A *Methodology for Biochar Projects* was prepared by The Climate Trust, the Prasino Group, and the International Biochar Initiative. Following public consultation, the methodology was submitted to a team of expert peer reviewers. Their review comments and the corresponding responses are summarized below.

Note to reviewers: This template is organized by section of the methodology/module. Please insert your review comments in the table for that section. In the first round of review, all peer reviewers should insert their comments in the first column, leaving the second column for methodology author responses. This will be followed by an abbreviated second round of review in which the reviewers comment on the authors' responses and methodology revisions, followed by a second round of responses from the authors.

Please add rows to each table as needed.

The numbering in the far left column of each table does not refer to sections in the methodology/module; it is only for tracking comments by number.

Overall comments on the methodology / module

	1st review	Response	2nd review	Response
0.1	This protocol is promoting the potential use of biochar amended soil as a means of carbon sequestration. The overall impression is that the science is not at a level yet to recommend that this methodology be accepted. There are numerous problems that should be addressed based on the estimation – in particular research is needed on the other pathways of degradation that are occurring as well in the field setting: physical and chemical degradation.	Ongoing research further validates the conservativeness of the test method to estimate biochar stability in the soil (BC+100) and the state of understanding of biochar persistence in soils, in general. Particularly, in a review of papers evaluating the persistence of carbon in soils, Lehmann et al (2014) used a global data set of both field and laboratory experiments and found that the measured mean residence time (MRT) of biochars with H/Corg ratios below 0.48 consistently exceeded 1000 years, and that 90% of the initial carbon would remain after 100 years. The authors conclude that charring of biomass significantly decreases the mineralization (transformation from organic carbon to CO2) of the biomass by at least one	The responses from the authors only are supporting the rates for microbial and chemical degradation – This is not being disputed by the reviewer. The main issue is the protocol does not address the physical degradation and alternative degradation mechanisms (e.g., water dissolution, freeze/thaw mechanical fragmentation, and UV photo-oxidation). These are known substantial mechanisms of biochar (black carbon) disappearance from soils. We know biochar degrades in the environment. If the biochar remained in the laboratory serum bottles, then it might still be there in 100 years. Once biochar is mixed with soil, nature is very brutal and the physical weathering forces degrade	We concur with the referee that biochar is degrading and mineralizes to carbon dioxide in the environment. This has not been disputed and is indeed the basis for the proposed methodology: to establish over what time frame how much of the biochar will mineralize to carbon dioxide. And we are pleased to hear that the referee concurs with the assertion of the methodology that biologically driven mineralization of biochar is adequately described by the H/Corg ratio. Regarding the concern that physical and chemical degradation increases

	1st review	Response	2nd review	Response
		and a half orders of magnitude under otherwise identical environmental conditions, such as moisture, temperature, soil mineralogy and the decomposer community. Please review Lehmann et al (2014) for a thorough discussion of potential decomposition pathways of biochar based on the existing peer reviewed literature on this topic.	every structure – even rock which has mechanical strengths well above charcoal – degrades under these forces. Charcoal degrades every time you touch it with your fingers – since you get fragments on your fingers– The amount that fragments on your fingers is often more mass that the microbial degradation potentials per year. To use the historic records of black carbon being found in the soil environment of >1000 years is not very informative, we have no idea of the initial concentration of charcoal, so no accurate assessment of disappearance rates can be made. The conditions of degradation are going to be a function of the physical state the charcoal -- clay encased charcoal is not subject to the same	"disappearance": it is important to clearly distinguish between "mineralization" (the term used to describe the transformation of organic materials to carbon dioxide), "degradation" (transformation to other organic forms without carbon dioxide losses, which includes surface oxidation, diminution, metabolization to microbial debris, etc), and "disappearance" which includes apart from "mineralization" also the physical movement. Only "mineralization" is relevant in the context of a carbon trading protocol. All other processes, while important in many other ways, do not generate carbon

	1st review	Response	2nd review	Response
			degradation forces as unprotected charcoal. Therefore, how do you account for these mechanisms? These have been observed to be significantly greater than microbial degradation rates, with this dissolution accounting for >50% mass loss estimates –see: Braadbaart, F., Poole, I., & Van Brussel, A. A. (2009). Preservation potential of charcoal in alkaline environments: an experimental approach and implications for the archaeological record. Journal of archaeological science, 36(8), 1672-1679. Wang, D., Zhang, W., Hao, X., Zhou, D., 2012. Transport of Biochar Particles in Saturated Granular Media: Effects of Pyrolysis	dioxide (considering the interactions discussed below). Here follows a discussion of the different processes other than biological mineralization that is not disputed by this referee comment: “Degradation”: (i) physical diminution/mechanical strength: we concur with the referee that biochars can be mechanically impacted and typically decrease in size over time (Nguyen et al, 2008). It is important to realize, however, that this does **not** mean that carbon is lost to the atmosphere as carbon dioxide, the biochar carbon is still in the soil, even if in smaller

	1st review	Response	2nd review	Response
			Temperature and Particle Size. Environ. Sci. Technol. 47, 821-828. Biochar typically is thought to be mechanically stronger than the original biomass, but is subject to structural fracturing at lower strains than the original biomass (Byrne and Nagle, 1997). Ding Y, Yamashita Y, Dodds W, Jaffe´ R (2013) Dissolved black carbon in grassland streams: is there an effect of recent fire history? Chemosphere 90(10):2557–2562 If you add these other mechanisms – the science is not at a level yet where the survival percentage of charcoal in soil can be predicted with any sense of accuracy. All the limits and amounts of	particles. Smaller particles may react differently than larger particles: (a) one may expect that biological mineralization increases with smaller particle sizes (Zimmerman et al., 2010 Abiotic and microbial oxidation of laboratory-produced black carbon (biochar). Environ. Sci. Technol. 44:1295-1301.); however, a smaller particle size does not mean the H/Corg ratio changes, the microorganisms still require the same activation energy to metabolize the biochar (this is also not disputed by the referee; this may differ for the easily non-fused aromatic portion of biochar that bears

	1st review	Response	2nd review	Response
			certainty in the protocol are arbitrary (Table A2-2 – The conservative nature is not been proven, it is assumed). UV exposure can also degrade charcoal (Gallo et al., 2006) – so biochar on the surface will experience more aggressive weathering than buried pieces – so if soil is tilled annually or biannually this will impact the rate of disappearance as well. Gallo ME, Sinsabaugh RL, Cabaniss SE (2006) The role of ultraviolet radiation in litter decomposition in arid ecosystems. Appl Soil Ecol 34:82–91 Not to mention how the changes in surface albedo should also be included in this analysis – reducing the climate mitigation by 13-20% in existing modeling	high H/Corg ratios). In contrast, one may even expect that smaller particles increase the opportunities for the biochar to interact with clay mineral surfaces and be incorporated into aggregates, both processes clearly leading to lower, not higher, mineralization (e.g., Six et al., 2000 and many more for all organic matter additions. Specific to biochar, Bruun et al, 2013 found lower biochar mineralization when clay content of the soil increased; Fang et al, 2014, and Santos et al, 2012 all found lower mineralization when more reactive clay minerals were present in soil, known to

	1st review	Response	2nd review	Response
			studies: See: Frank, G.A.V., Simon, J., Marijn van der, V., Vít, P., Martin, B., Ana Catarina, B., Jan Jacob, K., 2013. Reductions in soil surface albedo as a function of biochar application rate: implications for global radiative forcing. Environmental Research Letters 8, 044008. Meyer, S., Bright, R. M., Fischer, D., Schulz, H., & Glaser, B. (2012). Albedo impact on the suitability of biochar systems to mitigate global warming. Environmental science & technology, 46(22), 12726-12734. So not only is there uncertainty in the prediction of the lifetime in the soil environment, there is also uncertainty over the indirect	interact with organic carbon. This interaction decreases as biochar particle size increases, then becoming dominantly found as particulate organic matter (Murage et al., Herath et al., 2014), (b) one may expect smaller particles to be exposed to greater abiotic oxidation (by water, accelerated by greater temperature, UV etc), which is likely to often be the case (with the caveat mentioned in (a)); see (ii) for discussion. (c) one may expect smaller particles to be more mobile (as mentioned by the referee), and we agree with that; please see the section “movement” below for further discussion on

	1st review	Response	2nd review	Response
			secondary impacts of dissolved biochar and alteration in surface energy balances that need to be considered more strongly in the methodology.	what that means for carbon dioxide evolution. (ii) Oxidation: Abiotic oxidation of biochar surfaces (through action of water, temperature) is indeed typically found. However, this process does not lead to production of carbon dioxide per se, and has been found to be restricted to the surfaces of biochars even over millennial time scales (Lehmann et al., 2005; Cheng et al., 2006, 2008; Liang et al., 2006, 2008, 2013). (iii) UV oxidation: UV oxidation has indeed been found to lead to carbon dioxide evolution of uncharred litter (e.g., as cited by

	1st review	Response	2nd review	Response
				the referee: Gallo et al; please mark that this experiment does NOT involve charcoal, char or biochar, but uncharred litter; a clear misrepresentation of the study by the referee). There is no scientific basis for a substantial (if any) carbon dioxide loss of biochar through UV oxidation for the following reasons: (1) the biochar is not (in contrast to plant litter in natural ecosystems, such as the cited Gallo study) present as a layer on the soil surface, but incorporated into the soil as a soil amendment, largely preventing UV exposure from the sun; (2) char/biochar/charcoal

	1st review	Response	2nd review	Response
				has been defined as the material that is resistant to oxidation, and one of the oxidative procedures uses UV (e.g., Skjemstad et al., 1996; Hammes et al., 2007); therefore, biochar/char/charcoal explicitly is a material resistant to UV radiation, amply proven to quantitatively remain in soil for decades, even with regular tillage and under intense sun (Skjemstad et al., 2004). "Movement": Physical movement, while certainly occurring as for any soil amendment, does per se **not** lead to carbon dioxide return to the atmosphere (which is

	1st review	Response	2nd review	Response
				what matters for this methodology). One may hypothesize that movement of biochar may increase its mineralization to carbon dioxide: however, no scientific evidence exists that this is actually the case, while an overwhelming body of literature on soil organic carbon and biochar/char/charcoal exists that suggests the opposite: erosion has been found to reduce carbon dioxide evolution and increase landscape carbon sequestration of any soil carbon (including char/charcoal/biochar) (van Oost et al., 2007; Quinton et al., 2010). Similarly, leaching into subsoils is a well-known mechanism that leads to lower

	1st review	Response	2nd review	Response
				rather than greater mineralization (Lorenz and Lal, 2005; Fontaine et al., 2007). Additional data have been reviewed and are in press that support the BC+100 methodology in *J. Lehmann, S. Abiven, M. Kleber, G. Pan, B.P. Singh, S. Sohi, A. Zimmerman. Persistence of biochar in soil. In: Biochar for Environmental Management - Science and Technology, 2nd edition. Johannes Lehmann and Stephen Joseph (eds.). Earthscan*: The data that relate the H/Corg ratios with the amount of biochar after 100 years do include both physical diminution, chemical oxidation as well as biological

	1st review	Response	2nd review	Response
				mineralization (they do not include physical movement, but as outlined above, this is irrelevant for the purpose of a carbon protocol that is only interested in whether the carbon is returned to the atmosphere or not; i.e., it is irrelevant where the carbon is, as long as it is not returned to the atmosphere), for the following reasons: (A) the data include field research over multiple years; (B) the biochar was in most of the studies ground to a very small size (especially in all incubation trials) that is similar to the sizes of biochars present in soil after hundreds to thousands of years, already pre-empting the effects of any

