storage conditions. For example, if a large pile of biochar has been stored outside and rained on extensively, material at or near the surface may experience differential weathering than material at the center of the pile.

Because of the non-uniform and unpredictable changes caused by weathering, the *IBI Biochar Standards* provide specific testing requirements for biochar material that has been exposed to "significant weathering" which, for the purposes of the *IBI Biochar Standards,* is deemed to occur when *biochar has been stored outdoors uncovered and has experienced any precipitation events*.

The testing requirements for biochar that has experienced significant weathering depend on whether the material has already been sampled and tested as follows:

- In cases where significant weathering occurs *before* biochar has been sampled and submitted for testing, the entire batch of weathered biochar must be thoroughly mixed to achieve material uniformity prior to sampling; and
- In cases where significant weathering occurs *after* biochar has been sampled and tested, *the entire batch of weathered biochar must be re-sampled and re-tested* for all of the required tests. Prior to re-sampling the entire batch of weathered biochar must be thoroughly mixed to achieve material uniformity.

Furthermore, it is the responsibility of the biochar producer to re-sample and re-test a biochar if any other weathering events besides precipitation are believed to substantially change the physicochemical properties of the biochar that has already been sampled and tested.

5.7 Timing of Testing for Post-Processed Biochar

After thermochemical conversion of feedstock(s) to biochar, additional steps may be taken by the biochar manufacturer to enhance, transform, or otherwise alter the physical, chemical or biological properties of the biochar material. For the purposes of these *IBI Biochar Standards*, such actions are called post-processing. In order for test results to accurately reflect biochar material properties, the timing of testing with respect to different types of post-processing treatments is critical. Therefore, biochar manufacturers who utilize post-processing must adhere to the following guidelines for timing of testing:

1) Biochar testing shall occur *before* the following types of post-processing, which constitute the addition of non-biochar materials to the biochar:
    a) *biological activation* including, but not limited to, treatment with microorganisms, organic compounds, and/or nutrients in a biologically active environment; or
    b) *mixing, blending, or adding* any non-biochar material including, but not limited to, compost, fungal mycorrhizae, ash, minerals, chemical fertilizers, animal manure, microbes, and seaweed.
2) Biochar testing shall occur *after* the following types of post-processing:
    a) *steam activation*; or

   b) *chemical activation* including treatment with acid or alkaline substances or oxygen (O_2); or

   c) *UV or concentrated solar light treatment*; or

   d) *microwave or ultrasonic treatment*; or

   e) *crushing, grinding, milling, pelletizing, selective segregation* or any other form of processing intended to alter or limit biochar particle size; or

   f) *weathering* of biochar—whether intentional or unintentional—that has been stored outdoors uncovered and experienced precipitation events.

Further, for those types of post-processing where testing is required to occur after post-processing treatments (listed in (2) above), *the biochar material must be re-tested if post-processing parameters are altered such that the physicochemical properties of the post-processed biochar material are rendered substantively different from the previously tested material*.

5.8 Provisions for High Carbon Biomass Ash

Biomass-fueled power generating stations produce biomass ash as a byproduct of energy generation. Biomass ash—or fractions thereof, including bottom ash and flyash—may display physicochemical properties that are similar to biochar materials, including high organic carbon content. Such materials may pass the required tests in Test Categories A and B of the *IBI Biochar Standards*. However, concern exists around 1) the potential formation and accumulation of toxicants in biomass ash including PAHs, PCDD/Fs, and heavy metals (Van Loo and Koppejan 2007; Vassilev et al 2013), and 2) the ability of the operator of the biomass boiler or furnace (i.e., the biochar manufacturer) to meet and document "material change" requirements outlined in Section 5.4.

Because of concerns outlined above, IBI requires the following provisions for consideration of high carbon biomass ash under the *IBI Biochar Standards:*

1) Only biomass ash produced from clean cellulosic biomass may be utilized. A statement signed by the producer of the biomass ash (see 2) below) stating that the facility only utilizes clean cellulosic biomass must be provided.

2) The producer of the biomass ash (i.e., the operator of the biomass boiler or furnace) is deemed to be the biochar manufacturer. Note that this means that an intermediary (i.e., an entity that acquires and distributes and/or markets the biomass ash) does not qualify as the manufacturer of the biochar pursuant to the *IBI Biochar Standards*.

3) In cases in which some fraction of the high carbon ash is segregated from the total ash product, the following applies:

   a) Material flow through the bioenergy production facility including the segregation process whereby the high carbon ash fraction is segregated from other ash fractions must be documented and clearly describe the ability to produce a consistent and uniform product.

b) The manufacturer must state which fraction of biomass ash is being utilized (bottom ash and/or flyash).

c) All documentation related to the segregation process must be retained per the requirements of Section 5.9 Conformity and Record Keeping.

4) In addition to testing requirements described in Section 5.3 Timing and Frequency of Testing, the following ongoing sampling and testing plan must be adhered to:

a) A grab sample shall be taken of every batch of biomass ash produced by the manufacturer. All grab samples shall be clearly labeled and archived for a period of one-year.

b) At the end of each quarter, all grab samples shall be composited into one quarterly composite sample. All quarterly composite samples shall be clearly labeled and archived for a period of one-year.

c) Composite samples shall be tested every quarter by an independent laboratory (see Section 5.2 Laboratory Standards) for: PAHs, PCDD/Fs, arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, and zinc.

d) If tests results for any of the parameters in c) above exceed the Maximum Allowed Thresholds (see Appendix 3 Toxicant Assessment and Determination of Thresholds), that batch of biomass ash does not meet the requirements of the *IBI Biochar Standards* and may not be considered for certification under the *IBI Biochar Certification Program*.

5.9 Conformity and Record Keeping

The biochar manufacturer must keep detailed records of biochar feedstock(s), including chain of custody, and mandatory and optional test results in order to provide assurance of end-product properties. Chain of custody and biochar traceability demonstrate that adequate care and transparency has been exercised along the entire biochar production and supply chain to enable trace-back of the biochar product beginning with feedstock providers to biochar manufacturers through to end users.

Record keeping is highly recommended (and is required for participation in the *IBI Biochar Certification Program*) in order to establish proof of adequate sampling, testing, and results. Documentation of biochar feedstock (see Appendix 6 for guidelines on identifying categories of feedstocks) and type (unprocessed or processed), thermochemical production parameters (processing temperature and processing time), and test results should be kept for seven years. Individual biochar manufacturers may wish to consult with a local attorney to determine whether recordkeeping for longer than seven years is appropriate, in light of state, regional, or provincial laws regarding product liability claims.

6 Revisions to the *IBI Biochar Standards*

IBI will make periodic revisions to the *IBI Biochar Standards* based on further developments in the fields of biochar science and technology, regulatory changes, and feedback from the public, particularly users of the *IBI Biochar Standards*. Revisions occur in two forms—policy revisions and technical program revisions—and are effective the date of publication on IBI's website.

6.1 Policy revisions

Policy revisions occur when there is a substantive change to the policies, rules, and/or scope of the *IBI Biochar Standards* that may change the eligibility or acceptability of a biochar material. A policy revision creates a new version of the *IBI Biochar Standards* (e.g., Version 1.0 undergoes a policy revision to become Version 2.0). Examples of policy revisions include: changes to feedstock parameters such as the threshold for contaminants; the addition of new toxicants under Test Category B; changes in testing timing and frequency for biochars derived from processed feedstocks; or changes to the "material change" threshold for mixed feedstocks.

When policy revisions are warranted, IBI may convene an expert panel or reach out to experts involved in the development of the *IBI Biochar Standards*. The experts may be asked to provide insight and guidance on the identified policy issues prior to a revised draft of the *IBI Biochar Standards* being circulated for a 30-day public comment period. IBI will incorporate feedback gathered during the public comment period before publishing the final revised version.

6.2 Technical program revisions

Technical program revisions occur when technical or editorial changes are deemed necessary. Technical program revisions create a new sub-version of the *IBI Biochar Standards* (e.g., Version 1.0 undergoes a technical program revision to become Version 1.1). Examples of technical program revisions include: changes to recommended test methods in Test Categories A, B or C; changes to sampling procedures for biochar analysis; or changes to the Maximum Allowed Thresholds for Test Category B toxicants based on revised guidance from regulatory bodies.

In the event of the need for a time-sensitive technical program revision, IBI may issue a technical note to describe the technical program revision, prior to the publication of a new sub-version of the *IBI Biochar Standards*. The issuance of the technical note will signal the implementation of the technical program revision to users of the *IBI Biochar Standards* and will be effective the date of publication on IBI's website.

As with policy revisions, IBI may seek guidance from experts when considering technical program revisions. However, a public comment period is not required and IBI will publish the revised sub-version of the *IBI Biochar Standards* once the identified issues have been resolved.

7 References

Amlinger, F., Faroino, E., and Pollack, M. (2004) *EU Heavy Metals and Organic Compounds from Waste Used as Organic Fertilizers Final Report.* ENV.A.2./ETU/2001/0024 REF.NR.: TEND/AML/2001/07/20. (Accessed January 2012)

AOAC (Association of Analytical Communities) International (2005) *Official Methods of Analysis. 18th Edition*. Latimer, G. (Ed.) www.eoma.aoac.org (accessed September 2011)

ASTM International (2009) *ASTM D6556-10 Standard Test Method for Carbon Black—Total and External Surface Area by Nitrogen Adsorption* http://www.astm.org/Standards/D6556.htm (accessed January 2012)

ASTM International (2007) *ASTM D1762-84 (2007) Standard Test Method for Chemical Analysis of Wood Charcoal* http://www.astm.org/Standards/D1762.htm (accessed September 2011)

ASTM International (2007) *ASTM D4373-02 (2007) Standard Test Method for Rapid Determination of Carbonate Content of Soils* http://www.astm.org/Standards/D4373.htm (accessed March 2013)

Brinton, W.F. (2000) *Compost quality standards and guidelines.* Woods End Research Laboratory, prepared for New York State Association of Recyclers. http://compost.css.cornell.edu/Brinton.pdf (accessed September 2011)

Bureau de normalisation du Québec (2005) *National Standard of Canada, Organic Soil Conditioners – Compost.* CAN/BNQ 0413-200 (2005) ISBN: 2-551-22659-7 http://www-es.criq.qc.ca/pls/owa_es/bnqw_norme.detail_norme?p_lang=en&p_id_norm=8184&p_code_menu=NORME (accessed September 2011)

Camps Arbestain M, J.E. Amonette, B. Singh, T. Wang, H-P. Schmidt. 2015. *A Biochar Classification System and Associated Test Methods*. In: Biochar for Environmental Management - Science and Technology, 2nd edition. J. Lehmann and S. Joseph (eds.). Routledge.