	1st review	Response	2nd review	Response
				diminution. If diminution leads as a net effect to greater carbon dioxide return (if this is at all the case, see arguments above on the effects of diminution on carbon dioxide evolution), then this will have been fully considered in the data that are used to establish the relationship between H/Corg and BC+100. Additional responses to the various points made by the referee under Section 0.1: - The referee substantiates the assertion that physical and chemical processes lead to large carbon dioxide losses by citing >50% loss with

	1st review	Response	2nd review	Response
				Braadbaart et al. (2009): (i) Braadbaart et al do not measure carbon dioxide evolution at all; (ii) the observed changes in a certain size class in highly alkaline soils (pH>8.5), which is not to be equated to carbon dioxide losses and is not an agricultural soil, but an archaeological setting. - The referee mentions albedo (which appears to be a mission creep, as the arguments in

	1st review	Response	2nd review	Response
				this Section 0.1 did originally not pertain to albedo), and we agree that albedo has to be evaluated. The cited studies by Meyer et al and Verheijen et al found very little changes in albedo even with an application rate that would exceed application rates likely to be used, unless the biochar was not incorporated into the soil. The studies also do not compare albedo with business as

	1st review	Response	2nd review	Response
				usual when uncharred organic matter is added to soil (any organic additions will change the albedo; if albedo changes are not considered in soil carbon trading methodologies, this must be consistently applied). In general, measurements of albedo changes of soil ignore the fact that plants will cover the soil for all or most periods of the year and that plant growth, water and energy budget

	1st review	Response	2nd review	Response
				change with different soil carbon contents, making measurements of soil albedo alone an interesting but not sufficient assessment of albedo of land surfaces. **References**: Bruun, S., Clauson-Kaas, S., Bubolska, L. and Thomsen, I. K. (2013) 'Carbon dioxide emissions from biochar in soil: role of clay, microorganisms and carbonates', *European Journal of Soil Science,* vol 65, pp 52–59 Cheng, C. H., Lehmann, J., Thies, J. E., Burton, S. D. and Engelhard, M. H. (2006) 'Oxidation of black carbon by biotic and abiotic processes', *Organic Geochemistry*, vol 37,

	1st review	Response	2nd review	Response
				pp1477-1488 Cheng CH, Lehmann J and Engelhard M 2008 Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. *Geochimica et Cosmochimica Acta* 72: 1598-1610. Fang, Y., Singh, B., Singh, B. P. and Krull, E. (2014) 'Biochar carbon stability in four contrasting soils', *European Journal of Soil Science*, vol 65, pp60–71 Fontaine, S., Barot, S., Barré, P., Bdioui, N., Mary, B., & Rumpel, C. (2007). Stability of organic carbon in deep soil layers controlled by fresh carbon supply. *Nature*, *450*(7167), 277-280. Hammes, K., Schmidt, M. W. I., Smernik, R. J., Lloyd, A., Currie, W. P., Nguyen, H., Louchouarn, P., Houel, S., Gustafsson, Ö., Elmquist, M., Cornelissen, G., Skjemstad, J. O., Masiello, C. A., Song, J. , Peng, P., Mitra, S., Dunn, J. C.,

	1st review	Response	2nd review	Response
				Hatcher, P. G., Hockaday, W. C., Smith, D. M., Hartkopf-Fröder, C., Böhmer, A., Lüer, B., Huebert, B. J., Amelung, W., Brodowski, S., Huang, L., Zhang, W., Gschwend, P. M., Flores-Cervantes, D. X., Largeau, C. R. J. N., Rumpel, C., Guggenberger, G., Kaiser, K., Rodionov, A., Gonzalez-Vila, F. J., Gonzalez-Perez, J. A., de la Rosa, J. M., Manning, D. A. C., López-Capél, E. and Ding, L. (2007) 'Comparison of quantification methods to measure fire-derived (black/elemental) carbon in soils and sediments using reference materials from soil, water, sediment and the atmosphere', *Global Biogeochemical Cycles,* vol 21, GB3016 Herath, H.M.S.K., M. Camps Arbestain, M. Hedley, R. Van Hale, J. Kaal. 2014a. Fate of biochar in chemically- and physically-defined soil organic carbon pools. Organic Geochemistry 73:35-46. Lehmann J, Liang B, Solomon D, Lerotic M,

	1st review	Response	2nd review	Response
				Luizão F, Kinyangi F, Schäfer T, Wirick S, and Jacobsen C 2005 Near-edge X-ray absorption fine structure (NEXAFS) spectroscopy for mapping nano-scale distribution of organic carbon forms in soil: application to black carbon particles. *Global Biogeochemical Cycles* 19: GB1013. Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J. O., Thies, J., Luizão, F. J., Petersen, J. and Neves, E. G. (2006) 'Black carbon increases cation exchange capacity in soils', *Soil Science Society of America Journal*, vol 70, pp1719-1730 Liang, B., Lehmann, J., Solomon, D., Sohi, S., Thies, J. E., Skjemstad, J. O., Luizão, F. J., Engelhard, M. H., Neves, E. G. and Wirick, S. (2008) 'Stability of biomass-derived black carbon in soils', *Geochimica et Cosmochimica Acta*, vol 72, pp6069-6078 Liang B, Wang CH, Solomon

	1st review	Response	2nd review	Response
				D, Kinyangi J, Luizão FJ, Wirick S, Skjemstad JO and Lehmann J 2013 Oxidation is key for black carbon surface functionality and nutrient retention in Amazon Anthrosols. *British Journal of Environment and Climate Change* 3: 9-23. Lorenz, K., & Lal, R. (2005). The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. *Advances in agronomy*, *88*, 35-66. Murage, E.W., P. Voroney, R.P. Beyaert. 2007. Turnover of carbon in the free light fraction with and without charcoal as determined using the 13C natural abundance method. Geoderma 138:133-143. Nguyen B, Lehmann J, Kinyangi J, Smernik R, Riha, SJ and Engelhard MH 2008 Long-term black carbon dynamics in cultivated soil. *Biogeochemistry* 89: 295-308.

	1st review	Response	2nd review	Response
				Quinton, J. N., Govers, G., Van Oost, K., & Bardgett, R. D. (2010). The impact of agricultural soil erosion on biogeochemical cycling. *Nature Geoscience*, *3*(5), 311-314. Santos, F., Torn, M. S. and Bird, J. A. (2012) 'Biological degradation of pyrogenic organic matter in temperate forest soils', *Soil Biology and Biochemistry*, vol 51, pp115-124 Six, J. A. E. T., E. T. Elliott, and Keith Paustian. "Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture." *Soil Biology and Biochemistry* 32.14 (2000): 2099-2103. Skjemstad, J. O., Clarke, P., Taylor, J. A., Oades, J. M. and McClure, S. G. (1996) 'The chemistry and nature of protected carbon in soil', *Australian Journal of Soil Research*, vol 34, pp251–271 Skjemstad, J. O., Spouncer, L. R., Cowie, B. and Swift, R.

	1st review	Response	2nd review	Response
				S. (2004) ‘Calibration of the Rothamsted organic carbon turnover model (RothC ver. 26.3), using measurable soil organic carbon pools’, *Australian Journal of Soil Research*, vol 42, pp79–88 Van Oost, K., Quine, T. A., Govers, G., De Gryze, S., Six, J., Harden, J. W., ... & Merckx, R. (2007). The impact of agricultural soil erosion on the global carbon cycle. *Science*, *318*(5850), 626-629.
0.2	The authors comments about the “fragments” of biochar as DOC not being important due to the fact that they are “still stable” are completely ignoring the documented effects of this nano-scale material on plant growth (Khodakovskaya et al., 2012) as well as the risks of these nano-scale charcoal fragments in the water and other ecosystems (Nowack and Bucheli, 2007).	Please provide more information for us to respond to. There is no instance of the word "fragment" in the methodology, nor "nano-scale", nor "still stable".	Charcoal is not mechanically strong and it fragments readily. This break-down is accelerated by water, UV, and freeze/thaw – everything that the biochar will experience in the soil as this method proposes. You state on page 122 –	A response to the notion that physical fragmentation increases carbon dioxide evolution to the atmosphere has been provided as part of Section 0.1 above. All points made by the referee here are either

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			"There is a small risk of losing C to the atmosphere from Biochar which has been exported through the mobilization of Biochar C into pyrogenic dissolved organic C (DOC)." However, this is not supported by the known studies – The proper terminology for this is dissolved black carbon (DBC). Abiven, S., Hengartner, P., Schneider, M.P.W., Singh, N., Schmidt, M.W.I., 2011. Pyrogenic carbon soluble fraction is larger and more aromatic in aged charcoal than in fresh charcoal. Soil Biol. Biochem. 43, 1615-1617. Stubbins, A., Niggemann, J., & Dittmar, T. (2012). Photo-lability of deep ocean dissolved black carbon. Biogeosciences, 9(5), 1661-	not relevant to the question of carbon dioxide return to the atmosphere or scientifically not defensible. In detail: - Abiven et al demonstrate in their study that a miniscule amount of biochar carbon (<0.3%) is mobilized as dissolved organic carbon. Even if large amounts were mobilized, the arguments under Section 0.1 would apply. - "Dissolved Pyrogenic Carbon" is the preferred term, as is "pyrogenic carbon" over "black carbon"

	1st review	Response	2nd review	Response
			1670. Dittmar et al. (2012) documented that the export rate of dissolved black carbon (DBC) from a watershed actually exceeded the watershed production rate of black carbon. Suggesting that the charcoal rate of dissolving will increase with time. Dittmar T, de Rezende CE, Manecki M, Niggemann J, Ovalle ARC, Stubbins A, Bernardes MC (2012) Continuous flux of dissolved black carbon from a vanished tropical forest biome. Nat Geosci 5(9):618–622 Wang, D., Zhang, W., Hao, X., Zhou, D., 2012. Transport of Biochar Particles in Saturated Granular Media: Effects of Pyrolysis Temperature and Particle Size. Environ. Sci. Technol.	(most of the recent articles use pyrogenic over black to avoid confusion with “black carbon” particles in the atmosphere) - The points made about contaminant transport are irrelevant to a carbon methodology. Regardless, the referee’s assessment of this topic is one-sided as also reduced transport has been found (Larsbo et al. (2013) J. Cont. Hydrol. 147:73-81.). In addition, the point also

	1st review	Response	2nd review	Response
			47, 821-828. Kindler, R., Siemens, J. A. N., Kaiser, K., Walmsley, D. C., Bernhofer, C., Buchmann, N., ... & Kaupenjohann, M. (2011). Dissolved carbon leaching from soil is a crucial component of the net ecosystem carbon balance. Global Change Biology, 17(2), 1167-1185. The DBC can actually aid in the transport of contaminants that are sorbed to organic materials – Kupryianchyk, D., Noori, A., Rakowska, M.I., Grotenhuis, J.T.C., Koelmans, A.A., 2013. Bioturbation and dissolved organic matter enhance contaminant fluxes from sediment treated with powdered and granular activated carbon. Environ. Sci. Technol. 47, 5092-5100.	ignores the fact that the adsorption reduces its bioavailability (Kookana, 2010; Oleszczuk et al., 2012ab; Josko et al., 2013). **References**: Josko I, Oleszczuk, P , Pranagal J, Lehmann J, Xing BS and Cornelissen G 2013 Effect of biochars, activated carbon and multiwalled carbon nanotubes on phytotoxicity of sediment contaminated by inorganic and organic pollutants. *Ecological Engineering* 60, 50-59. Kookana, R. S. (2010). The role of biochar in

	1st review	Response	2nd review	Response
				modifying the environmental fate, bioavailability, and efficacy of pesticides in soils: a review. *Soil Research*, *48*(7), 627-637. Oleszczuk P, Hale SE, Lehmann J, and Cornelissen G 2012a Activated carbon and biochar amendments decrease pore-water concentrations of polycyclic aromatic hydrocarbons (PAHs) in sewage sludge. *Bioresource Technology* 111, 84-91. Oleszczuk P, Hale SE, Lehmann J, and Cornelissen G 2012b Influence of activated carbon and biochar on phytotoxicity of air-dried sewage sludges to *Lepidium sativum*. *Ecotoxicology and*

	1st review	Response	2nd review	Response
				Environmental Safety 80, 321–326.
0.3	This methodology is based on the conversion of biomass into a more stabilized form of carbon (biochar); however, all the protocol currently addresses is laboratory derived microbial degradation rates. There has been immense difficulty reconciling the differences between these and field rates of degradation for other carbon sources and often no relationships observed between field and laboratory rates (Nielsen et al., 1995; Di et al., 1998). Therefore, the heavy reliance on laboratory derived rates is very troubling. Particularly, when there is field data showing decreasing amounts of black carbon observed in some soils (aka "black carbon paradox"). This is a major shortcoming of the proposed method, since it solely examines one degradation mechanism – microbial as assessed through laboratory incubations. Overall, the science of biochar stability in soils is a very complex process. The authors of the proposed methodology have based their conclusion solely on laboratory derived degradation rates.	A recent and extensive review of both laboratory and field studies of biochar carbon persistence in soils (Lehmann et al 2014) found that when controlling for environmental and biological variability (soil moisture and temperature, soil properties, soil biota, etc), all biochars with an H/Corg value below 0.7 had mean residence times exceeding 100 years (at 95% confidence), the definition of permanence under this methodology (see Figure 11.4c in Lehmann et al 2014).	This response addresses solely the microbial and partial chemical degradation.	Responses pertaining to the degradation pathways (chemical vs physical vs biological) are compiled in Section 0.1. We repeat that data including from field trials support the parameterization of the method (Lehmann et al 2014 Persistence of biochar in soil. In: Biochar for Environmental Management - Science and Technology, 2nd edition). (Also a note on the 1st review: Di et al (1998) study was done on pesticides, and not litter or biochar.)

	1st review	Response	2nd review	Response
	However, these could be greatly questioned, since the fungi are also involved and our ability to capture a true representative sample of their activity in the lab is very limited (Cohen and Gabriele, 1982; Scott et al., 1986). The likelihood of laboratory derived rates properly representing true degradation rates is very slim.			
0.4	Another aspect ignored is the importance of soil mineralogy and physical protection as a factor controlling mineralization rates in the soil profile (Marschner et al., 2008).	See 1.2 below.		
0.5	Chemical degradation through reactions with water and oxygen. Charcoal is a very interesting material, since it has an exothermic reaction with water sorption (Adams et al., 1988) and this leads to a multiple of potential storage and transport issues – internationally charcoal is recognized as a hazardous material due to the potential of self-ignition (Miyake et al., 2005).	With respect to spontaneous combustion, the IBI Biochar Standards require compliance with applicable regulations related to transport of goods and also recommend the testing of biochar for potential for self-heating and flammability during storage and transport with results to be embedded in an MSDS—please see Section 3.2. Because biochar may be classified as a flammable material, its	In addition to the safety issues with the creation and transport, you did not address the reactions of the biochar in soil with water infiltration/freeze thaw/ soil heating/ etc. All of these will decrease the residence time of the charcoal as we know from existing data that these reactions do impact the longevity of charcoal in the soil profile: 1) Huisman, D. J., Braadbaart, F., van Wijk, I. M., & van Os,	Please see responses in Section 0.1

	1st review	Response	2nd review	Response
		storage and transport will be governed by laws intended to minimize risks from spontaneous combustion.	B. J. H. (2012). Ashes to ashes, charcoal to dust: micromorphological evidence for ash-induced disintegration of charcoal in Early Neolithic (LBK) soil features in Elsloo (The Netherlands). Journal of Archaeological Science, 39(4), 994-1004. 2) Kalisz, P.J., Sainju, U.M., 1991. Determination of carbon in coal "Blooms". Commun. Soil Sci. Plant Anal. 22, 393-398.	
0.6	This methodology does not adequately account for the carbon sequestration occurring through the baseline addition of organic amendments. This would need to be subtracted from the calculated biochar sequestration rates.	See 1.3 below	The baseline scenario for all agricultural residues would be decomposition and incorporation into microbial biomass and humic substances in the soil. Therefore, the baseline is not zero. However, I see further discussion/review of	The challenge is that over the 100 year time scale there is not general excepted sequestration amount for organic matter to soil. Sequestration of organic matter is not traditionally accounted

	1st review	Response	2nd review	Response
			baseline scenarios as unnecessary; since there is not a defendable method presented to accurately predict the longevity in soil – the current method gives a very good tool to predict the ability of microbial and chemical mineralization – but we already know that different soils will degrade biochar at different rates since the 1960's, so the index on the biochar only is not enough: Shneour EA: Oxidation of graphitic carbon in certain soils. Science 151, 991-992 (1966).	for in landfill or other natural system baselines. There is no precedent in other methodologies for this sort of deduction to account for natural sequestration. It is prudent and more defensible to not include this in the baseline.
0.7	The methodology would benefit from inclusion of a verification section. While some verification requirements are mentioned throughout, these requirements could be fleshed out and certain aspects defined to ensure a consistent verification process. Also, no reference is made to the ACR verification and validation guideline (ACR, 2012). In particular detail of verification should be	Soil testing will not be feasible and would have to go on well beyond the length of the projects. Verification requirements are addressed in the appendix and one requirement is reports be submitted to 3rd party verification body.	The response does not address the point raised - soil testing was not suggested. This comment was made as the verification requirements given in the appendix would benefit from review against the ACR reasonable assurance requirements for projects.	See #9 under Applicability Conditions, as reference to ACR verification and validation guideline (ACR, 2012) was added.

	1st review	Response	2nd review	Response
	provided for verification of sustainable feedstock criteria. It should be noted that there are a number of voluntary standards and schemes that are in existence for bioenergy, but these generally rely on a 'limited' level of assurance, so would not necessarily meet the ACR 'reasonable' assurance requirements.		Also, a section detailing the overall project verification requirements (or at least referencing the ACR verification and validation guidelines) would enable more consistent verification.	
0.8	This is a good first draft, and after revision should be applicable to the biochar community.	☑	The reviewers comments indicate that this draft will be superficially modified, but it lags in significant adjustments to be fully implementable.	

1. Methodology Description

	1st review	Response	2nd review	Response
1.1	You specific MSW waste here in the introduction – however, if you examine the requirements that you later develop for a sustainable feedstock, MSW would not be able to meet these requirements.	Mixed feedstock from the same general source, considering there is no more than 10% change, is considered no material change. Unless there is reason to believe that the biomass component of MSW	What reference do you have that 10% does not change properties of the biochar? There is much we do not understand about the resulting chemistry – For example, there is no stipulation at	The 10% material change threshold is based on a conservative assumption that biochar properties, particularly H/Corg, will not vary significantly with any changes in feedstock composition <10%. We agree that additional data could be used to support this point. Note that the European Biochar Certificate Guidelines—a related biochar physicochemical testing standard—utilizes a 15% change threshold (EBC (2012) 'European Biochar Certificate – Guidelines for a Sustainable Production of Biochar.' European Biochar Foundation (EBC), Arbaz, Switzerland. http://www.european-biochar.org/en/download. Version 5).

	1st review	Response	2nd review	Response
	(need to be over 90% biomass in composition). Ever 10% change in feedstock composition for some of these listed waste streams could be daily or multiple times per day (MSW/manures) In addition, the landfilling of organic wastes is now prohibited in a number of countries (US, Germany, etc..) Therefore, the recommendation is to entirely drop this as the baseline scenario or an alternative if the absence of biochar since the biomass wastes are typically not currently collected and	varies more widely than that then this should suffice.	all in the "IBI Guidelines" for inert purge flow rates. The flow rate of N2 in the pyrolysis unit at a set temperature has virtually the same impact on yield of products as pyrolysis temperature [Demiral, İ., Ayan, E.A., 2011. Pyrolysis of grape bagasse: Effect of pyrolysis conditions on the product yields and characterization of the liquid product. Bioresour. Technol. 102, 3946-3951.]	Regarding N2 gas purging, please note that in Version 2.0 of the IBI Biochar Standards (published in October 2014 and applicable to this methodology) there is a new section 5.7 Timing of Testing for Post-Processed Biochar which indicates that biochars that have undergone various forms of processing after pyrolysis must be re-tested: "for those types of post-processing where testing is required to occur after post-processing treatments, 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." (IBI Biochar Standards V2.0 2014)

	1st review	Response	2nd review	Response
	deposited in landfills. They are solely collected for composting, bioenergy production, and anaerobic digestion projects… but not directly for deposition in the landfill. The "baseline" scenario for the definition of agricultural wastes should be deposition for aerobic degradation in the field. However, this decomposition also can produce carbon sequestration. The use of demolition and construction debris is not typically part of MSW fraction, since these are collected and usually deposited in			

	1st review	Response	2nd review	Response
	C&D landfills (internationally). There are already existing methodologies for the MSW fraction anyway—so why worry about these in this methodology?			
1.2	Looking across all soils in New Zealand, the major factors controlling soil carbon sequestration rates were not climate and temperature, but actually soil mineralogy (Percival et al., 2000) - In other words, the form of added carbon is not as critical of a factor as once assumed, but instead is the physical protection of this soil carbon in aggregates that	When comprised of already decomposed organic materials, the mineralization of soil organic matter is indeed a result of its interactions with clay minerals, its compartmentalization within aggregates, and temperature and moisture regimes, to name a few of the more important ecosystem parameters. However, before	**Yes, but the rate of mineralization will also be dependent on biochar particle size:** Sigua, G.C., Novak, J.M., Watts, D.W., Cantrell, K.B., Shumaker, P.D., Szögi, A.A., Johnson, M.G., 2014. Carbon mineralization in two ultisols amended with different sources and particle sizes	See Section 0.1 for a response on particle size. Additional comment on Sigua et al (2014): it is difficult to put this study into context of this question, as H/Corg values nor any other values for their properties are not reported in this publication. All that is shown are the pH values and they are significantly different between pellets and powder, suggesting that the different sizes of biochars tested were not identical. In addition, (i) the low temperature of pyrolysis (350C) suggests incomplete charring; and (ii) the short incubation period (50 days) suggests that only non-pyrogenic carbon forms mineralized during this period. Therefore, this study does not allow any relevant insight into the question examined here. It is true that there is a paradigm shift in our understanding of carbon stability: ecosystem properties are more important than we previously realized (Schmidt et al 2011, Persistence of soil organic matter as an ecosystem property, Nature). A general assessment of the significance of these stabilization processes that are numerous and complex is however not possible now (or ever?): the surrounding climate, microbial

	1st review	Response	2nd review	Response
	leads to soil C sequestration. This is now the model used moving forward in the determination of soil carbon storage (Blanco-Canqui and Lal, 2004; Müller and Höper, 2004; Müller et al., 2006; Wagai et al., 2013)	added organic matter (e.g., leaves, wood, compost, biochar) is decomposed, it mineralizes according to decomposer preferences and the activation energy needed to metabolize it. For this reason biochar is not a preferred energy source for microorganisms. The same is true for wood as compared to leaves. Once the wood and the leaves (or biochar) have been decomposed to microbial metabolites in soil, the mineralization is now determined by ecosystem properties, rather than whether it is a	of pyrolyzed biochar. Chemosphere 103, 313-321. Which will change with weathering and soil exposure: Naisse, C., Girardin, C., Lefevre, R., Pozzi, A., Maas, R., Stark, A., & Rumpel, C. (2014). Effect of physical weathering on the carbon sequestration potential of biochars and hydrochars in soil. GCB Bioenergy. Also remember that there are abiotic reactions with charcoal and oxides as well as	population, and presence of nutrients would need to be predicted separately for each individual soil where biochar is applied, and such predictions of future soil status would themselves be based on assumptions. Because the chemical changes in biomass brought on by charring are as great as they are, we have focused on the intrinsic stability of biochar. Stable biochars (those produced over a certain temperature) have been shown to be two orders of magnitude more stable than fresh biomass, and on average 60 times more stable (Budai et al. in prep.) This difference in intrinsic stability is much greater than differences in the stability of non-pyrolyzed biomass. We are aware that chemical and physical stabilization processes work alongside the degradation of all biomass and we deliberately avoided attempting the impossible task of account for all (or any) of them.