Canadian Council of Ministers of the Environment (CCME) (2002) *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health: Polychlorinated Dibenzo*-p-*Dioxins and Polychlorinated Dibenzofurans (PCDD/Fs).* In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg Manitoba, Canada. ISBN 1-896997-34-1 http://ceqg-rcqe.ccme.ca/ (accessed March 2013)

Canadian Council of Ministers for the Environment (CCME) (2005) *Guidelines for Compost Quality*. PN 1340 Winnipeg Manitoba, Canada. ISBN 1-896997-60-0.

Enders, A. and Lehmann, J. (2012) Comparison of wet digestion and dry ashing methods for total elemental analysis of biochar. *Communications in Soil Science and Plant Analysis*. 43:1042–1052.

European Commission Agriculture and Rural Development (2010) *Biomass Potential* http://ec.europa.eu/agriculture/bioenergy/potential/index_en.htm (accessed September 2011)

European Commission COM (2006) *Establishing a Framework for the Protection of Soil and Amending Directive* 2004/35/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52006PC0232:en:NOT (accessed April 2013)

Hilber I., Blum F., Leifeld J., Schmidt H.-P., Bucheli T. *Quantitative determination of PAHs in biochar: A prerequisite to ensure its quality and safe application.* Journal of Agricultural and Food Chemistry. 60, (12), 2012, 3042-3050

International Biochar Initiative (2010) *IBI Guidelines for the Development and Testing of Pyrolysis Plants to Produce Biochar* http://www.biochar-international.org/sites/default/files/IBI-Pyrolysis-Plant-Guidelines.pdf (accessed September 2011)

Milne, T.A.; Brennan, A.H.; Glenn, B.H. *Sourcebook of Methods of Analysis for Biomass Conversion and Biomass Conversion Processes*. SERI/SP-220-3548. Golden, CO: Solar Energy Research Institute, February 1990.

National Institute of Health, National Cancer Institute, *Dictionary of Cancer Terms*, http://www.cancer.gov/dictionary?cdrid=687391 (Accessed February 2012)

OECD Organisation for Economic Co-operation and Development (1984) Terrestrial Plants, Growth Test no. 208. In *Guideline for Testing of Chemicals*. http://www.oecd.org/dataoecd/18/0/1948285.pdf. (Accessed January 2012)

Rajan, S.S.S., Brown, M.W., Boyes, M.K., and Upsdell, M.P. (1992) Extractable phosphorus to predict agronomic effectiveness of ground and unground phosphate rocks. *Nutrient Cycling in Agroecosystems*. 32(3):291-302.

Rajkovich, S., Enders, A., Hanley, K., Hyland, C., Zimmerman, A.R., and Lehmann, J. (2011) Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils* 48, 271–284.

Rayment, G.E. and Higginson, F.R. (1992). *Australian Laboratory Handbook of Soil and Water Chemical Methods*. Reed International Books, Australia/ Inkata Press, Port Melbourne.

Rayment, G.E., and Lyons, D.J. (2011) *Soil Chemical Methods – Australasia*. CSIRO Publishing, Collingwood, Victoria, Australia.

Stockholm Convention. *What are POPs?* http://chm.pops.int/Convention/ThePOPs/tabid/673/Default.aspx (Accessed March 2012)

US Composting Council and US Department of Agriculture (2001) *Test methods for the examination of composting and compost. (TMECC)* Thompson W.H. (ed.) http://compostingcouncil.org/tmecc/. (Accessed January 2012)

US Environmental Protection Agency (2007) *METHOD 7471B MERCURY IN SOLID OR SEMISOLID WASTE (MANUAL COLD-VAPOR TECHNIQUE).* http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/7471b.pdf (Accessed November 2013).

US Environmental Protection Agency (2007) *METHOD 8082A POLYCHLORINATED BIPHENYLS (PCBs) BY GAS CHROMATOGRAPHY.* http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/8082a.pdf (Accessed November 2013)

US Environmental Protection Agency (2007) *METHOD 8270D SEMIVOLATILE ORGANIC COMPOUNDS BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS).* http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/8270d.pdf (Accessed November 2013)

US Environmental Protection Agency (1996) *METHOD 8275A Semivolatile organic compounds (PAHs and PCBs) in soils/sludges and solid wastes using thermal extraction/gas chromatography/mass spectrometry (TE/GC/MS).* http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/8275a.pdf (Accessed September 2011)

US Environmental Protection Agency (2007) *METHOD 8290A Polychlorinated Dibenzo-P-Dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS).* http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/8290a.pdf (Accessed September 2011)

US Environmental Protection Agency (1999) *Background report on fertilizer use, contaminants and regulations.* Prepared by BATELLE, Columbus OH. National Program Chemicals Division; Office of Pollution Prevention and Toxics, Washington D.C. http://www.epa.gov/oppt/pubs/fertilizer.pdf via http://www.epa.gov/agriculture/tfer.html. (Accessed February 2012)

US Geological Service. *Polynuclear Aromatic Hydrocarbons (PAHs)/Polycyclic Aromatic Hydrocarbons (PAHs)* http://toxics.usgs.gov/definitions/pah.html (Accessed March 2012)Van Loo, S., & Koppejan, J. (Eds.). (2007). *The handbook of biomass combustion and co-firing*. Earthscan.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S., and Cowie, A. (2010) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and Soil* 327:235-246. DOI 10.1007/s11104-009-0050-x.

Vassilev, S. V., Baxter, D., Andersen, L. K., & Vassileva, C. G. (2013). An overview of the composition and application of biomass ash.: Part 2. Potential utilisation, technological and ecological advantages and challenges. *Fuel*, *105*, 19-39.

Wang, T., Camps-Arbestain, M., Hedley, M., & Bishop, P. (2012). Predicting phosphorus bioavailability from high-ash biochars. *Plant and soil*, *357*(1-2), 173-187.

Appendix 1 – Expanded Information on Test Methods for Category B Toxicants Assessment

All of the elements (except mercury) in Test Category B Toxicants Assessment require the use of test methods outlined in the *Test Methods for the Examination of Composting and Compost* (TMECC; US Composting Council and US Department of Agriculture, 2001). These test methods involve a digestion step followed by a determination step. In some cases there are multiple digestion and/or determination methods allowable. Table A1.1 below provides clarification on the allowable digestion and determination methods for each parameter. Testing labs can choose the appropriate digestion and/or determination method when more than one method is listed for a given parameter. Table A1.2 provides a description of each test method that is abbreviated in Table A1.1.

Table A1.1. Allowable digestion and determination test methods for parameters in Category B that require the use of TMECC methods. For a description of each test method see table A1.2.

Parameter	Source (TMECC Chapter)	Test Method						
		Digestion Method					Determination Method	
		Digestion1	Digestion2	Digestion3	Digestion4	Digestion5	Determin1	Determin2
Arsenic	4.06	TMECC 04.12-A	TMECC 04.12-B	-	-	-	US EPA 7000	-
Cadmium	4.06	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	-	-	US EPA 7000	US EPA 6010
Chromium	4.06	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	-	-	US EPA 7000	US EPA 6010
Cobalt	4.05	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	TMECC 04.12-D	TMECC 04.12-C	US EPA 7000	US EPA 6010
Copper	4.06	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	-	-	US EPA 7000	US EPA 6010
Lead	4.06	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	-	-	US EPA 7000	US EPA 6010
Molybdenum	4.06	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	-	-	US EPA 7000	US EPA 6010
Nickel	4.06	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	-	-	US EPA 7000	US EPA 6010
Selenium	4.06	TMECC 04.12-A	TMECC 04.12-B	-	-	-	US EPA 7000	US EPA 6010
Zinc	4.06	TMECC 04.12-A	TMECC 04.12-B	-	-	-	US EPA 7000	US EPA 6010
Boron	4.05	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-D	-	-	US EPA 6010	-
Chlorine	4.05	TMECC 04.12-D	-	-	-	-	ion chromatography	ion-selective electrode
Sodium	4.05	TMECC 04.12-A	TMECC 04.12-B	TMECC 04.12-E	TMECC 04.12-D	TMECC 04.12-C	US EPA 7000	US EPA 6010

Table A1.2. Description of TMECC and US EPA test methods in Table A1.1.

TMECC Test Methods		
Method Number	**Name**	**Adapted from**
TMECC 04.12-A	microwave assisted nitric acid digestion for compost	US EPA 3051 (2007) microwave assisted acid digestion of sediments, sludges, soils and oils
TMECC 04.12-B	nitric acid digestion of compost and soils	US EPA 3050 (1996) acid digestion of sediments, sludges, and soils
TMECC 04.12-C	dry ash sample digestion for plant nutrients	AOAC method 985.01
TMECC 04.12-D	water soluble elements	n/a
TMECC 04.12-E	aqua regia procedure	n/a
US EPA 7000 (2007)	flame atomic absorption spectrophotometry	n/a
US EPA 6010 (2007)	inductively coupled plasma - atomic emission spectroscopy	n/a

References

US Composting Council and US Department of Agriculture (2001) *Test methods for the examination of composting and compost. (TMECC)* Thompson W.H. (ed.) http://compostingcouncil.org/tmecc/ (Accessed January 2012).

US Environmental Protection Agency (1996) *Method 3050B ACID DIGESTION OF SEDIMENTS, SLUDGES, AND SOILS*. http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3050b.pdf (Accessed November 2013).

US Environmental Protection Agency (2007) *Method 3051A MICROWAVE ASSISTED ACID DIGESTION OF SEDIMENTS, SLUDGES, SOILS, AND OILS*. http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3051a.pdf (Accessed November 2013).

US Environmental Protection Agency (2007) *Method 6010C INDUCTIVELY COUPLED PLASMA-ATOMIC EMISSION SPECTROMETRY*. http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/6010c.pdf (Accessed November 2013).

US Environmental Protection Agency (2007) *Method 7000B FLAME ATOMIC ABSORPTION SPECTROPHOTOMETRY*. http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/7000b.pdf (Accessed November 2013).

Appendix 2 – PAH, PCDD/F and PCB Compounds to be Tested

PAHs, PCDD/Fs, and PCBs are each suites of related chemical compounds (congeners), sometimes numbering in the hundreds. The US EPA maintains a list of 126 Priority Pollutants as part of the Clean Water Act that have been determined to have detrimental human and environmental health impacts; these compounds must be reported under requirements of the Clean Water Act. Contained therein are the primary PAHs and PCBs of concern. For PCDD/Fs, the World Health Organization (WHO) maintains a list of the primary PCDD/Fs of concern as well as the toxic equivalency factor (TEF) of each PCDD/F (Van den Berg et al, 2005).