	1st review	Response	2nd review	Response
		lipid or a lignin monomer, for example. Direct comparison between charred and uncharred organic matter have shown in the field and in the laboratory that charring results in lower mineralization, typically one order of magnitude or more (Baldock and Smernik, 2002; Santos et al, 2012; Maestrini et al, 2014).	water; that will degrade the charcoal - Huisman, D. J., Braadbaart, F., van Wijk, I. M., & van Os, B. J. H. (2012). Ashes to ashes, charcoal to dust: micromorphological evidence for ash-induced disintegration of charcoal in Early Neolithic (LBK) soil features in Elsloo (The Netherlands). Journal of Archaeological Science, 39(4), 994-1004.	
1.3	The methodology also takes an assumed position that the additions of organic matter to soils does not lead to carbon	The challenge is that over the 100 year time scale there is not general excepted sequestration amount for organic	Peat deposits are just one example. See the review for some practices that do lead to increased soil C without charring	Soil organic carbon storage may be directly enlarged by increasing C returns to the soil as crop residues, manure or other organic amendments. Carbon inputs to the system may also be increased indirectly by fertilization or irrigation treatments that increase crop productivity, biomass and root production. However, at some stage mineral soils – as opposed to organic soils – will tend to become saturated with

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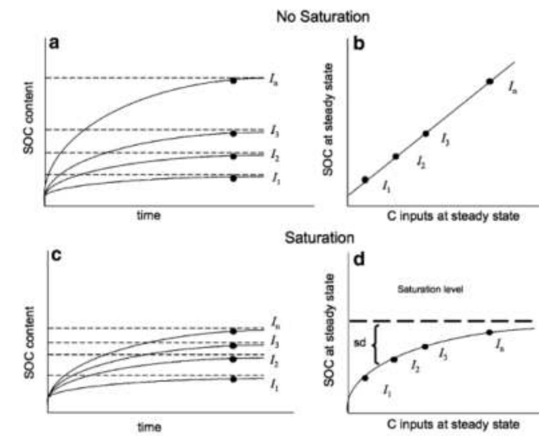
	sequestration (baseline condition). However, field data supports the concept that organic amendments (without charring) also supports soil carbon sequestration through incorporation of this organic matter inside soil aggregates (Ryals et al., 2014) , which incidentally has also been proposed linked to the mineralization and sequestration rates of biochar (Awad et al., 2013; Bruun et al., 2014; Fang et al., 2014).	matter to soil. Sequestration of organic matter is not traditionally accounted for in landfill or other natural system baselines. There is no precedent in other methodologies for this sort of deduction to account for natural sequestration. It is prudent and more defensible to not include this in the baseline.	the biomass. Diacono, M., Montemurro, F., 2010. Long-term effects of organic amendments on soil fertility. A review. Agron. Sustain. Dev. 30, 401-422.	respect to C input and show little or no increase in steady-state soil C stocks with increasing C input levels (Stewart et al., 2007, 2008a,b; 2009). **Fig. 1** Theoretical relationship between C input level and soil organic C (SOC) contents at steady-state, with and without C saturation. Steady-state SOC accumulation dynamics expressed over time (**a**) produces a linear relationship when expressed over C input level (**b**) Under the conditions of C saturation, SOC stabilization with increasing input rates (at steady state) is not proportional (**c**) resulting in an asymptotic relationship when expressed over C input level (**d**)  (Figure from Stewart et al., 2007). This suggests that carbon accumulation in mineral soils does not necessarily depend on the protective capacity (e.g., clay content) of the soil alone, but on the degree to which the protective capacity is already occupied by organic matter (the so-called saturation deficit; Stewart et al., 2008). In other words, the greater efficiency in soil C sequestration is expected to occur in soils further from their C saturation (e.g., those that have the greatest saturation deficit). However, the C gain of mineral soils caused by the addition of biochar − in contrast to other organic amendments/management techniques − does not depend on the C saturation level of the specific soil to which is added, but on the chemical stability of biochar C itself, which arises from

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				the condensed aromatic structures it contains at the molecular level. Moreover, biochar can increase the C saturation level of a specific soil by increasing the surfaces to which the native organic matter can react with and become stabilized (e.g., chemical protection). The accumulation of C in organic soils – peat deposits – is not that related to specific chemical, biochemical or physical stabilization mechanisms, but to the unfavorable environmental conditions existing in those soils, which do not sustain the decomposition of organic matter (e.g., suboxic/anoxic conditions, acidity, low temperature). These conditions are generally the exception in agricultural soils. Stewart et al. 2007. Biogeochemistry 86:19-31. Stewart et al. 2008a. Soil Biol Biochem 40:1741-1750. Stewart et al. 2008b. SSSAJ 72:379-392. Stewart et al. 2009. Soil Biol. Biochem. 41:357-366.
1.4	The definition of biochar – will this continual be updated with new definitions from IBI? What happens if IBI no longer exists or is supported?	The definition of biochar as defined by IBI's most recent standards are to be followed by this methodology. The definition of biochar will be updated if IBI decides that changes in science merit a new	No comment.	

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		definition. IBI will update the IBI Biochar Standards as the science merits. In the event that IBI no longer exists, the last version of the standards will apply for the duration of the methodology. If IBI were to cease to exist, future methodologies can utilize a definition and/or standards being developed by the British Biochar Foundation or other recognized groups. All other standards being developed at this date are based upon the IBI Biochar Standards.		
1.5	Moisture content of the feedstock – this should be defined and the methodology to	Moisture content will affect processing conditions and parameters, but not	Actually the moisture content of the feedstock does exert a very important control	We agree that moisture content exerts a very important control on the chemistry and yield of the product. This is precisely the reason why the property of the product is measured, and any differences in moisture of the feedstock would change the H/Corg ratio. The methodology is therefore

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	assess this. Is moisture included in your contaminant or diluents?	the final product. The methodology is focused on the biochar product, and the moisture content of the feedstock is not relevant to the methodology. Moisture is not included in the definition of contaminants or diluents in feedstock in the IBI Biochar Standards.	on the chemistry during pyrolysis – Water content also effects the yield of products: it reduces the heating value of the solid char, alters pH, reduces the viscosity of the bio-oil, and influences both chemical and physical stabilities [see A.V. Bridgwater, 1990] Bridgwater, A.V., 1990. Biomass pyrolysis technologies, G. Grassi, G. Gosse, G. Dos Santos (Eds.), Biomass Energy Ind. Environ. 5th E.C. Conference, Elsevier, London, New York (1990),	designed to assess the properties of the final biochar product, not the numerous feedstock properties (moisture, composition and particle size of the feedstock) or the numerous parameters of the charring method (temperature, carrier gas and flow rate, batch size, etc.). Including these in the methodology would deviate from the goal of the document and is irrelevant.

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			pp. 2489–2496. Xiong, S., Zhuo, J., Zhang, B., Yao, Q., 2013. Effect of moisture content on the characterization of products from the pyrolysis of sewage sludge. J. Anal. Appl. Pyrolysis 104, 632-639.	
1.6	The style of charcoal production has also been observed to impart different structural properties to charcoal, particularly evident in overall bulk density and resistance to shattering (Khristova and Khalifa, 1993)	Regardless of structural variations in specific biochar products, the methodology is focused on the final product and its carbon sequestration values. The primary criteria are for the biochar to meet IBI and H:Corg standards.	Yes, but structural stability is also paramount to your methodology. Since all studies have shown the particle size alters microbial mineralization rates of all substrates. How is the methodology adapted to	Section 0.1 addresses the concerns about particle size. Differences in soil type are certainly important, as are soil temperature, soil moisture and other environmental factors. The methodology takes this into account by assuming conditions that are the most conducive to mineralization: sandy soil, high temperatures, and small particle sizes. A new data base (Lehmann et al 2014 Persistence of biochar in soil. In: Biochar for Environmental Management - Science and Technology, 2nd edition) includes many different soil types.

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			different soil types?	
1.7	Gasification – What do you refer to “partial” oxidation process? A majority of the full-scale plants for bioenergy production are approaching 80-95% efficiencies for energy conversion – which is a complete combustion technology.	Agreed and removed “partial” from the methodology text from definition of Gasification.	Ok.	
1.8	The use of the ASTM methodology of proximate and ultimate analyses for “wood based charcoals” to other biomass feedstock types is a potential issue – particularly for the ultimate analysis where the assumption of only containing C, H, N, S, and O may not be valid as shown in	The BC+100 test method (procedure outlined in Appendix 1) does not prescribe the use of ultimate analysis for wood charcoals (ASTM 1762). This method is simply mentioned in a discussion of potential methods to determine volatile matter content of biochars	Ok.	

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	recent TGA comparisons of different feedstocks without some modifications to the methodology – See Cantrell, K.B., Martin, J.H., Ro, K.S., 2010. Application of thermogravimetric analysis for the proximate analysis of livestock wastes. Journal of ASTM International (JAI) 7, JAI102583.	in Appendix 2.		
1.9	In the table referring to the Proximal and Ultimate analyses -- specific what is meant by "dry" – air (as received) or oven dry.	Common standard test methodologies are specific on this.	Ok.	
1.10	"above ground biomass" increases – This is a very difficult area, since there has been no	The methodology is making no claims for credit regarding increases in above-ground biomass.	Remove these items and references from the protocol, since it has no	This methodology is making no claims for credit regarding increases in above-ground biomass. Therefore the items in question were not included in the protocol and were only used in response to previous comments.

	1st review	Response	2nd review	Response
	correlation to date observed with biochar properties and the potential plant yield increases (Crane-Droesch et al., 2013).	Nevertheless, Jeffery et al (2011) report positive crop yield gains for biochars made from 10 out of 11 feedstocks i.e., only 1 negative response. An updated meta-analysis by Jeffery et al (2014) using three times the number of studies, shows that all application rates of biochars had statistically significant yield increases (with the exception of 1-5 tons/ha and >150 tons/ha which showed no statistically significant response). Spokas et al (2013) report "Approximately 50% of the	bearing.	

	1st review	Response	2nd review	Response
		compiled studies observed short-term positive yield or growth impacts, 30% reported no significant differences, and 20% noted negative yield or growth impacts." So, it can be said that in general studies demonstrate that most biochars result in positive crop yield gains.		
1.11	Noted that the change to 'thermochemical Conversion' was made after the public commentary, but consideration should be given to referencing, defining or requiring applicable processes (slow/ fast pyrolysis, gasification,	This methodology is intended not to be selective of specific processes, as these are changing rapidly, but to provide quality control that is feasible to the producer. The $H:C_{org}$ test fits these requirements.	Accepted, though it seems a missed opportunity to entirely focus on the carbon aspect.	There is an assumption that the agronomic benefits of applying biochar to soils in projects supported by this methodology will also be a driving factor in project development. The methodology developers all agree that biochar's benefit extends beyond carbon sequestration, based on the growing body of evidence described in other responses. However, these are not currently quantifiable in a carbon offset methodology.