For the purposes of biochar testing for PAHs, PCDD/Fs, and PCBs, testing labs shall test for the following priority compounds as determined by the US EPA and WHO.

The 16 PAH priority compounds to be tested are:

	PAH	CAS number
1	Acenaphthene	83-32-9
2	Acenaphthylene	208-96-8
3	Anthracene	120-12-7
4	Benz(a)anthracene	56-55-3
5	Benzo(a)pyrene	50-32-8
6	Benzo(b)fluoranthene	205-99-2
7	Benzo(k)fluoranthene	207-08-9
8	Benzo(ghi)perylene	191-24-2
9	Chrysene	218-01-9
10	Dibenz(a,h)anthracene	53-70-3
11	Fluoranthene	206-44-0
12	Fluorene	86-73-7
13	Indeno(1,2,3-cd)pyrene	193-39-5
14	Naphthalene	91-20-3
15	Phenanthrene	85-01-8
16	Pyrene	129-00-0

The 7 PCB priority compounds to be tested are:

	PCB	CAS number
1	Aroclor 1016	12674-11-2
2	Aroclor 1221	11104-28-2
3	Aroclor 1232	11141-16-5
4	Aroclor 1242	53469-21-9
5	Aroclor 1248	12672-29-6
6	Aroclor 1254	11097-69-1
7	Aroclor 1260	11096-82-5

The 17 PCDD/PCDF congeners to be tested are:

	PCDD/F	Acronym
1	2,3,7,8-Tetrachlorodibenzo-p-dioxin	TCDD
2	1,2,3,7,8-Pentachlorodibenzo-p-dioxin	PeCDD
3	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	HxCDD
4	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	HxCDD
5	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	HxCDD
6	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	HpCDD
7	1,2,3,4,5,6,7,8-Octachlorodibenzo-p-dioxin	OCDD
8	2,3,7,8-Tetrachlorodibenzofuran	TCDF
9	1,2,3,7,8-Pentachlorodibenzofuran	PeCDF
10	2,3,4,7,8-Pentachlorodibenzofuran	PeCDF
11	1,2,3,4,7,8-Hexachlorodibenzofuran	HxCDF
12	1,2,3,6,7,8-Hexachlorodibenzofuran	HxCDF
13	1,2,3,7,8,9-Hexachlorodibenzofuran	HxCDF
14	2,3,4,6,7,8-Hexachlorodibenzofuran	HxCDF
15	1,2,3,4,6,7,8-Heptachlorodibenzofuran	HpCDF
16	1,2,3,4,7,8,9-Heptachlorodibenzofuran	HpCDF
17	1,2,3,4,5,6,7,8-Octachlorodibenzofuran	OCDF

References

US Environmental Protection Agency (2013) Clean Water Act Priority Pollutants http://water.epa.gov/scitech/methods/cwa/pollutants.cfm (accessed November 2013).

Van den Berg, Martin, et al. "The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds." *Toxicological sciences* 93.2 (2006): 223-241.

Appendix 3 – Toxicant Assessment and Determination of Thresholds

The following table indicates the maximum allowed toxicant thresholds for some jurisdictions, including the European Union (EU), the United Kingdom (UK), Australia, Canada, and the United States (US), that were used to help develop reporting levels for the *IBI Biochar Standards*. These entities were chosen as resources for toxicant standards due to their history of regulations addressing these toxicants in soils and other substrates, and their development of similar soil quality standards (e.g. land-application of biosolids, wood ash, and/or compost). Toxicant ranges for reporting to the IBI are *not* indicated within this appendix, and are instead indicated within Table 2 as part of Test Category B. Table A3.1 below is intended to provide a better understanding of how IBI developed the Maximum Allowed Threshold (MAT) ranges listed in Table 2 through a survey of international regulations.

Table A3.1. International toxicant regulations and thresholds used for determining range of Maximum Allowed Thresholds for biochar materials.

Toxicant	International Regulatory Maximum Allowed Thresholds (MATs)	
Polycyclic Aromatic Hydrocarbons (PAHs), total (sum of 16 US EPA PAHs[13])	6(A), 300(B)	mg/kg (dry wt)
Polycyclic Aromatic Hydrocarbons (PAHs), B(a)P Toxic Equivalency (TEQ) basis[14]	3(B)	mg/kg B(a)P-TEQ (dry wt)
Dioxin/Furan (PCDD/Fs), WHO-Toxic Equivalency (TEQ) basis[15]	17 (F)	ng/kg WHO-TEQ (dry wt)
Polychlorinated Biphenyls (PCBs), total (sum of 7 US EPA PCBs[16])	0.2(A), 1(B), 0.5(C)	mg/kg (dry wt)
Arsenic	100(B), 41(D), 13(E)	mg/kg (dry wt)

[13] See Appendix 2.
[14] B(a)P Toxic Equivalency (TEQ) is calculated by multiplying the concentration of each carcinogenic PAH by its Toxic Equivalency Factor (TEF) and summing the products. TEFs of the 8 carcinogenic PAHs are derived from the Australia National Environment Protection Measure 1999 (2013) Table 1A(1) *Health investigation levels for soil contaminants* and are listed in Table A3.2 below.
[15] Toxic Equivalency (TEQ) is calculated by multiplying the concentration of each PCDD/F by its World Health Organization (WHO) Toxic Equivalency Factor (TEF) and summing the products. TEFs of PCCD/Fs are derived from Van den Berg, Martin, et al. "The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds." Toxicological sciences 93.2 (2006): 223-241 and are listed in Table A3.3 below.
[16] See Appendix 2.

Table A3.1 (continued). International toxicant regulations and thresholds used for determining range of Maximum Allowed Thresholds for biochar materials.

Toxicant	International Regulatory Maximum Allowed Thresholds (MATs)	
Cadmium	1.4(A), 20(B), 39(D), 3(E)	mg/kg (dry wt)
Chromium	93(A), 100(B), 1200 (D), 210(E)	mg/kg (dry wt)
Cobalt	100(B), 34(E)	mg/kg (dry wt)
Copper	143(A), 6000(B), 1500(D), 400(E)	mg/kg (dry wt)
Lead	121(A), 300(B), 300(D), 150(E)	mg/kg (dry wt)
Mercury	1(A), Methyl mercury 10(B), Inorganic mercury 40(B), 17(D), 0.8(E)	mg/kg (dry wt)
Molybdenum	75(D)[17], 5(E)	mg/kg (dry wt)
Nickel	47(A), 400(B), 420(D), 62(E)	mg/kg (dry wt)
Selenium	200(B), 36(D), 2(E)	mg/kg (dry wt)
Zinc	416(A), 7400 (B), 2800(D), 700(E)	mg/kg (dry wt)

Table A3.2. Toxic Equivalency Factors (TEFs) for the 8 carcinogenic PAHs (see Table 1A(1) *Health investigation levels for soil contaminants* in Reference (B)).

PAH compound	TEF	PAH compound	TEF
benzo[a]anthracene	0.1	benzo[a]pyrene	1
chrysene	0.01	indeno[1,2,3-cd]pyrene	0.1
benzo[b]fluoranthene	0.1	dibenz[a,h]anthracene	1
benzo[k]fluoranthene	0.1	benzo[ghi]perylene	0.01

Table A3.3. Toxic Equivalency Factors (TEFs) for PCDD/Fs (see Table 1 *Summary of WHO 1998 and WHO 2005 TEF Values* in Reference (G)).

PCDD compound	TEF	PCDF compound	TEF
2,3,7,8-TCDD	1	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	1	1,2,3,7,8-PeCDF	0.03
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.3
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1

[17] For molybdenum, EPA only provides a concentration limit for "All Biosolids". All other EPA limits listed in Table A3.1 are derived from "Environmental Quality and Pollutant Concentration Biosolids".

Table A3.3 (continued). Toxic Equivalency Factors (TEFs) for PCDD/Fs (see Table 1 *Summary of WHO 1998 and WHO 2005 TEF Values* in Reference (G)).

PCDD compound	TEF	PCDF compound	TEF
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,7,8,9-HxCDF	0.1
OCDD	0.0003	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		OCDF	0.0003

References

(A) Amlinger F., Favoino E. and Pollack M., (2004) Heavy metals and organic compounds from wastes used as organic fertilisers. Final Report July 2004. REF. Nr. TEND/AML/2001/07/20 ENV.A.2./ETU/2001/0024 http://www.bvsde.paho.org/bvsacd/cd43/used.pdf See Table S1 *Averaged limit values of EU countries* (Austria, Belgium, Germany, Denmark, Spain, France, Finland, Greece, Italy, Ireland, Luxembourg, Netherlands, Portugal, Sweden, and United Kingdom) for specific toxicant information. *NB*: Individual nations within the EU will have different regulatory expectations than the average values reported herein; appropriate regulatory values should be followed, rather than regional averages. (accessed March 2013)

(B) Australia National Environment Protection (Assessment of Site Contamination) Measure 1999. (2013) Schedule B(1) Guideline on Investigation Levels for Soil and Groundwater. http://www.scew.gov.au/nepms/assessment-site-contamination See Table 1A(1) *Health investigation levels for soil contaminants* for specific toxicant information. (accessed August 2014)

(C) Canadian Council of Ministers of the Environment (CCME) 2001; 2006 Soil Quality Guidelines for the Protection of Environmental and Human Health (first published 1999, updated 2001, 2002, 2003, 2004, 2005, 2006 & 2007). http://st-ts.ccme.ca See *Agricultural concentration limits* for soil PCB limit. (accessed March 2013)

(D) United States Environmental Protection Agency (US EPA) 1994. A Plain English Guide to the EPA Part 503 Biosolids Rule, Office of Wastewater Management, Washington DC. EPA/832/R-93/003. http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm See Table 2-1 *Pollutant Concentration Limits for EQ and PC Biosolids* for specific toxicant information. (accessed March 2013)

(E) Bureau de Normalisation du Quebec 2005. National Standard of Canada. Organic Soil Conditioners – Composts http://www-es.criq.qc.ca/pls/owa_es/bnqw_norme.detail_norme?p_lang=en&p_id_norm=8184&p_code_menu=NORME See *Maximum Acceptable Trace Element Content in Compost* for Type AA Compost. (accessed April 2013)

(F) Ministère du Développement durable, de l'Environnement et des Parcs Quebec 2008. Guidelines for the Beneficial Use of Fertilising Residuals. Reference Criteria and Regulatory Standards. http://www.mddelcc.gouv.qc.ca/matieres/mat_res-en/fertilisantes/critere/guide-mrf.pdf. See Table 8.2 Maximum limits for chemical contaminants (C categories). (accessed October 2014)

(G) Van den Berg, Martin, et al. "The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds." Toxicological sciences 93.2 (2006): 223-241.

Appendix 4 – Biochar Sampling Procedures

Equipment required for sampling

Because of contamination risks all equipment should be thoroughly cleaned with metals-free soap and rinsed with de-ionized water prior to sampling.

- Stainless steel trowel or shovel
- Container for mixing: a large stainless steel tray is ideal
- Plastic tarpaulin for mixing (if necessary)
- Permanent marking pen
- Sample submission form (provided by testing laboratory)
- Sample containers (described in detail below)

Sample containers

Gallon- or quart-sized zip-loc plastic bags (or glass jars) are adequate containers for most of the parameters to be tested in the *IBI Biochar Standards*. However, because organic pollutants including PAHs, PCDD/Fs, and PCBs are prone to volatilization and because plastics may absorb or desorb the target organic pollutants, samples to be tested for those compounds and for the germination inhibition assay must be packaged in special glass containers with Teflon lids or exclusively Teflon containers. Manufactures should check with the testing laboratory to confirm sample amounts to be collected as well as container types. In most cases, labs will provide the Teflon containers for the PAHs, PCDD/Fs, and PCBs tests. Table A4.1 below lists the container types allowed as well as the maximum recommended holding time by each testing parameter.

Table A4.1. Sample containers and holding times by test category parameters.

	Container type[1]			
Parameter	**P**	**G**	**GwT or T**	**Max holding time[2]**
Category A - all parameters	x	x		14 days
Category B - germination inhibition assay			x	7 days
Category B - PAHs, PCDD/Fs, and PCBs			x	7 days until extraction
Category B - metals	x	x		28 days
Category C - all parameters	x	x		14 days

P = Plastic; G = Glass; GwT or T = Glass with Teflon lid or exclusively Teflon

[2] Max holding time = Maximum holding time recommended at lab (Woods End, 2014)

Composite sampling

Because of spatial variability of biochar stored in a pile, bin or other storage method, it is necessary to take a composite sample consisting of material collected from several locations within the entire biochar material being sampled. A representative biochar sample must be collected through random selection of subsamples throughout the entire material being sampled. The sampling technique will depend on the type of storage of the material and consist of no less than 15 subsamples (USDA and USCC, 2001).

Composite sampling procedure by storage method

Pile or other uncontained storage method:

1. Remove any covers and thoroughly mix the pile, if possible.
2. Proceed to the first randomly selected sampling location and collect approximately 1 pint of material from near the surface, another pint midway through the pile, and another pint near the bottom of the pile. Place the subsamples in the 5-gallon bucket.
3. Repeat this process at least 5 times at random locations in the biochar pile.
4. When all subsamples have been collected, thoroughly mix the material in the bucket being careful to avoid stratification of the biochar based on particle size. If necessary, mixing may be facilitated by dumping the material in the bucket onto a clean plastic tarpaulin, and mixing thoroughly.
5. Collect the composite sample from the mixed material. Fill the material to overflowing in double wrapped zip-loc bags. Clearly mark the bag contents with permanent marker including name of the biochar, and sampling date and time.

Enclosed containers or bagged product:

1. Open the container/bag and thoroughly mix the material inside, if possible.
2. Proceed to the first randomly selected container/bag and take 3 subsamples consisting of approximately 1 pint of material each from several different depths inside the container/bag. Place the subsamples in the 5-gallon bucket.
3. Repeat this process at least 5 times from randomly selected containers/bags.
4. When all subsamples have been collected, thoroughly mix the material in the bucket being careful to avoid stratification of the biochar based on particle size. If necessary, mixing may be facilitated by dumping the material in the bucket onto a clean plastic tarpaulin, and mixing thoroughly.
5. Collect the composite sample from the mixed material. Fill the material to overflowing in double wrapped zip-loc bags. Clearly mark the bag contents with permanent marker including name of the biochar, and sampling date and time.

Number of samples to collect

To ensure statistical accuracy of the composite sample it is necessary to adjust the subsample size based on the overall amount of the biochar material being sampled. Biochar manufacturers should adhere to the following subsampling thresholds:

- For amounts up to 10 metric tons of biochar material the manufacturer shall take a minimum of 15 random subsamples, as outlined above.
- For each increase in 10 metric tons of biochar material, at least 15 additional subsamples shall be taken. For example, if 60 metric tons of biochar are being sampled for testing, a minimum of 90 random subsamples should be taken throughout the entire biochar material.

Sampling from multiple biochar production units

In cases where biochar is produced from multiple production units, biochar manufacturers may sample from only one unit using the protocols described above *provided that there are no material differences (i.e., changes) in feedstock and/or thermochemical production parameters between the production units as established in these* IBI Biochar Standards (see Section 5.4 and Appendix 6). Where feedstock and/or thermochemical production parameters between production units are above the thresholds established in these *IBI Biochar Standards*, the biochar manufacturer must sample and test the biochars separately as distinct biochar materials.

Shipping biochar samples

Once a composite sample has been taken, the sample must be properly packaged for shipping to the testing laboratory. Standard practice involves securely packaging the double-wrapped biochar samples in sturdy boxes or other containers. The biochar should be clearly marked with the name of the sample and the time and date of sampling. *It is the responsibility of the biochar manufacturer to confirm any special procedures for packaging and labeling, quantities needed, as well as pricing with the laboratory being used to conduct the testing*. In some cases, laboratories may provide proprietary containers for shipping. Furthermore, because of the possibility of volatilization of organic pollutants at ambient temperatures, it is recommended that samples to be tested for PAHs, PCDD/Fs, and PCBs be chilled on dry ice directly after sampling and during shipping (TMECC).

References

US Composting Council and US Department of Agriculture (2001) *Test methods for the examination of composting and compost.* (TMECC) Thompson W.H. (ed.) http://compostingcouncil.org/tmecc/. (Accessed January 2012).

Woods End Laboratories, Inc. (2014) *Principles and Practice: Compost Sampling for Lab Analysis.* http://woodsend.org/wp-content/uploads/2011/03/sampli1.pdf (Accessed August 2014)

Appendix 5 – Recommended General Sample Analysis Procedures and Protocols for Specific Tests

Sample handling and processing

Since sample handling and processing is analysis methodology-dependent, appropriate procedures should be selected based upon the chemical tests that will be conducted. Sample processing can vary depending upon the physicochemical analyses to be conducted; sample preparation methods followed should be specifically intended for the selected physicochemical tests to be conducted. For example, sample preparation methods can include grinding and sieving or oven-drying for analysis, to provide the dry weight measure indicated in Table 3 of the biochar test categories. General sample preparation procedures can be found in TMECC Section 02.02 Laboratory Sample Preparation (TMECC, 2001). Caution should be exercised, however, since the methodologies recommended therein are designed for compost, and not for biochar. Comments within the TMECC document indicate that sample heating can occur while grinding, which can result in a change in sample qualities and characteristics. To avoid this, it is recommended that samples be ground in a mortar and pestle and sieved to a smaller size range (e.g. 2mm) , to reduce the risk of heating, sparking, or ignition (following sample grinding methods for pH and EC assessment noted in Rajkovich et al, 2011).

Combined approach to analyzing pH and EC

Generic pH and EC analysis procedures have been drawn from the TMECC methodologies (US Composting Council and US Department of Agriculture (2001)). These procedures for the use of control and reference pH samples and electrode probes have been adapted for use with biochar, as follows: where the TMECC methodology recommends a 1:5 (v:v or w:w)[18] solution of compost:deionized water, a 1:20 (w:v)[19] solution of biochar:deionized water should be used for biochar pH and EC analysis, following Rajkovich et al (2011). Similarly, additional time should be allotted for solution equilibration after the combination of deionized water and biochar. Following Rajkovich et al (2011), 1.5 hours should be provided for the shaking and equilibration of biochar-deionized-water solutions prior to pH and EC analysis. Upon completion of the shaking and equilibration phase, pH and EC analysis may be conducted on the same

[18] v:v – volume:volume denotes a ratio based on equivalent units of volume measurement in a dilution or blend (e.g. a 1:5 v:v biochar:water blend indicates the need to blend 1 ml of biochar with 5 ml of water)

w:w – weight:weight denotes a ratio based on equivalent units of weight measurement in a dilution or blend (e.g. a 1:5 w:w biochar:soil blend indicates the need to blend 1 g of biochar with 5 g of soil)

[19] w:v – weight:volume denotes a blend or dilution ratio expressed as grams of solid per milliliter of liquid. (e.g. a 1:20 w:v biochar:water blend indicates the need to blend 1 mg of biochar with 20 ml of water)

samples, rather than making separate replicates for pH and EC. To complete the pH and EC analysis follow methodologies 04.10 and 04.11 of the TMECC methodology (US Composting Council and US Department of Agriculture (2001)).

Germination Inhibition Assay

The purpose of the analysis is to determine whether adding biochar to soil has an effect on seed germination. It is assumed that a negative effect indicates the presence of undesirable compounds in the biochar material. The Germination Inhibition Assay analysis follows procedures outlined by Van Zwieten et al (2010). The recommended approach for biochar analysis is to follow Van Zwieten et al's method, as it is drawn from the initial 1984 OECD methodology, and to report seedling germination as it relates to the potential failure to germinate in biochar-soil. Lettuce (*Lactuca sativa L.*) is the most widely recommended species to use in germination assessments, due to its sensitivity. Other species that can be used are found within the OECD (1984) methodology. Results should be reported as a "fail" to reflect a failure of seedling germination and growth in biochar-blended soils, thus rejecting the null-hypothesis that there is no difference between biochar-soil blends and unamended soils within the test. Results can be reported as a "pass" where there is no difference of germination and seedling growth success between biochar-soil blends and (control or unamended) soil, or where biochar-soil blends are preferred; both conditions are considered to pass these tests.

Analysis of Surface Area

The analysis of surface area will follow the methodologies presented in ASTM D6556-10 Standard Test Method for Carbon Black – Total and External Surface Area by Nitrogen Adsorption. Although carbon blacks can be made at much higher temperatures than biochar, the following Brunauer, Emmett, and Teller (BET) procedure will be effective for analyzing biochar surface area, with the following additional steps:

1. The relevant measure is the B.E.T. nitrogen surface area ("BET NSA").
2. The Vacuum Degassing method should be used (section 8.5) in preference to the Flow Degassing (8.4).
3. Section 8.5.3 Degassing temperature should not exceed 250°C to avoid further thermochemical alteration of the sample, as some biochars are made at temperatures as low as 300°C. The times necessary to degas may greatly exceed the ½ hour mentioned in this section of the analysis; up to 48 hours can be used to conduct the analysis, however this time must be reported along with the results. The actual time needed will depend on the instrument tolerance level, which is dictated by the manufacturer.
4. As indicated in section 9.6, a minimum of five evenly-spaced data points can be presented between 0.05 and 0.5 p/p0. Two additional data points, at 0.05 and 0.075 p/p0 should also be presented in the results.
5. The mass of sample on which the measurement is based should be determined <u>after</u> the surface area measurement has been completed.