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	torrefaction). There can be significant differences in chars produced via these different thermochemical conversion processes, both with regard to stability (though this is covered in this methodology through H/C_{org} test) and properties as a 'soil improver' such as surface area (Brownsort, 2009; Mašek et al, 2013). Thought the main consideration for this methodology is carbon sequestration, the benefits of biochar as a soil improver should not be overlooked.			
1.12	Under the definition of biochar, it is	Carbon sequestration is the primary	OK. This committee has made their	We are in agreement that biochar has the potential to offer benefits other than carbon-Sequestration, however as this is a carbon offset methodology, is the primary focus of this

	1st review	Response	2nd review	Response
	unfortunate that there is no wiggle room for biochars which have properties that exceed the protocols. "To be credited by this methodology, biochar must comply with all requirements"—There is no room to scientifically maneuver here. Biochars are produced which have properties that do not comply with all of the protocols Research has shown that, in spite of them not complying, the biochars are capable of positively improving soil health. In other words, this definition may need	requirement of this methodology and so long as the biochar produced meets this minimum stability standard, the other properties of the biochar allow for flexibility. Perhaps future updates can further classify biochars according to specific properties, but for the purposes of this methodology, C stability is the most important metric, regardless of other co-benefits. Also, this methodology is not meant to support research (referencing the final statement of the comment), and should in no way hamper research in	statement about the primary requirement for their biochar standards as C sequestration. Arguably, this approach loses sight that a primary reason for biochar addition is to improve soil health and rec'd commensurate crop yield improvements. Biochars are expensive and must justify a return as in improved crop yields. While C sequestration is very important for GHG reductions, farmers or landowners are	methodology. This methodology requires the biochar to be used as a soils amendment and therefore the additional benefits of biochar will be realized, as valuable co-benfits to carbon-sequestration. In no way is this methodology discouraging or impeding these additional benefits of biochar. Carbon Market revenue will add revenue to the biochar industry and incentivize additional commercial viability for this industry.

	1st review	Response	2nd review	Response
	to be softened/ expanded. The positive outcome of this decision is that it allows for research to be conducted with biochars that do not fully comply, but are still acceptable as a biochar-type material.	this or any other area.	concerned with making a profit to continue raising crops, trees, and horticultural crops.	
1.1 3	Recent research has shown the benefits of mixing feedstock blends for creation of engineered biochars (Novak et al., 2014). If you call it a “Material change” then this is OK to discern that the feedstock is from a mixture. Mixing feedstocks such as plant + manure; or green wastes (consortia of yard/urban wastes) may be the most	Agreed and that is the intention of this methodology.	Ok.	

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	important approach for creating specialized biochars.			
1.14	The definition of soil amendment is limited in scope. Biochar can do more than just improve the root environment or physical conditions. A few research reviews (Atkinson et al. 2010; Spokas et al., 2012; Biederman and Harpole, 2013) report that biochars can also improve nutrient retention (CEC) or sorption/precipitation of toxic elements in soils (i.e., Al, other salts). Therefore, this definition should mention a few soil chemical/fertility	Agreed and revised to include.	Ok.	

	1st review	Response	2nd review	Response
	improvements obtained after biochar addition.			

2. Applicability Conditions

	1st review	Response	2nd review	Response
2.1	The baseline condition – Energy will always be the competing endues of biomass, and historically has always won out in terms of economics. What do you propose to do to substitute for the loss of bioenergy source for the energy producer? Will this force the production of energy from fossil fuels to replace the lost bioenergy energy source? This seems a bit backwards… I see the only baseline situation that works for this methodology is for current unused biomass streams, and not the higher value biomass being used for energy currently? IN other words, why is it better to removing 1 ton of biomass from bioenergy production and make biochar? Under this situation, I fail to see an option that will work economically since you are leaving energy in the biochar (unburned C).	The default baseline condition assumes feedstock combustion for bioenergy production. Under this baseline, it is required to calculate emissions from any fossil fuels used to make up for losses in bioenergy production. If the economics under this scenario are not favorable, the project proponent is highly unlikely to pursue project validation. More importantly, there are many other baseline scenarios that do not include bioenergy production. Under these scenarios the economics may be much more favorable to biochar production and use, e.g., as	From life cycle analyses – the most effective and for that matter the most documentable and defendable use of biochar as a climate mitigation tool is : "*Comparing the use of the same quantity of biomass in a biochar system to a bioenergy district heating system which replaces natural gas combustion, bioenergy heating systems achieve 99–119% of the climate benefit of biochar systems according to the model calculation.* "	Please provide reference for the quote. Reference required to understand context of quote. Based on best practice guidance from other protocols and based on principals of ISO 14064-2; for conservatism the approach selected represents the appropriate baseline scenario for potential use of biomass.

	1st review	Response	2nd review	Response
		noted by the commenter for feedstocks that do not have a current use or a low value use.		
2.2	MSW or any type of collected stream would have a difficult time meeting the less than 10% of diluents/contaminants It is important to note that very little organic matter is actually deposited into landfills; including countries with regulations against land filling of organic materials (e.g. Germany, and many US states).	The IBI Biochar Standards permit maximum 10% diluents and 2% contaminants. We agree that use of the biomass fraction of MSW as a feedstock may have difficulties meeting these restrictions, which were put in place to ensure biochar materials meet necessary thresholds for safety and consistency for use as a soil amendment. As a result, MSW may not be an important biochar feedstock, except in cases where the clean biomass fraction of MSW can be consistently and safely separated from contaminants and diluents.		
2.3	There is no minimum particle size stated; has consideration been given to loss of fine particulates to air during mixing, spreading and runoff? This	The IBI Biochar Standards outline and recommend best management practices for biochar production and	Accepted, though as these are recommendations, not requirements, they may not be followed.	

	1st review	Response	2nd review	Response
	could result in substantial carbon losses if there are a large proportion of very fine particles (Blackwell et al, 2009). Referencing or requiring best practice soil application and mixing techniques may go some way to mitigate the risk of air pollution and translocation.	material handling and require adherence to regulations pertaining to air emissions (and others)—please see section 3.2. Standard biochar materials handling practices include wetting of biochar to reduce losses to the atmosphere during mixing or application. Further, injection or slurry application and subsequent incorporation into the soil via tilling are common modes of application and greatly reduce losses to atmosphere and translocation.		
2.4	Point 2 refers to pyrolyzed material, while elsewhere reference is made to generic thermochemical conversion.	We have corrected Applicability Condition 2 to refer to thermochemically converted, not pyrolyzed, material.	Accepted - no further comment.	
2.5	Point 4 refers to the “Standard Test Method for Estimating Biochar Carbon Stability”, as this is contained in Appendix 1, it would be worth referencing Appendix 1 here.	We have added a reference to Appendix 1 in Applicability Condition 4.	Accepted - no further comment.	
2.6	Point 5 offers a very weak approach to	With respect to	Section 2 is much improved,	The ability to provide

	1st review	Response	2nd review	Response
	address one of the greatest risks of fraud with this methodology: that the produced char is used to generate carbon credits, but is sold as a fuel. The response to the public comments does not appear to be adequate. Attestations alone are not sufficient to allow a verifier to reach a reasonable level of assurance as to the end use of the material. At a minimum, attestations should be supported by additional evidence, for example invoices, weighbridge tickets, production records, third party testing records, etc. Size of particles alone is no guarantee of use, the material can be injected into a furnace as powder, or compacted into briquettes for a fuel. At a minimum, this requirement should be combined with several others to make a suite of requirements for this aspect. A requirement for biochar to be mixed with soil at the production site would go some way to reduce the fraud risk, and may also limit any risk of reversal and safety risk in transportation through spontaneous combustion (Blackwell et al, 2009). Spontaneous combustion (leading to reversals) should also be	spontaneous combustion, the IBI Biochar Standards require compliance with applicable regulations related to transport of goods and also recommend the testing of biochar for potential for self-heating and flammability during storage and transport with results to be embedded in an MSDS; please see Section 3.2. Because biochar may be classified as a flammable material, its storage and transport will be governed by laws intended to minimize risks from spontaneous combustion. Thus the threat of reversals is mitigated. We have added additional criteria in 2.6 for documentation requirements. We have removed the particle size option for	though this still has minimal value as "marketing materials" and "comparison of heating value and production price" are still offered as an option for demonstrating use. These are both very weak forms of evidence, and consideration should be given to requiring "substantive proof" for which records can be sampled per load of biochar material (e.g. delivery notes). These could be further supported by the "Comparison of Heating Value and Production Price" and "marketing materials", but these are not substantive evidence in their own right. Even if the reversal risk is minimized by following the IBI Standard, there still exists a risk of reversal, which should be take account of in this protocol.	specific proof by load of biochar must be measured against the fact that loads of biochar will vary and could be as small as 100 grams. As such it is important to apply a performance standard approach to substantiate the project condition, which is the use of the biochar in the soil. The methods provided will meet that performance standard when applied against the applicable verification standards. As such, we believe the reversal risk as suggested in the comment is effectively eliminated. The documentation suggested and the justification provided

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	considered with regard to storage of produced char, especially where particle size is small.	demonstrating soil end use in 2.6. With respect to spontaneous combustion, the IBI Biochar Standards require compliance with applicable regulations related to transport of goods and also recommend the testing of biochar for potential for self-heating and flammability during storage and transport with results to be embedded in an MSDS; please see Section 3.2. Because biochar may be classified as a flammable material, its storage and transport will be governed by laws intended to minimize risks from spontaneous combustion. Thus the threat of reversals is mitigated.		in the protocol would be required to meet a standard and would be confirmed during verification. Therefore no further action is required.
2.7	Point 6 only refers to air quality laws for production. Also this only refers to developed country laws for developing countries, but local laws may equally	We have revised Applicability Condition 6 to include applicable local or national laws within	Accepted - no further comment.	

	1st review	Response	2nd review	Response
	apply in developing countries. Consideration should also be given to laws regarding soil application and runoff. For example application of biochar to soil is illegal in many jurisdictions, as it is often classed (inaccurately) as a waste product (Shackley & Sohi, 2010). Also airborne particulates may be an issue if best practice for soil application is not followed.	developing countries. We have revised the text to include regulations pertaining to air and water quality and application of amendments to soils. Please see response to 2.5 above in response to best practices for soil application.		
2.8	The ratio of H/OC_{org} for a pyrolysis product to be called biochar is limited in scope. It would be more encompassing to the biochar community, if it was recognized that other biochar type material are acceptable to the IBI community. For example, in certain biochar programs, biochars are produced that have H/OC_{org} ratios between 0.6 to 0.8. This occurs because the pyrolysis temperature is adjusted to engineer a biochar with specific physico-chemical characteristics. We have found that biochars with this range of H/OC_{org} ratios, in the short term (months), are sometimes more effective at improving soil health. In comparison, biochars with H/C_{org} ratio <<0.7 are effective as a C sequestration agent. In	This Methodology for Biochar Projects is concerned first and foremost with biochar C sequestration in soils over a period of 100 years which is estimated using the BC+100 test (see Appendices 1 and 2). To this end, predicting biochar persistence (stability) in soils is critical. The expert panel convened by IBI to develop BC+100 reviewed numerous methodologies and determined that only biochars with H:Corg <0.7 could be considered stable over 100 years and should	This reviewer understands that the primary goal of the biochar expert panel was to have a characteristic protocol (H/Corg) for BC+100 yrs (stability). It still this reviewer's continuation of the alternate paradigm that biochars with larger H/Corg rations will be better for soil health improvement. Perhaps, it would be good to re-consider why biochars are applied to soils (C sequestration vs. soil health) and next develop a	The carbon methodology is geared towards reductions of greenhouse gas emissions (as submitted here to ACR), and not soil fertility management; these are two different objectives that have to be dealt with in different methodologies. Including both of these facets in one document would require that the importance of each

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	comparison, it will take a longer period of time for this biochar to be oxidized and improve soil fertility. It can be argued that in some regions to improve soil health, it may require using biochars that do not comply with the IBI standards. Consequently, it may be more prudent if within this document, there is a modification to accept that some biochars do improve soil health even if they have properties that exceeds the <0.7 H/C_{org} ratio standard.	be allowed for consideration under this methodology. We agree that the soil fertility benefits of biochars will vary and believe that project proponents will seek to match biochars to soil and cropping scenarios based on biochar physicochemical properties. The H:Corg ratio is by no means the only property that will have an effect on soil health e.g., nutrient content, pH, liming potential, surface area, etc. are also important.	multipurpose based approach. In other words, have a route that splits the definition of biochar based on its intended multi-uses. A one-style approach (i.e. C sequestration) for the definition of biochar is one-dimensional, considering that biochar has such a faceted benefit to soils.	be pre-determined. Having separate methodologies allows society to utilize each methodology with frequency that is proportional to societies changing demands.