6. The instrument should be calibrated periodically with a reference standard supplied by the manufacturer to make sure it is in good working order according the manufacturer's specifications.

Final units for surface area analysis should be reported in square meters per gram (m^2/g).

References

ASTM International (2009) *ASTM D6556-10 Standard Test Method for Carbon Black—Total and External Surface Area by Nitrogen Adsorption* http://www.astm.org/Standards/D6556.htm (accessed January 2012).

OECD Organisation for Economic Co-operation and Development (1984) Terrestrial Plants, Growth Test no. 208. In *Guideline for Testing of Chemicals*. http://www.oecd.org/dataoecd/18/0/1948285.pdf. (Accessed January 2012).

Rajkovich, S., Enders, A., Hanley, K., Hyland, C., Zimmerman, A.R., and Lehmann, J. (2011) Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils* 48(3):271-284.

US Composting Council and US Department of Agriculture (2001) *Test methods for the examination of composting and compost. (TMECC)* Thompson W.H. (ed.) http://compostingcouncil.org/tmecc/. (Accessed January 2012).

Van Zwieten, L., Kimber, S., Morris, S., Chan, K.Y., Downie, A., Rust, J., Joseph, S., and Cowie, A. (2010) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant Soil* 327:235-246. DOI 10.1007/s11104-009-0050-x.

Appendix 6 – Determining a "Material Change" in Feedstock

This appendix addresses the process for determining a "material change" in feedstock composition. It is necessary to monitor material changes in feedstock in order to meet the requirement that biochar physicochemical properties are tested and reported after every material change in feedstock as stated in Section 5.3.

Classification of Unprocessed and Processed Feedstocks

Feedstocks are classified by type in order to determine material changes in feedstock composition. Table A6.1 is a list of unprocessed[20] feedstock types based on biomass composition. Unprocessed feedstocks not listed in this table may be used to make biochar if they meet 1) the definition of unprocessed feedstock in the glossary and 2) the other feedstock requirements outlined in Section 3.1.

Table A6.1. Unprocessed feedstock types for determining a material change in feedstock composition.

Unprocessed Feedstock Types
Rice hulls & straw
Maize cobs & stover
Non-maize cereal straws
Sugar cane bagasse & trash
Switch grass, Miscanthus & bamboo
Oil crop residues e.g., sugar beet, rapeseed
Leguminous crop residues e.g., soy, clover
Hemp residues
Softwoods (coniferous)
Hardwoods (broadleaf)

Table A6.2 is a list of processed feedstock types based on biomass composition. Processed feedstocks not listed in this table may be used to make biochar if they meet 1) the definition of processed feedstock in the glossary and 2) the other feedstock requirements outlined in Section 3.1.

[20] See Appendix 9 – Glossary for definitions of processed and unprocessed feedstocks.

Table A6.2. Processed feedstock types for determining a material change in feedstock composition.

Processed Feedstock Types
Cattle manure
Pig manure
Poultry litter
Sheep manure
Horse manure
Paper mill sludge
Sewage sludge
Distillers grain
Anaerobic digester sludge
Biomass fraction of MSW – woody material
Biomass fraction of MSW – yard trimmings
Biomass fraction of MSW – food waste
Food industry waste

Determining a Material Change in Feedstock

As described in Section 5.3, a change of 10% or greater between any feedstock type listed in Tables A6.1 or A6.2 will constitute a material change in feedstock and require a new round of testing. If an unprocessed feedstock is not listed in Table A6.1, then a material change in feedstock shall be based on the species of plant material used for the feedstock, so that a change of 10% or greater in species composition constitutes a material change in feedstock.

For processed feedstocks, any significant change in processing parameters (e.g., a change in process chemistry for paper sludge, or a change from dairy cow manure to dairy cow manure digestate from an anaerobic digester), or processing facility (e.g., a change from paper mill sludge provided by Facility A to that provided by Facility B) shall result in the processed feedstock being classified as a new type.

The following are illustrative examples for determining material changes in unprocessed and processed feedstocks:

1. a change from 100% softwoods to 100% hardwoods;
2. a change from 100% cow manure to 100% pig manure;
3. a change from 100% maize stover to 100% poultry litter;
4. a change from 100% sewage sludge from Facility A to 100% sewage sludge from Facility B; or

5. a change from 100% Switch grass to 90% Switch grass plus 10% sugar cane bagasse.

Mixed Feedstocks

When a mix of feedstocks is used—whether unprocessed, processed or a combination—a change of 10% or more in the total feedstock composition shall constitute a material change in feedstock. The magnitude of the change in the feedstock shall be calculated by adding up the decreases in percentages for each individual feedstock type composing the mixed feedstock. The following is an illustrative example:

Rosie's biochar is originally made of the following mix of unprocessed and processed feedstock types:

- 35% spruce wood chips,
- 25% poultry litter,
- 15% wheat straw,
- 15% assorted leaves, and
- 10% corn stover.

This past year, due to a change in spruce availability, her feedstocks changed to:

- 25% spruce wood chips,
- 35% poultry litter,
- 15% wheat straw,
- 15% assorted leaves, and
- 10% corn stover.

Because a 10% total change in feedstock has occurred, Rosie must re-test her biochar.

If Rosie's biochar had instead changed from her original blend in the following way, she would still need to re-test her biochar because there has been greater than 10% change in feedstocks:

- 38% spruce wood chips,
- 20% poultry litter,
- 20% wheat straw,
- 17% assorted leaves, and
- 5% corn stover.

Appendix 7 – The Use of $H:C_{org}$ to Indicate C Stability

The molar $H:C_{org}$ ratio is recommended to distinguish biochar from other thermochemically altered organic matter for several reasons:

1. H:C ratios change substantially with thermochemical treatment (Keiluweit et al., 2010);
2. O:C ratios have been shown to correlate well with stability of biochars (Spokas, 2010);
3. H:C and O:C ratios are closely related (for low-ash biochars <50% ash and <80% volatiles (ash-free basis));
4. H is determined directly in most laboratories, whereas O is calculated by subtraction.

The modification of using the organic C values rather than total C for this ratio is motivated by the presence of inorganic carbonates in some high-ash biochars. These inorganic carbonates do not form aromatic groups distinctive of biochar materials.

The molar $H:C_{org}$ ratio is a material property that is correlated with the degree of thermochemical alteration that produces fused aromatic ring structures in the material. The presence of these structures is an intrinsic measure of the stability of the material.

The upper $H:C_{org}$ limit of 0.7 is used to distinguish biochar from biomass that has not been thermochemically altered and from other materials that have been only partially thermochemically altered. We use the term "thermochemically converted" to refer to thermochemically altered materials that have an $H:C_{org}$ below 0.7. These materials have a greater proportion of fused aromatic ring structures. Other thermochemically processed materials that have an $H:C_{org}$ value greater than 0.7 may be thermochemically "altered" but they are not considered to be thermochemically "converted".

Figure A7.1 below shows relationships between processing temperature and $H:C_{org}$ molar ratio for a number of thermochemically altered materials, as compared to unprocessed biomass.

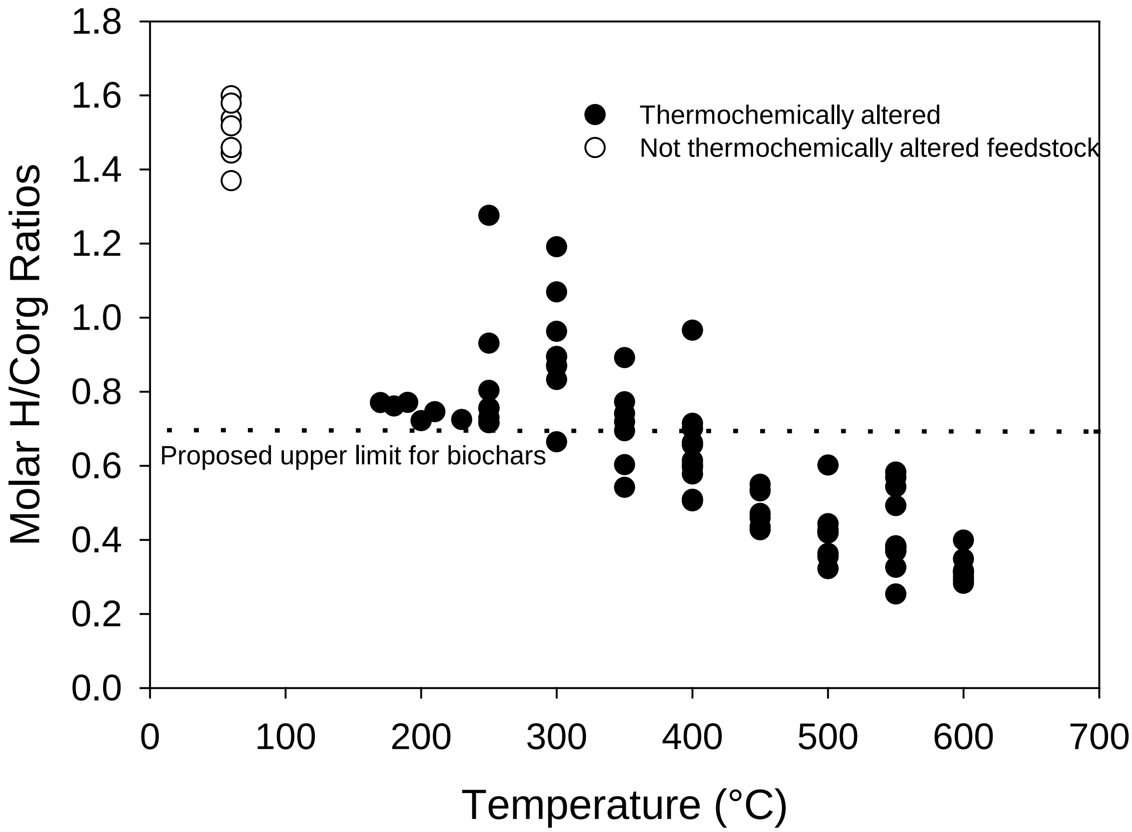

Figure A7.1. Relationship between molar H:C_{org} ratios and temperature of thermochemically altered organic matter in comparison to untreated biomass. The dashed line is the upper limit of 0.7. Data points below the 0.7 line are thermochemically altered materials that are considered to be thermochemically "converted" (data from Sevilla and Fuertes, 2009ab; Calvelo Pereira et al, 2011; Enders et al., 2012).

References

Enders A., Hanley K., Whitman T., Joseph S. and Lehmann J. Characterization of biochars to evaluate recalcitrance and agronomic performance. *Bioresource Technology* 114, 644-653.

Keiluweit M., Nico P.S., Johnson M.G. and Kleber M. (2010) Dynamic molecular structure of plant-derived black carbon (biochar). *Environmental Science and Technology* 44:1247-1253.

Sevilla M. and Fuertes A.B. (2009a) Chemical and structural properties of carbonaceous products obtained by hydrothermal carbonization of saccharides. *Chemistry - A European Journal* 15:4195-4203.

Sevilla M. and Fuertes A.B. (2009b) The production of carbon materials by hydrothermal carbonization of cellulose. *Carbon* 47:2281–2289.

Spokas K.A. (2010) Review of the stability of biochar in soils: predictability of O:C molar ratios. *Carbon Management* 1:289-303.

Calvelo Pereira, R., Kaal, J., Camps Arbestain, M., Pardo Lorenzo, R., Aitkenhead, W., Hedley, M., Macías, F., Hindmarsh, J., Maciá-Agulló, J.A. (2011) Contribution to characterisation of biochar to estimate the labile fraction of carbon. *Organic Geochemistry* 42:1331–1342.

Appendix 8 – Glossary

List of Acronyms and Abbreviations

AOAC – Association of Analytical Communities

ASTM – ASTM International (formerly known as the American Society for Testing and Materials)

BNQ – Bureau de Normalisation du Quebec (a member of the National Standards System of Canada involved in developing product and process standards for Canadians)

C – Carbon

$CaCO_3$ – Calcium Carbonate

C_{org} – Organic Carbon

CCME – Canadian Council of Ministers of the Environment

CSIRO – Commonwealth Scientific and Industrial Research Organisation, Australia

dS – decisiemens

dS/m – decisiemens per meter

dry wt – dry weight

EC – Electrical Conductivity

EPA – Environmental Protection Agency, United States

EU – European Union

F – Polychlorinated Dibenzofuran (Furan)

g – gram

GHG – greenhouse gas

H – Hydrogen

HCl – hydrochloric acid

HMIS – Hazardous Materials Identification System

IBI – International Biochar Initiative

ICP – Inductively Coupled Plasma

IEEE – Institute of Electrical and Electronics Engineers

ISO – International Organization for Standardization

I-TEQ – International Toxicity Equivalent

K – Potassium

KCl – potassium chloride

kg – kilogram

m – meter

mg – milligram

M – molar

MAT – Maximum Allowed Threshold

MSDS – Material Safety Data Sheet

MSW – Municipal Solid Waste

N – Nitrogen

NEPC – National Environment Protection Council, Australia

ng – nanogram

OECD – Organisation for Economic Co-operation and Development

OMS – Office of Mobile Sources, division of US EPA

P – Phosphorus

PAH – Polycyclic Aromatic Hydrocarbon

PCB – Polychlorinated Biphenyl

PCDD – Polychlorinated Dibenzodioxin (Dioxin)

PCDD/F – Dioxins/Furans

POPs – Persistent Organic Pollutants

S – Siemens

S/m – Siemens per meter

SA – Surface Area

TMECC – Test Methods for the Examining of Composting and Compost (from US Composting Council and USDA)

USDA – United States Department of Agriculture

USGS – United States Geological Service

µg – microgram

Definition of Terms

Note: Terms and definitions have been adapted from the references given. Terms and definitions created specifically for this document are referenced as "IBI".

Ash: The inorganic matter, or mineral residue of total solids, that remains when a sample is combusted in the presence of excess air. (Adapted from US Composting Council and US Department of Agriculture, 2001)

Batch: 75 m^3 or 20 metric tonnes of biomass ash i.e., the quantity of biomass ash approximately equivalent to a tractor trailer load of material. (IBI, 2014)

Biochar: A solid material obtained from thermochemical conversion of biomass in an oxygen-limited environment. (IBI, 2012)

Biochar Characteristics: For the purposes of these standards, biochar characteristics are those physical or chemical properties of biochar that affect the following uses for biochar: 1) biochar that is added to soils with the intention to improve soil functions; and 2) biochar that is produced in order to reduce emissions from biomass that would otherwise naturally degrade to GHG, by converting a portion of that biomass into a stable carbon fraction that has carbon sequestration value. (IBI, 2012)

Biological Material: Material derived from, or produced by, living or recently living organisms. This material can be "unprocessed" or "processed". Unprocessed biological material is living material, or recently living material from the plant kingdom (or other non-animal taxa such as fungi) that may have been mechanically resized (such as wood chips), but has not been processed in an animal's body or gone through an anthropogenic chemical modification. Processed biological material is recently living material that has been chemically modified by anthropogenic or biological processes (e.g., paper sludge, manure). All animal products, including bones, offal, food-waste containing animal products, and animal manures are considered to be processed biological material. (IBI, 2012)

Biomass: The biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry, and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (including municipal solid waste). (Adapted from European Commission Agriculture and Rural Development, 2010)

Biomass Ash: Ash generated as a byproduct of energy generation in biomass-fueled furnaces or boilers. Biomass ash is subdivided into bottom ash and flyash. (IBI, 2014)

Bottom Ash: The component of biomass ash that falls to the bottom of the burner unit of a biomass-fueled furnace or boiler and that has a consistency of ash or a semi-solid slag material. (Oregon DEQ, 2011)

Clean Cellulosic Biomass: Those residuals that are akin to traditional cellulosic biomass such as forest-derived biomass (e.g., green wood, forest thinnings, clean and unadulterated bark, sawdust, trim, and tree harvesting residuals from logging and sawmill materials), corn stover and other biomass crops used specifically for energy production (e.g., energy cane, other fast growing grasses), bagasse and other crop residues (e.g., nut shells), wood collected from forest fire clearance activities, trees and clean wood found in disaster debris, clean biomass from land clearing operations, and clean construction and demolition wood. These fuels are not secondary materials or solid wastes unless discarded. Clean biomass is biomass that does not contain contaminants at concentrations not normally associated with virgin biomass materials. (US CFR, 2014)

Composite Sample: Grab samples from one source of biomass ash that are thoroughly mixed to produce a consistent sample. (IBI, 2014)

Contaminant: An undesirable material in a biochar material or biochar feedstock that compromises the quality or usefulness of the biochar or through its presence or concentration causes an adverse effect on the natural environment or impairs human use of the environment (adapted from Canadian Council of Ministers of the Environment, 2005). Contaminants include fossil fuels and fossil fuel-derived chemical compounds, glass, and metal objects. (IBI, 2012)

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. (IBI, 2012)

Dioxin: The term "dioxin" is commonly used to refer to a family of chemicals that share chemical structures and characteristics. These compounds include polychlorinated dibenzo dioxins (PCDDs) and polychlorinated dibenzo furans (PCDFs), which are unwanted by-products of industrial and natural processes, usually involving combustion. Dioxins are listed as Persistent Organic Pollutants by the Stockholm Convention. (IBI, 2012)

Feedstock: The material undergoing the thermochemical process to create biochar. Feedstock material for biochar consists of biological material, but may also contain diluents. (IBI, 2012)

Flyash: The lightest-weight component of biomass ash in a biomass-fueled furnace or boiler that rises with the flue gases and is captured by a boiler or incinerator's air contaminant control equipment. (Oregon DEQ, 2011)

Fossil Fuel-Derived Chemical Compounds: This category of contaminant includes any compound of a synthetic nature, created from hydrocarbons, including, but not limited to plastics, solvents, paints, resins, and tars. Because of the blending of wastes and use of synthetic materials to bind and label other materials (e.g. plastic flagging tape in forestry residues), fossil fuel-derived chemical compounds have become commonplace in multiple waste streams, and are often difficult to separate from feedstocks prior to processing. These contaminants can contain highly toxic chemicals like polychlorinated biphenyls (PCBs) that may act as bioaccumulators and affect the resulting quality of biochar. (IBI, 2012)

Grab Sample: An individual sample collected at a selected time. (IBI, 2014)

Hazardous Materials or Wastes: Potential environmental pollutants that, when concentrated, can be a source of regulatory concern for any use or application that may influence human or environmental health and wellbeing. (Adapted from US Composting Council and US Department of Agriculture, 2001)

IBI Biochar Certification Program: A voluntary, self-certifying, biochar certification program administered by the International Biochar Initiative that offers biochar manufacturers the opportunity to certify their biochar(s) as having met the minimum criteria established in the *IBI Biochar Standards*. For further information please visit http://www.biochar-international.org/certification. (IBI, 2013)

Heat Treatment Temperature: The temperature at which a feedstock material is processed during thermochemical conversion in a given thermochemical process. (IBI, 2013)

Manufacturer: The party or parties who process(es) feedstock materials into biochar, and submit(s) the biochar for testing according to these *IBI Biochar Standards*. (IBI, 2012)

Material Change: Changes in feedstock type (listed in Tables A6.1 and A6.2) or residence time of greater than 10%, or changes in heat treatment temperature of +/- 50°C. (IBI, 2013)

Municipal Waste/Municipal Solid Waste (MSW): solid non-hazardous refuse that originates from residential, industrial, commercial, institutional, demolition, land clearing, or construction sources (adapted from 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. (Adapted from US Environmental Protection Agency, 1995)

Organic Carbon: Biologically degradable carbon-containing compounds found in the organic fraction of biochar feedstocks. Biochar feedstocks can contain such compounds as sugars, starches, proteins, fats, cellulose, and lignocellulose, which are thermochemically degradable.

Other organic carbon forms can include petroleum and petroleum by-products such as plastics and contaminated oils, which are, for the purposes of these standards, included within the definition of contaminants, but may also be thermochemically degraded. The organic carbon fraction does not include inorganic carbonate concretions such as calcium and magnesium carbonates. (Adapted from US Composting Council and US Department of Agriculture, 2001)

Persistent Organic Pollutants (POPs): POPs are organic chemical substances, that is, they are carbon-based. They possess a particular combination of physical and chemical properties such that, once released into the environment, remain intact for exceptionally long periods of time (many years); become widely distributed throughout the environment as a result of natural processes involving soil, water and, most notably, air; accumulate in the fatty tissue of living organisms including humans, and are found at higher concentrations at higher levels in the food chain; and are toxic to both humans and wildlife. (Adapted from Stockholm Convention, 2012)

Policy revision: A revision to the *IBI Biochar Standards* that occurs when there is a substantive change to the policies, rules, and/or scope of that may change the eligibility or acceptability of a biochar material, and that results in the publication of a new version of the *IBI Biochar Standards*.