3. Project Boundaries

	1st review	Response	2nd review	Response
3.1	In Table 2 – Please explain why you have included the anaerobic process for the production of CH4 and N2O for aerobic degradation?	There are trace amounts of CH_4 and N_2O produced in aerobic degradation. This is supported by the IPCC work.	So if you are including the negative aspects of residue decomposition – why aren't the positive benefits also included ?	The approach as documented in the protocol represents a conservative methodology which is consistent with similar protocols across various GHG reduction systems.

	1st review	Response	2nd review	Response
3.2	You should also clearly indicate which are sources/sink versus keeping both text in the description; for example how can drying of feedstock be a sink? Refer to your figure – this can be very helpful to provide an overview of this process diagram.	Change title of Table 2 to GHG Sources and Sinks. No need to identify difference between sources and sinks in the figures and tables. This is not common practice		
3.3	Bio-oil processing – you state that this one should be included because it will likely have a material impact on project, but then the very next box is bio-oil transport you say to exclude since a majority do not produce bio-oil – a bit confusing. Bio-oil use – included ? Again same question as above. Why do you selective include the "benefit" factors and leave the "negative" factors out for the project?	Question answered in explanation in Table 2. Transportation excluded as either consumed on site or part of distribution network for liquid fuels. Processing and use are included as there are material GHGs which are different from project to baseline. In any event, it is always conservative to include project emission sources.		
3.4	Justify the values selected for the production of N2O and CH4 from aerobic degradation processes.	These values are to be taken from IPCC materials if local/regional/etc. values are not available.	Same thought as above.	See response outlined in comment 3.1. No change required.
3.5	Combustion of feedstock as the baseline?	Yes. This is a possible baseline given the combustion of biomass in either beehive burners or in-block. Need to account		

	1st review	Response	2nd review	Response
		for all possible baselines, even if unlikely.		
3.6	I would separate the methodology based on feedstock to be considered – agricultural crop residues, manures, forest wastes, organic food collections, etc…since each of these have a different baseline condition.	This is effectively accomplished as we treat each pathway separately. Multiple feedstocks can follow the same or different pathways. As such, listing by feedstock may result in multiple listings (and equations) for the same pathway. The approach taken is both accurate/complete, most efficient and common practice. The GHG assessment is not tied to the particular feedstock but the disposal method for that feedstock. As such, we have effectively accomplished this as we treat each pathway separately.	The main concern with combining them is triggering the arbitrary 10% feedstock composition change of the "guidelines".	The 10% material change threshold is only triggered if after an initial production run the feedstock composition changes by >10%. As currently written and described in our initial response, each feedstock can be treated separately using the pathways described for feedstock disposal under the baseline scenario.
3.7	Need to include additional energy for residue collection from the field. Application of biochar – these right now are excluded – However, a majority of	Feedstock production is not included – but transportation of that feedstock is included.	But no direct data on the number or amount of idealized reductions.	Comment seems incomplete. The approach taken is consistent with

	1st review	Response	2nd review	Response
	studies are indicating a joint application is needed and the this matches historically the need for fertilizer to be applied with charcoal to overcome the reduction in nutrient aviability (Keeley et al., 1985; Inderjit and Callaway, 2003).	Growing the biomass material is the same in baseline/project. Harvesting that biomass is typically done for other purposes and thus the same in baseline/project. Transportation of that material is included as it may not otherwise occur without some value on that material. Exclusion of emissions associated with application of biochar holds. Biochar does not replace fertilizer (at least not in all cases) but may replace other soil amendments – especially given the time cycle for biochar's effectiveness in the soil compared to alternative soil amendments.		similar protocols. No change required.
3.8	Biochar transportation – Due to the density differences and potential difference of application style (i.e. manure slurries through irrigation or injection; compared to broadcast	We do not agree with this statement. We believe it is conservative to exclude this source as the density of biochar is so much lower	See comment above – Yes the density of biochar is lower, so there will be a lower mass of truck, but the application will require a	We do not agree with this comment. As we do not understand the requirement for a higher number of

	1st review	Response	2nd review	Response
	spreading of a litter density material), there could be significant differences in the application energy use.	and the application rates are lower as well.	higher number of trips therefore more application trips to be performed – increase in GHG emissions.	trips. If the density is lower so is the application rates
3.9	Biochar transport – reasoning for exclusion of this source from the project boundaries in the response to public comment does not appear adequate. The fact that it may be “not currently economically feasible” to transport biochar long distances does not mean that this will be the case for the life of this methodology. Biomass for energy production is currently transported significant distances, and it may well become viable to transport biochar significant distances in future years when this methodology is still in use. Biochar may be added to soil where a soil amendment has not been used previously, therefore justifying exclusion of transport emissions (and biochar application emissions) by excluding soil amendment transportation emissions in the baseline case is not sufficient. It is not a conservative assumption to exclude biochar transportation emissions from the project boundaries.	See 3.8. In addition, transportation of biochar over long distances is matched by other soil amendments transported long distances (with higher densities).	Are you able to provide any evidence to support the assertion that anticipated biochar transport emissions would not exceed current soil amendment transportation emissions? For example, studies of transport distances for soil amendments, versus transport distances for biomass pellets as a comparator? If so, then then this exclusion may be justified.	Given the discussions in previous comments about density of biochar and in consideration of the regional nature of soil amendments and biochar production. We continue to assert that the emissions from biochar transport are equivalent to that of other soil amendments.

	1st review	Response	2nd review	Response
3.10	Feedstock transportation is excluded on the boundary map, but included (in non *de mimimis* cases) in the SSR list for the project condition.	Biomass transportation is not included within the site boundary map. This is true, however it is included as a sources and sinks within the project as a whole. Biomass transportation occurs offsite which is what the boundary map indicates	For clarity the feedstock transportation should be included within the project boundary, with a footnote to state “Can be excluded if the Project Proponent can demonstrate the emissions are De Minimis or the Feedstocks originate at the site of the Thermochemical Conversion unit.” At present the table and the boundary map are not consistent.	We agree, the footnote has been included in the protocol. To confirm; the project boundary is a physical boundary not a theoretic boundary as to what is part of the project. The physical boundary shows the site where as the project boundary may extend across multiple sites. As such, we believe there is a misunderstanding of what project boundaries and site boundaries mean un the context of this protocol. Project boundaries can extend beyond sites but site boundaries are limited by geographic location
3.11	An assessment of what constitutes *de*	Text change:	Accepted - no further	

	1st review	Response	2nd review	Response
	minimis for transport emissions is not defined (needs a number or %).	"Included. Potentially important emission source. Can be excluded if the Project Proponent can demonstrate the emissions are *De Minimis* "i.e. Estimated at less than 2% of emissions reduction value" or the Feedstocks originate at the site of the Thermochemical Conversion unit.	comment.	
3.12	The baseline boundary is not shown in figure 2 (this is illustrated by a dashed line for the project condition in figure 1)	There is no project boundary in the baseline condition as there is no project. Thus, these baseline activities would not (necessarily) occur at the same project site. Thus, no boundary line can be drawn.	Perhaps a comment to this effect in the methodology would be of benefit?	The approach taken in the protocol is standard for methodologies. As such a footnote is unlikely to add an additional clarity to the document.
3.13	CH_4 and N_2O are included for baseline electricity production, but excluded for project electricity consumed – this is not consistent or conservative.	CH_4 and N_20 should be included for electricity production in the project condition. This was revised in methodology (Table 2, Electricity Consumed).	Accepted - no further comment.	
3.14	If a mobile thermal conversion unit is used, consideration should be given to	Agreed: Included in Table 2 as Mobile Thermal	Accepted - no further comment.	

	1st review	Response	2nd review	Response
	emissions from transport of the unit to the field site.	Conversion Unit Transportation.		
3.15	As noted in the literature review of this article, there are reports that biochars are capable of being translocated via erosion, eluviation of solid material, disintegration and solubilization of compounds. However, the assumption that the new area of biochar accumulative has the same environment as the former is a bit reaching. Just consider if the smaller size biochar is translocated to a new soil series and is exposed to new environmental degradation kinetics. All this considered, it is plausible that the translocated biochar is less stable and the environmental degradation could be harsher. Perhaps the 100 yr degradation time span could be << 100yrs. Could the BC_{+100} time span be realistically better described as say BC_{+75}?	The methodology for permanence of the biochar accounts for the issues outlined in this question. The approach is conservative – and thus suitable for use in a GHG protocol.	The response to this comment is unsatisfactory. This reviewer suggests that the committee should address the longevity of biochars will vary under different soils conditions (texture, Water & N avail., etc.). While the residence time of biochars can be > 100 yrs, there will probably be a situation where biochar decompose in less time. Perhaps, this is another instance where the committee should provide the biochar community a range of longevity (i.e., BC+75 to BC+100). In a situation like this, why not have some flexibility in your certification protocols.	We agree with the referee that longevity of biochar will vary under different soil conditions (please see Sections 0.1 and 1.6 for additional comments) and that different biochars will persist for different periods of time. This is precisely the reason why this methodology adopts a conservative approach by adopting thresholds developed for environments with high temperatures (known to increase mineralization), optimum water contents (known to maximize mineralization), including sand (known to show the greatest

	1st review	Response	2nd review	Response
				mineralization rates); and (iii) introduces the H/Corg values that are a valid proxy for fused aromatic ring structures, known to persist in soil, which was shown to relate to biochar mineralization in this protocol.
3.16	A few reports have found that biochar addition to soil caused positive priming of fresh residue or indigenous soil organic matter (SOM, Kuzyakov et al., 2000; Novak et al., 2010). Therefore, biochars can cause positive priming unlike the statement 'not commonly found where biochar is added'. While it is minor in terms of the % SOM decomposed, the correction factor is a good idea to account for this phenomena.	It appears that this commentator agrees with our position. ☑	Ok.	

4. Procedure for Determining the Baseline Scenario and Additionality

	1st review	Response	2nd review	Response
4.1	One aspect that I think deserves more attention is the syngas phase – and if this is un-captured then the potential exists for the release of compounds that can	Release of syngas, without combustion, would appear impossible given requirements of the IBI	Ok.	

	1st review	Response	2nd review	Response
	negate a significant portion of the calculated sequestration value (see (Greenberg et al., 1984; Jenkins et al., 1998; Wang et al., 2008; Estrellan and Iino, 2010; Alves et al., 2011).	Biochar Standards to meet industrialized country regulations for air quality and environmental impacts, which in effect mandates the use of best available production technologies and systems without negative environmental impacts. The operating temperatures and configurations of the systems would also suggest that syngas capture and combustion is necessary to operate the systems.		
4.2	When looking across a field landscape, there are not uniform SOC levels, these assemble in "hotspots" in specific areas of the field based on topography and local hydraulic properties. How the spatial variability across a field be accounted for in this methodology?	Regardless of where biochar is applied in a field landscape, it is the volume of biochar applied and it's stability that is the focus of the methodology, regardless of field spatial variability. No incremental benefit is being assigned to SOC levels. All benefits is being assigned to carbon sequestered within biochar. Distribution of biochar to the soil does imply even distribution across the soil.	Granted the machine effort would be lower, but the number of passes with a set truck would be higher for the same weight of other materials, since the trucks can only carry a fixed volume of biochar. This lack of proposed application detail will confound validation protocols.	We do not believe that the protocol as written would provide any barriers to validation or verification to projects where the records as required in the protocol are provided.