Polychlorinated biphenyls (PCBs): PCBs are a group of organic compounds used in the manufacture of plastics, as lubricants, and dielectric fluids in transformers, in protective coating for wood, metal and concrete, and in adhesives and wire coating. PCBs have been banned in most countries and are no longer manufactured, but sources remain in the environment in the form of products and waste. The Stockholm Convention lists PCBs as POPs. (IBI, 2012)

Polycyclic aromatic hydrocarbons (PAHs): PAHs refer to a family of compounds built from two or more benzene rings. Sources of PAHs include fossil fuels and incomplete combustion of organic matter, in auto engines, incinerators, forest fires, charcoal grilling, or other biomass burning. PAHs are usually found as a mixture containing two or more of these compounds, such as soot. Out of hundreds of different PAH compounds, only a few are considered to be highly toxic and of regulatory concern. (Adapted from USGS, 2012)

Post-processing: Any action undertaken by the biochar manufacturer to enhance, transform or otherwise alter the physicochemical properties of the biochar material after completion of the thermochemical conversion process. (IBI, 2014)

Processed Feedstock: Biomass that has gone through chemical processing (for example, paper pulp sludge) or biological processing (for example, digestion, such as manures and sludge from waste effluent treatment) beyond simple mechanical processing to modify physical properties. Because animals may bioaccumulate toxicants in their tissues, all animal parts and products are considered to be processed feedstocks for purposes of these guidelines. Any biomass material that may have been grown on soils contaminated with heavy metals or other toxicants will also be considered a processed feedstock for purposes of these guidelines. (IBI, 2012)

Residence Time: The time a feedstock is held within a consistent temperature range in a given thermochemical process. (IBI, 2012)

Residues: Secondary products derived from agricultural, forestry, food or industrial production and processing chains. (RSB, 2013)

Soil Functions: Soil functions include: "(i) biomass production, including in agriculture and forestry; (ii) storing, filtering and transforming nutrients, substances and water; (iii) hosting the biodiversity pool, such as habitats, species and genes; (iv) acting as a platform for human activities; (v) source of raw materials; (vi) acting as carbon pool; and (vii) storing geological and archeological heritage." (Adapted from European Commission COM, 2006)

Technical Note: A note issued by IBI to describe a time-sensitive technical program revision prior to the publication of a new sub-version of the *IBI Biochar Standards*.

Technical Program Revision: A revision to the *IBI Biochar Standards* that occurs when technical or editorial changes are deemed necessary, and resulting in the publication of a new sub-version of the *IBI Biochar Standards*.

Toxicants: Chemical or physical agents that, depending on dose, can produce adverse effects in biological organisms (adapted from Trush 2008). These chemicals may be essential for some plants and animals at low levels, or in a specific oxidation state, but can be toxic at higher concentrations or in a different oxidation state. Toxicants may be naturally present in soils or artificially produced by human activity. (Adapted from US EPA, 1999)

Unprocessed Feedstock: Biomass from the plant kingdom (or other non-animal taxa such as fungi), grown in a clean, uncontaminated environment, that may have gone through mechanical processing to change its physical properties (e.g., particle size), but has not gone through chemical processing or treatment, or biological processing (e.g., digestion). (IBI, 2012)

Volatile Matter: Those products, exclusive of moisture, given off by a material as a gas or vapor, determined by definite prescribed methods that may vary according to the nature of the material. (Adapted from Milne et al, 1990)

Weathering: Changes in biochar physicochemical properties due to precipitation, freeze-thaw cycles, fluctuations in temperature, deposition of atmospheric chemicals, and/or exposure to ambient air. (IBI, 2014)

References

Canadian Council of Ministers for the Environment (CCME) (2005) *Guidelines for Compost Quality*. PN 1340 Winnipeg Manitoba, Canada. ISBN 1-896997-60-0.

European Commission Agriculture and Rural Development (2010) *Biomass Potential* http://ec.europa.eu/agriculture/bioenergy/potential/index_en.htm (accessed September 2011).

European Commission COM (2006) *Establishing a Framework for the Protection of Soil and Amending Directive* 2004/35/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52006PC0232:en:NOT (accessed April 2013).

Milne, T.A.; Brennan, A.H.; Glenn, B.H. Sourcebook of Methods of Analysis for Biomass Conversion and Biomass Conversion Processes. SERI/SP-220-3548. Golden, CO: Solar Energy Research Institute, February 1990.Oregon Department of Environmental Quality. *Fact Sheet: Management of Wood Ash Generated from Biomass Combustion Facilities.* Updated 5/5/2011. http://www.deq.state.or.us/lq/pubs/factsheets/sw/ManagementWoodAshGenBiomassCombustionFac.pdf (Accessed November 2013).

Oregon Department of Environmental Quality. *Fact Sheet: Management of Wood Ash Generated from Biomass Combustion Facilities.* Updated 5/5/2011. http://www.deq.state.or.us/lq/pubs/factsheets/sw/ManagementWoodAshGenBiomassCombustionFac.pdf (Accessed November 2013)

RSB - Roundtable on Sustainable Biomaterials. (2013) *RSB-STD-01-010-ver.1.6-RSB Standard for end-of-life products, by-products and residues*. http://rsb.org/pdfs/standards/RSB-STD-01-010%20-%20ver%201.6%20RSB%20Standard%20on%20end-of-life-products,%20residues%20and%20by-products.pdf (Accessed April 2014).

Stockholm Convention. *What are POPs?* http://chm.pops.int/Convention/ThePOPs/tabid/673/Default.aspx (Accessed March 2012).

Trush, Michael A. *Adsorption, Distribution, and Excretion.* (2008) The Johns Hopkins University Johns Hopkins Bloomberg School of Public Health. http://ocw.jhsph.edu/courses/publichealthtoxicology/PDFs/Lecture1_Trush.pdf

US Code of Federal Regulations, 40 CFR § 241.2

US Composting Council and US Department of Agriculture (2001) *Test methods for the examination of composting and compost. (TMECC)* Thompson W.H. (ed.) http://compostingcouncil.org/tmecc/ (Accessed January 2012).

US Environmental Protection Agency (1999) *Background report on fertilizer use, contaminants and regulations.* Prepared by BATELLE, Columbus OH. National Program Chemicals Division; Office of Pollution Prevention and Toxics, Washington D.C. http://www.epa.gov/oppt/pubs/fertilizer.pdf, via http://www.epa.gov/agriculture/tfer.html. (Accessed February 2012).

US Environmental Protection Agency (1995) *Characterization of Municipal Solid Waste in the United States: 1995 Update.* http://www.epa.gov/osw/nonhaz/municipal/pubs/msw95.pdf (Accessed April 2013).

US Geological Service. *Polynuclear Aromatic Hydrocarbons (PAHs)/Polycyclic Aromatic Hydrocarbons (PAHs)* http://toxics.usgs.gov/definitions/pah.html (Accessed March 2012).

Appendix 9 – Creative Commons License

Creative Commons Legal Code

Attribution-NonCommercial-NoDerivs 3.0 Unported

CREATIVE COMMONS CORPORATION IS NOT A LAW FIRM AND DOES NOT PROVIDE LEGAL SERVICES. DISTRIBUTION OF THIS LICENSE DOES NOT CREATE AN ATTORNEY-CLIENT RELATIONSHIP. CREATIVE COMMONS PROVIDES THIS INFORMATION ON AN "AS-IS" BASIS. CREATIVE COMMONS MAKES NO WARRANTIES REGARDING THE INFORMATION PROVIDED, AND DISCLAIMS LIABILITY FOR DAMAGES RESULTING FROM ITS USE.

License

THE WORK (AS DEFINED BELOW) IS PROVIDED UNDER THE TERMS OF THIS CREATIVE COMMONS PUBLIC LICENSE ("CCPL" OR "LICENSE"). THE WORK IS PROTECTED BY COPYRIGHT AND/OR OTHER APPLICABLE LAW. ANY USE OF THE WORK OTHER THAN AS AUTHORIZED UNDER THIS LICENSE OR COPYRIGHT LAW IS PROHIBITED.

BY EXERCISING ANY RIGHTS TO THE WORK PROVIDED HERE, YOU ACCEPT AND AGREE TO BE BOUND BY THE TERMS OF THIS LICENSE. TO THE EXTENT THIS LICENSE MAY BE CONSIDERED TO BE A CONTRACT, THE LICENSOR GRANTS YOU THE RIGHTS CONTAINED HERE IN CONSIDERATION OF YOUR ACCEPTANCE OF SUCH TERMS AND CONDITIONS.

1. Definitions

a. "Adaptation" means a work based upon the Work, or upon the Work and other pre-existing works, such as a translation, adaptation, derivative work, arrangement of music or other alterations of a literary or artistic work, or phonogram or performance and includes cinematographic adaptations or any other form in which the Work may be recast, transformed, or adapted including in any form recognizably derived from the original, except that a work that constitutes a Collection will not be considered an Adaptation for the purpose of this License. For the avoidance of doubt, where the Work is a musical work, performance or phonogram, the synchronization of the Work in timed- relation with a moving image ("synching") will be considered an Adaptation for the purpose of this License.

b. "Collection" means a collection of literary or artistic works, such as encyclopedias and anthologies, or performances, phonograms or broadcasts, or other works or subject matter other than works listed in Section 1(f) below, which, by reason of the selection and arrangement of their contents, constitute intellectual creations, in which the Work is included in its entirety in unmodified form along with one or more other contributions, each constituting separate and independent works in themselves, which together are assembled into a collective whole. A work that constitutes a Collection will not be considered an Adaptation (as defined above) for the purposes of this License.

c. "Distribute" means to make available to the public the original and copies of the Work through sale or other transfer of ownership.

d. "Licensor" means the individual, individuals, entity or entities that offer(s) the Work under the terms of this License.

e. "Original Author" means, in the case of a literary or artistic work, the individual, individuals, entity or entities who created the Work or if no individual or entity can be identified, the publisher; and in addition (i) in the case of a performance the actors, singers, musicians, dancers, and other persons who act, sing, deliver, declaim, play in, interpret or otherwise perform literary or artistic works or expressions of folklore; (ii) in the case of a phonogram the producer being the person or legal entity who first fixes the sounds of a performance or other sounds; and, (iii) in the case of broadcasts, the organization that transmits the broadcast.

f. "Work" means the literary and/or artistic work offered under the terms of this License including without limitation any production in the literary, scientific and artistic domain, whatever may be the mode or form of its expression including digital form, such as a book, pamphlet and other writing; a lecture, address, sermon or other work of the same nature; a dramatic or dramatico-musical work; a choreographic work or entertainment in dumb show; a musical composition with or without words; a cinematographic work to which are assimilated works expressed by a process analogous to cinematography; a work of drawing, painting, architecture, sculpture, engraving or lithography; a photographic work to which are assimilated works expressed by a process analogous to photography; a work of applied art; an illustration, map, plan, sketch or three-dimensional work relative to geography, topography, architecture or science; a performance; a broadcast; a phonogram; a compilation of data to the extent it is protected as a copyrightable work; or a work performed by a variety or circus performer to the extent it is not otherwise considered a literary or artistic work.

g. "You" means an individual or entity exercising rights under this License who has not previously violated the terms of this License with respect to the Work, or who has received express permission from the Licensor to exercise rights under this License despite a previous violation.

h. "Publicly Perform" means to perform public recitations of the Work and to communicate to the public those public recitations, by any means or process, including by wire or wireless means or public digital performances; to make available to the public Works in such a way that members of the public may access these Works from a place and at a place individually chosen by them; to perform the Work to the public by any means or process and the communication to the public of the performances of the Work, including by public digital performance; to broadcast and rebroadcast the Work by any means including signs, sounds or images.

i. "Reproduce" means to make copies of the Work by any means including without limitation by sound or visual recordings and the right of fixation and reproducing fixations of the Work, including storage of a protected performance or phonogram in digital form or other electronic medium.