	1st review	Response	2nd review	Response
		There would be no differential impact to the carbon sequestration of the biochar whether it was put in a “hotspot” in a given topography.		
4.3	As it is highly likely that alternative baseline scenarios will be used for projects wherever possible, it is essential that the assessment of additionality is robust. Consideration should be given to limiting the list to a defined set, in particular the last bullet point, stating “any other uses of the biomass residue”. The investment analysis aspect to the UNFCC tool has attracted particular criticism for the number of loopholes that can be exploited (Gillenwater & Seres, 2011). Further detail, benchmarking or set conditions could be provided in the methodology regarding the validation requirements for the alternative scenarios to support the UNFCC tool and make for a more robust validation process. Is there a reason the ACR three-prong approach for validating additionality (ACR, 2013) is not used in this methodology in place of the UNFCC tool?	After review; we agree with the statement that Additionality should be tightened up. Therefore it is proposed that the phrase ‘all other biomass residue’ is removed; as it does not clearly define and/or gives loopholes for potential projects to miss-claim baseline emissions within this protocol. The ACR and UNFCC approach to determining baselines are similar but the UNFCC tool does not address Institutional barriers. The ACR Standards V3 – Three Pronged Approach will be used. Change made to text throughout Section 4.	Accepted - no further comment.	

5. **Quantification of GHG Emission Reductions and Removals**

	1st review	Response	2nd review	Response
5.1	This is largely adapted from landfill projects. Except the authors fail to justify the heavy use of landfilling as the baseline for field generated residues.	Landfilling is only one baseline option – and is not the default. As such, 'heavy use' appears to be an overstatement.		
5.2	Table 7 – this seems to contradict with your list of acceptable feedstocks in the appendix. Fix.	Comment has been accepted and changes have been made. Table 7 and appendix 4 feedstock lists have been altered to match.	Ok.	
5.3	I would remove the landfill of organic waste from this methodology – the MSW waste stream in the countries that do allow it, would not meet your less than 10% diluents standard	This protocol is applicable in places where this baseline is appropriate. Further, there are waste streams currently entering landfills that are >90% organics. As such, the multiple layers of criteria limit when baselines can be used.		
5.4	The authors have not properly represented the true environmental and human hazards of the biochar production process – These are well established in the literature from past pyrolysis efforts, and can lead to significant air emissions which would easily offset any environmental benefit of the biochar that is produced (Wilkins and Murray, 1980).	This is a methodology for GHG emissions. However, the IBI Biochar Standards, which are embedded in the Protocol, require that industrialized nation environmental and health (e.g. air quality, safety) regulatory issues be		

	1st review	Response	2nd review	Response
	In addition, to the potential for soil contamination from liquid and bio-oil soaked solids (Mac Culloch, 1814; Ré-Poppi and Santiago-Silva, 2002; Rey-Salgueiro et al., 2004; Oleszczuk et al., 2014). Even though the ending product might pass the "IBI test", the biochar plants could be as bad as the historic wood distillation factories (Hawley, 1926), which are still undergoing clean-up and remediation activities. The Food and Agriculture Organization of the United Nations have a report that states the following for the process of carbonization: 4.2. Industrial safety in carbonization Carbonisation produces substances which can prove harmful and simple precautions should be taken to reduce risks. The gas produced by carbonization has a high content of carbon monoxide which is poisonous when breathed. Therefore, when working around the kiln or pit during operation and when the kiln is opened for unloading, care must be taken that proper ventilation is provided to allow the carbon monoxide, which is also produced during unloading through	met and or exceeded during the production of biochar in order to qualify for this methodology. Additionally, the standards require testing of the biochar material for toxic and harmful compounds, such that only biochar safe for use as a soil amendment qualifies for use under the methodology.		

	1st review	Response	2nd review	Response
	spontaneous ignition of the hot charcoal, to be dispersed. The tars and smoke produced from carbonization, although not directly poisonous, may have long-term damaging effects on the respiratory system. Housing areas should, where possible, be located so that prevailing winds carry smoke from charcoal operations away from them and batteries of kilns should not be located in close proximity to housing areas. Wood tars and pyroligneous acid can be irritant to skin and care should be taken to avoid prolonged skin contact by providing protective clothing and adopting working procedures which minimize exposure. The tars and pyroligneous liquors can also seriously contaminate streams and affect drinking water supplies for humans and animals. Fish may also be adversely affected. Liquid effluents and waste water from medium and large scale charcoal operations should be trapped in large settling ponds and allowed to evaporate so that this water does not pass into the local drainage system and contaminate streams. Fortunately kilns and pits, as distinct from			

	1st review	Response	2nd review	Response
	retorts and other sophisticated systems, do not normally produce liquid effluent - the by-products are mostly dispersed into the air as vapours. Precautions against airborne contamination of the environment are of greater importance in this case.			
5.5	The worked example of equation 3 would benefit from inclusion of samples for clarity.	It is not typical to include examples in protocols. In one system, this was frowned upon as it game numbers that became 'best practice' as they were included in a protocol example. We believe that the paragraph that follows the equation is a good middle ground for providing clarity without risk of leading users astray.	Accepted - no further comment.	
5.6	On page 40, the units for DOC should be mentioned in the equation? Is it mg/L or as a % of the total mass?	Units for DOC are stated in Section 6.1 Data and Parameters Available at Validation; Equation 6. DOC_j is a % of total mass. Units will be added to equation on page 40	OK. I re-examined the units for DOCj and it is on a % wet basis. Thank you for putting on page 40 for the reader.	
5.7	The use of the 0.95 correction factor in equation (33) looks acceptable to account for the + priming. It could be argued that	Agreed. Protocol errs on side of conservatism.	Ok.	

	1st review	Response	2nd review	Response
	this is on high side, with a coefficient of 0.97-0.99 probably being closer to the amount of background SOM lost from + priming of biochar.			
5.8	The definition of leakage in section 5.3 is vague. I would request that this term be more clearly defined. What is 'leakage from upstream sources"—biochar solubilization and transported downstream or in water runoff?	The mechanisms for leakage described in this comment are addressed in the biochar stability piece. After "upstream sources" add "(i.e. sources upstream of project boundary)."	Ok.	

6. Monitoring

	1st review	Response	2nd review	Response
6.1	Monitoring – I fail to see any true validation – solely based on modeling and archived data outputs. – no field based proof. The validation step is the most critical for any CDM methodology – This requires more development.	The stable carbon methodology (BC+100 test) addresses the issue of residence time of the biochar in soils. Data are based on both lab and field studies and they demonstrate the conservative nature of the BC+100 test. (Lehmann et al 2014). See also 6.2 below.	No, your "stable carbon methodology BC+100test" solely addresses the rate of microbial degradation – this index itself does not predict the longevity as a cumulative effect of all the other weathering processing and different soil types/soil microbial populations that are possible once it is placed in the environment.	See Section 0.1 for comments on microbial vs physical vs chemical degradation and mineralization. All published information show that the H/Corg value is a valid proxy for fused aromatic ring structures of charred organic matter that persist longer in soil than uncharred organic

	1st review	Response	2nd review	Response
				matter.
6.2	The methodology must include a mechanism that truly validates the project's data streams. The current methodology relies solely on the output of models to state that sequestration is occurring.	Ongoing research since publication of the BC+100 test method further validates the conservativeness of the test method. Particularly, in a review of papers evaluating the persistence of carbon in soils, Lehmann et al (2014) used a global data set of both field and laboratory experiments and found that the measured mean residence time (MRT) of biochars with H:Corg ratios below 0.48 consistently exceeded 1000 years, and that 90% of the initial carbon would remain after 100 years. In the context of BC+100 and this methodology, biochars with H:Corg < 0.7 and < 0.4 are conservatively estimated to have 50% and 70%, respectively, of their initial Corg remaining after 100 years. Thus, the data in Lehmann et al (2014) show		

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		that BC+100 values for the H/Corg thresholds are highly conservative.		
6.3	Again – why the parallel to the LFG modeling? The degradation rates and constants need to be developed for your particularly processes in the field.	If the reviewer is referring to equation 6 - anaerobic decomposition in a solid waste disposal system i.e., landfill, as an alternative baseline scenario -- the degradation rates and constants are taken from IPCC estimates for landfill gas generation and from existing models developed for that purpose. This is independent of estimating emissions from biochar application under the project scenario. If however, that is not what this comment is in reference to, we do not understand the reference, and ask for clarification. Degradation of organics is not addressed in this model, just stability of biochar.		
6.4	The major focus here was on production	See response to 6.1		

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	variables to achieve a desired biochar property and did not address the long-term carbon stability monitoring.			
6.5	While not all data parameters for equations need to be available at validation, it should be made clear that these must all be provided at verification.	Agreed. Revised methodology (under 6.3).	Accepted - no further comment.	
6.6	Equation 3 – z –More detail here to reference the procedure for the sample in appendix (see separate comment under Appendix 1). Data unit should be stated for Z.	Equation 3 refers to the method to calculate feedstock prevented from baseline disposal, and Z refers to number of feedstock samples collected during the year. The IBI Biochar Standards do not prescribe sampling procedures for feedstocks, rather only for the biochar end product. We have updated the methodology to reflect this. Z is simply an integer (number of samples collected during year y) and has no units.	Accepted - no further comment.	
6.7	Equation 17 – Flow meters should be calibrated to manufactures specifications, and in accordance with industry standards. Different makes/	This must be done in accordance with manufacturer specifications. We cannot presume a	Accepted - no further comment.	

	1st review	Response	2nd review	Response
	models of flow meters can have significantly different calibration requirements.	universal industry standard, when it is specific to manufacturer. Add to follow manufacturer specifications (clarify which manufacturer and make).		
6.8	Giving multiple options for data units for equation 20, 33 and 37 (in chapter 6) is likely to give rise to errors of magnitude in project proponent calculations. Suggest giving one measure which matches that in the equation. For example, equation 33 requires BC_j in metric tonnes, so the data unit in section 6 should state metric tonnes.	When calculating (G_y) volume of syngas produced in the project condition; equation 20. Multiple options for data units are necessary as one must multiply by the emission factor for each type of fuel. This does not lead to errors of magnitude but provides options for projects that use varying types of fuel. Equation 33 has been changed to match the parameters set out in section 6 and will use Tonnes.	If calculated correctly, then this would not lead to errors of magnitude – the point is that giving multiple options for units seems unnecessary, and may well introduce *potential* for error in calculations which could easily be avoided by consistently using the same units in the methodology.	It is reasonable to assume that as part of the verification and validation process the selected set of units from the project proponent would be check to ensure they are appropriate. This is a standard part of verification and therefore not an issue.
6.9	Consider requiring 'Accredited' laboratories to carry out measurements, in place of 'reputed'.	Agreed and revised, though we have found that 'accreditation' varies widely by country.	Accepted - no further comment.	
6.10	Monitoring frequency of $FS_{i,j,y}$ should match that required for Z (equation 3). Why is the frequency of measurement required for Z, C_{org} and NCV_j not consistent?	The measurements procedures for frequency are outlined on page 80-81 are consistent. A measurement frequency for variables is not always	Accepted, though detail of this could be clarified in the methodology.	A footnote has been inserted into the protocol to provide further clarification. As such the footnote states that "A

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		consistent given both technical and practical consideration given the ability to get the data. Some measurements are better taken continuously while others are better taken on a periodic basis.		measurement frequency for variables is not always consistent given both technical and practical consideration given the ability to get the data. Some measurements are better taken continuously while others are better taken on a periodic basis.”
6.11	Consider replacing “performing recalculations” with “conducting an internal audit of calculations, methodology and data parameters”	Agreed and changed in methodology (under 6.3).	Accepted - no further comment.	
6.12	So you are assuming that 50% of the DOC solubilized from biochar is decomposable? This sound overly optimistic and there should be a reference here. A big concern about the 0.5 decomposition factor is that you assumed that it was minimal during biochar re-deposition to a different micro-environment. Back there, you assumed that the micro-environment would not make biochar susceptible to degradation causing the 0.5 index value	Please clarify where you are finding the reference to 50% of the DOC in biochar is assumed to be solubilized. I believe this may be incorrectly taken from Equation 6 which is the IPCC determined fraction of degradable organic carbon that can decompose under the alternative baseline scenario of anaerobic	OK. After re-inspecting the wording the 0.5 is a value to be applied in equation 6. Yes, this reviewer sees that this is the fraction of degradable organic carbon that can decomposed. The decomposition values for different waste products are shown in table 10. This reviewer was confused and	

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	to be an over-adjustment.	decomposition in a SWDS.	thought that you were referring to a 50% decomposition in biochar as DOC.	