2. Fair Dealing Rights. Nothing in this License is intended to reduce, limit, or restrict any uses free from copyright or rights arising from limitations or exceptions that are provided for in connection with the copyright protection under copyright law or other applicable laws.

3. License Grant. Subject to the terms and conditions of this License, Licensor hereby grants You a worldwide, royalty-free, non-exclusive, perpetual (for the duration of the applicable copyright) license to exercise the rights in the Work as stated below:

a. to Reproduce the Work, to incorporate the Work into one or more Collections, and to Reproduce the Work as incorporated in the Collections; and,

b. to Distribute and Publicly Perform the Work including as incorporated in Collections.

The above rights may be exercised in all media and formats whether now known or hereafter devised. The above rights include the right to make such modifications as are technically necessary to exercise the rights in other media and formats, but otherwise you have no rights to make Adaptations. Subject to 8(f), all rights not expressly granted by Licensor are hereby reserved, including but not limited to the rights set forth in Section 4(d).

4. Restrictions. The license granted in Section 3 above is expressly made subject to and limited by the following restrictions:

b. You may Distribute or Publicly Perform the Work only under the terms of this License. You must include a copy of, or the Uniform Resource Identifier (URI) for, this License with every copy of the Work You Distribute or Publicly Perform. You may not offer or impose any terms on the Work that restrict the terms of this License or the ability of the recipient of the Work to exercise the rights granted to that recipient under the terms of the License. You may not sublicense the Work. You must keep intact all notices that refer to this License and to the disclaimer of warranties with every copy of the Work You Distribute or Publicly Perform. When You Distribute or Publicly Perform the Work, You may not impose any effective technological measures on the Work that restrict the ability of a recipient of the Work from You to exercise the rights granted to that recipient under the terms of the License. This Section 4(a) applies to the Work as incorporated in a Collection, but this does not require the Collection apart from the Work itself to be made subject to the terms of this License. If You create a Collection, upon notice from any Licensor You must, to the extent practicable, remove from the Collection any credit as required by Section 4(c), as requested.

c. You may not exercise any of the rights granted to You in Section 3 above in any manner that is primarily intended for or directed toward commercial advantage or private monetary compensation. The exchange of the Work for other copyrighted works by means of digital file-sharing or otherwise shall not be considered to be intended for or directed toward commercial advantage or private monetary compensation, provided there is no payment of any monetary compensation in connection with the exchange of copyrighted works.

d. If You Distribute, or Publicly Perform the Work or Collections, You must, unless a request has been made pursuant to Section 4(a), keep intact all copyright notices for the Work and provide, reasonable to the medium or means You are utilizing: (i) the name of the

Original Author (or pseudonym, if applicable) if supplied, and/or if the Original Author and/or Licensor designate another party or parties (e.g., a sponsor institute, publishing entity, journal) for attribution ("Attribution Parties") in Licensor's copyright notice, terms of service or by other reasonable means, the name of such party or parties; (ii) the title of the Work if supplied; (iii) to the extent reasonably practicable, the URI, if any, that Licensor specifies to be associated with the Work, unless such URI does not refer to the copyright notice or licensing information for the Work. The credit required by this Section 4(c) may be implemented in any reasonable manner; provided, however, that in the case of a Collection, at a minimum such credit will appear, if a credit for all contributing authors of Collection appears, then as part of these credits and in a manner at least as prominent as the credits for the other contributing authors. For the avoidance of doubt, You may only use the credit required by this Section for the purpose of attribution in the manner set out above and, by exercising Your rights under this License, You may not implicitly or explicitly assert or imply any connection with, sponsorship or endorsement by the Original Author, Licensor and/or Attribution Parties, as appropriate, of You or Your use of the Work, without the separate, express prior written permission of the Original Author, Licensor and/or Attribution Parties.

a. For the avoidance of doubt:

i. Non-waivable Compulsory License Schemes. In those jurisdictions in which the right to collect royalties through any statutory or compulsory licensing scheme cannot be waived, the Licensor reserves the exclusive right to collect such royalties for any exercise by You of the rights granted under this License;

ii. Waivable Compulsory License Schemes. In those jurisdictions in which the right to collect royalties through any statutory or compulsory licensing scheme can be waived, the Licensor reserves the exclusive right to collect such royalties for any exercise by You of the rights granted under this License if Your exercise of such rights is for a purpose or use which is otherwise than noncommercial as permitted under Section 4(b) and otherwise waives the right to collect royalties through any statutory or compulsory licensing scheme; and,

iii. Voluntary License Schemes. The Licensor reserves the right to collect royalties, whether individually or, in the event that the Licensor is a member of a collecting society that administers voluntary licensing schemes, via that society, from any exercise by You of the rights granted under this License that is for a purpose or use which is otherwise than noncommercial as permitted under Section 4(b).

b. Except as otherwise agreed in writing by the Licensor or as may be otherwise permitted by applicable law, if You Reproduce, Distribute or Publicly Perform the Work either by itself or as part of any Collections, You must not distort, mutilate, modify or take other derogatory action in relation to the Work which would be prejudicial to the Original Author's honor or reputation.

5. Representations, Warranties and Disclaimer

UNLESS OTHERWISE MUTUALLY AGREED BY THE PARTIES IN WRITING, LICENSOR OFFERS THE WORK AS-IS AND MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND

CONCERNING THE WORK, EXPRESS, IMPLIED, STATUTORY OR OTHERWISE, INCLUDING, WITHOUT LIMITATION, WARRANTIES OF TITLE, MERCHANTIBILITY, FITNESS FOR A PARTICULAR PURPOSE, NONINFRINGEMENT, OR THE ABSENCE OF LATENT OR OTHER DEFECTS, ACCURACY, OR THE PRESENCE OF ABSENCE OF ERRORS, WHETHER OR NOT DISCOVERABLE. SOME JURISDICTIONS DO NOT ALLOW THE EXCLUSION OF IMPLIED WARRANTIES, SO SUCH EXCLUSION MAY NOT APPLY TO YOU.

6. Limitation on Liability. EXCEPT TO THE EXTENT REQUIRED BY APPLICABLE LAW, IN NO EVENT WILL LICENSOR BE LIABLE TO YOU ON ANY LEGAL THEORY FOR ANY SPECIAL, INCIDENTAL, CONSEQUENTIAL, PUNITIVE OR EXEMPLARY DAMAGES ARISING OUT OF THIS LICENSE OR THE USE OF THE WORK, EVEN IF LICENSOR HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

7. Termination

a. This License and the rights granted hereunder will terminate automatically upon any breach by You of the terms of this License. Individuals or entities who have received Collections from You under this License, however, will not have their licenses terminated provided such individuals or entities remain in full compliance with those licenses. Sections 1, 2, 5, 6, 7, and 8 will survive any termination of this License.

b. Subject to the above terms and conditions, the license granted here is perpetual (for the duration of the applicable copyright in the Work). Notwithstanding the above, Licensor reserves the right to release the Work under different license terms or to stop distributing the Work at any time; provided, however that any such election will not serve to withdraw this License (or any other license that has been, or is required to be, granted under the terms of this License), and this License will continue in full force and effect unless terminated as stated above.

8. Miscellaneous

a. Each time You Distribute or Publicly Perform the Work or a Collection, the Licensor offers to the recipient a license to the Work on the same terms and conditions as the license granted to You under this License.

b. If any provision of this License is invalid or unenforceable under applicable law, it shall not affect the validity or enforceability of the remainder of the terms of this License, and without further action by the parties to this agreement, such provision shall be reformed to the minimum extent necessary to make such provision valid and enforceable.

c. No term or provision of this License shall be deemed waived and no breach consented to unless such waiver or consent shall be in writing and signed by the party to be charged with such waiver or consent.

d. This License constitutes the entire agreement between the parties with respect to the Work licensed here. There are no understandings, agreements or representations with respect to the Work not specified here. Licensor shall not be bound by any additional provisions that may appear in any communication from You. This License may not be modified without the mutual written agreement of the Licensor and You.

e. The rights granted under, and the subject matter referenced, in this License were drafted utilizing the terminology of the Berne Convention for the Protection of Literary and Artistic Works (as amended on September 28, 1979), the Rome Convention of 1961, the WIPO Copyright Treaty of 1996, the WIPO Performances and Phonograms Treaty of 1996 and the Universal Copyright Convention (as revised on July 24, 1971). These rights and subject matter take effect in the relevant jurisdiction in which the License terms are sought to be enforced according to the corresponding provisions of the implementation of those treaty provisions in the applicable national law. If the standard suite of rights granted under applicable copyright law includes additional rights not granted under this License, such additional rights are deemed to be included in the License; this License is not intended to restrict the license of any rights under applicable law.

Creative Commons Notice

Creative Commons is not a party to this License, and makes no warranty whatsoever in connection with the Work. Creative Commons will not be liable to You or any party on any legal theory for any damages whatsoever, including without limitation any general, special, incidental or consequential damages arising in connection to this license. Notwithstanding the foregoing two (2) sentences, if Creative Commons has expressly identified itself as the Licensor hereunder, it shall have all rights and obligations of Licensor.

Except for the limited purpose of indicating to the public that the Work is licensed under the CCPL, Creative Commons does not authorize the use by either party of the trademark "Creative Commons" or any related trademark or logo of Creative Commons without the prior written consent of Creative Commons. Any permitted use will be in compliance with Creative Commons' then-current trademark usage guidelines, as may be published on its website or otherwise made available upon request from time to time. For the avoidance of doubt, this trademark restriction does not form part of this License.

Creative Commons may be contacted at http://creativecommons.org.