7. References

	1st review	Response	2nd review	Response
7.1	These should be updated as there is more recent information available from biochar studies.	Correct; relevant references commented on by reviewers are updated as part of this response round. New relevant citations have been added. All references will be updated in the final methodology, given the speed with which peer-reviewed biochar research is being published.		

Appendix 1: Standard Test Method for Estimating Biochar Carbon Stability (BC_{+100})

	1st review	Response	2nd review	Response
A1.1	8.5.1 – there is no field study that justifies these percentages.	Field studies align with the values in Section 8.5.1, as shown by Lehmann et al (2014).		
A1.2	9.1 – these should be completed prior to method	H and total C measurements using		

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	development	Dumas combustion (as prescribed in the methodology) have been utilized for decades and are well-established methods, often under the term "ultimate analysis" in the charcoal and biomass industries. Inorganic C is measured using an industry accepted method, ASTM D4373; this method also has a long history of usage. Based on well-established experience with these methods using similar biomass materials, there is no need to conduct separate precision and bias tests before the prescribed H and C analyses can be used for biochar.		
A1.3	Assessment of material changes should be reviewed in verification. This could be demonstrated by documents	Record keeping of documents related to the "material change" provision is a	"VBB could request" is very different from a verification requirement. Suggest	Agreed and added to #9 of Applicability Conditions.

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	such as transport records, waste transfer notes (if applicable) and invoices. If no assessment is included in the verification, the methodology entirely relies on the project proponent to declare if a material change has occurred.	requirement of the IBI Biochar Standards (see Section 5.3 Conformity and Record Keeping). "Record keeping will be mandatory in order to establish proof of adequate sampling, testing, and results. Documentation of biochar feedstock (see Appendix 4 for guidelines on identifying feedstocks) and type (unprocessed or processed), production parameters (processing temperature and residence time), and test results should be kept for seven years." Therefore, the VVB could request documents on feedstocks or production parameters to verify if a material change has occurred.	detailing requirements in a verification section.	
A1.4	Allowing the project proponent to take all samples presents an opportunity for fraud. This	Sampling procedures are outlined in Appendix 2 of the IBI Biochar Standards.	As per original comment, the sampling process does not seem	We are willing to incorporate biochar sampling requirements that are above and beyond those required by the IBI Biochar Standards. These could be temporal as well

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	relies on the honesty and integrity of the project proponent to take representative samples of the biochar, and to present these samples for analysis in a timely manner. There does not appear to be a requirement for analysis at a third party accredited laboratory. Requiring increased sampling interval, third party sample collection and analysis would significantly increase robustness of this aspect (though would increase costs for the project proponent).	"Strict adherence to standardized biochar sampling procedures is critical to ensure reliable, representative, and replicable test results. Following accepted compost analysis practices, the Test Methods for the Examination of Composting and Composts (TMECC) (US Composting Council and US Department of Agriculture (2001)) has been identified as an effective general sampling procedure to comply with the IBI Biochar Standards". Further, as stated above in response to A1.3, record keeping is mandatory, including for sampling procedures. Therefore, documentation of biochar sampling will enable the VVB to provide reasonable assurance that no fraud has occurred.	controlled enough given the outcome of these tests is the whole determination for the permanence of the biochar under this methodology. Third party analysis is required, but not third party sample collection – we are relying on the sample collection of the project proponent for annual samples. There is no requirement to increase frequency based on volumes of biochar produced, and the proponent could select from any batch they decide may have the most favorable H/C_{org} ratio. The frequency of sampling, methodology for collection of samples and consideration of	as volumetric and would be designed using guidance from other programs such as the US Composting Council's Seal of Testing Assurance.

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		There is a requirement under the IBI Biochar Standards that third party accredited laboratories are used (please see Section 6.1 Laboratory Standards). Annual resampling has been determined sufficient by the IBI expert panel that developed these recommendations.	sampling regime with project size need further consideration to support the robustness necessary for the 100 year permanence.	
A1.5	It would seem that a way to account for biochar having > 0.7 H/C_{org} ratio, would be to reduce the BC_{+100} to BC_{+75}. This adjustment provides a little wiggle room for biochars that do not meet your H/C_{org} ratio, but still have the potential to sequester C for between 75 to 100 yrs.	Materials with $H:C_{org}$ >0.7 do not have a sufficient degree of C aromaticity and thus are deemed not to be fully thermochemically converted and cannot be labeled a biochar under the IBI Biochar Standards, which is a requirement of this methodology.	The biochar certification committee may be missing the point that it may be more beneficial to apply a biochar with a H:Corg <0.7 as in attempting to increase soil microbial fungi populations.	If the point is that it will increase soil microbial fungi populations, the literature does support that, and, we have not qualms or disagreements. If the point is that biochars with H:Corg ratios >0.7 increase soil microbial fungi populations, that may well be, but it does not meet the stability test.
A1.6	A biochar produced using pyrolysis techniques that has a H/C_{org} ratio of > 0.7 is not	While biochars may have end uses such as those listed by the	This reviewer doesn't agree with the rigidity of this committee.	See responses to Comment 0.7.

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	considered a feedstock precursor. Basically, there needs to be some scientific wiggle room to account for scientists, biochar users, and consultants who want to apply biochars with H/C_{org} ratio of >0.7. Biochars with these characteristics may be useful in soils for short-term binding hydrophilic pollutants, or serve as a site for cation exchange, and also serve as a hydrophilic domain for water sorption.	reviewer, for the purposes of this methodology it is critical that a measurable fraction of the biochar C persist in soils for a minimum of 100 years (as determined via BC_{+100}). Materials with $H:C_{org}$ >0.7 do not have a sufficient degree of C aromaticity and thus are deemed not to be fully thermochemically converted and cannot be labelled a biochar under the IBI Biochar Standards—a requirement of this methodology.	This reviewer creates biochars using pyrolysis conditions temperatures between 350 to 700°C. The biochars are characterized for atomic ratios and NMR. I do not look forward to a reviewer who states that my biochars do not meet the committees protocols. As a suggestion, the committee might want to consider establishing protocols for biochars under a multi-function conditions. Why not establish the following areas for biochars uses; 1. for C sequestration; 2. for soil fertility; 3. for soil physical improvement;	

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			4. for greenhouse media; 5. for compost; 6. filtration media; then develop a protocol under each role. This is a re-freshing approach and can be a win-win for all parties.	
A1.7	Text on page 124 says that biochars with a H/C_{org} ratio of < 0.7 are highly stable. The stability can be linked to the biochar having a large aromatic character. Then it is plausible that this type of biochar is useful when improving soil C sequestration. However, it probably will take a few years for a recalcitrant biochar to be oxidized and have an impact on improving soil health (i.e., pH, CEC, aggregates). If this policy is enacted, then folks who apply a highly recalcitrant biochar to soils will not receive immediate	The text states that biochars with $H:C_{org}$ <0.4 are "highly stable" and $H:C_{org}$ <0.7 are "stable". The reviewer's statement that recalcitrant biochars may take a few years to have an impact on soil health is not necessarily true. For example, stable biochars may sorb more native soil organic matter and thus raise the CEC indirectly. Furthermore, biochars have many characteristics that confer soil fertility	Maybe.	No response.

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	soil fertility improvements since the biochar is highly stable.	benefits that are not related to their stability (i.e. their H:C_{org} ratio) such as a porous structure that serves as soil biota habitat. There is scientific agreement that the soil fertility benefits of biochars will evolve over time. However, those benefits are independent of the long-term stability of the biochar C in the soil, determined by BC_{+100}, which is the critical component of this methodology.		
A1.8	The recent meta-analyses by Jeffery et al., (2011) and JEQ article by Spokas (2013) report that not all biochars deliver a positive service to improve crop yields. Wouldn't it be more prudent to focus on applying biochars with their H/C_{org} ratio based on a specific purpose in soil (sequestration vs. soil health)	Jeffery et al (2011) report positive crop yield gains for biochars made from 10 out of 11 feedstocks i.e., only 1 negative response. An updated meta-analysis by Jeffery et al (2014) using three times the number of studies, shows that all	Ok.	

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	improvement? In turn, the correct biochar is apply to soil and a positive outcome is achievable.	application rates of biochars had statistically significant yield increases (with the exception of 1-5 tons/ha and >150 tons/ha which showed no statistically significant response). Spokas et al (2013) report "Approximately 50% of the compiled studies observed short-term positive yield or growth impacts, 30% reported no significant differences, and 20% noted negative yield or growth impacts." So, it can be said that in general studies demonstrate that most biochars result in positive crop yield gains. The $H:C_{org}$ ratio is intended for use as a predictor of biochar C stability in soil (BC_{+100}), not as a predictor of		

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		potential soil fertility benefits. To that end, other physical/chemical tests in the IBI Biochar Standards may be utilized; specifically, Test Category C Advanced Analysis and Soil Enhancement Properties which include parameters such as mineral N, total P and K, available P and total and external surface area.		
A1.9	Concerning standard reference materials (SRM). • Section 7.1 is too vague to be of use. • SRMs should be divided into method verification standards, calibration verification standards, and continuing calibration verification standards as described by Ruiz.and Ehrman (1996). Although this protocol is described for HPLC analyses, it is equally	We have revised the text in Section 7.1 to address the reviewers concern.	The revision of section 7.1 largely ignores my constructive suggestion.	The revision in 7.1 specifies that the SRM is to be used to calibrate the equipment. For the purposes of this methodology with limited replicates needed for testing we believe a SRM for calibration purposes is sufficient.

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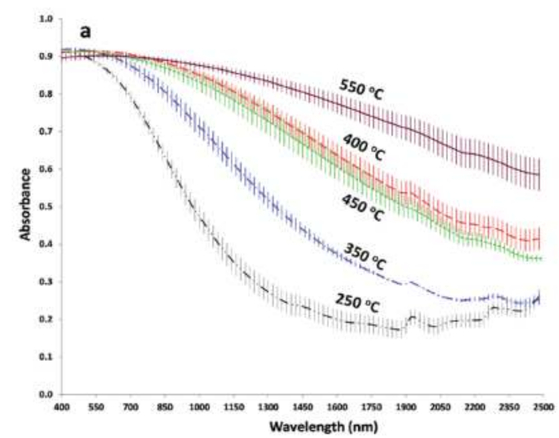
	applicable to other analyses based on SRMs (e.g. titration analyses (Legarra et al, 2013).			
A1.10	Concerning the determination of moisture content (MC). • Biochar, charcoal, and biocarbon are all hygroscopic. If the MC of a sample is measured and subsequently, the sample is ground, the sample will regain moisture and will no longer be dry. Thus the recommended procedure of 7.2 will compromise all subsequent measurements. • The use of a mortar and pestle to grind biochar would only be recommended by an ivory-tower professor who enjoyed free student labor. • Various ASTM standards recommend procedures for measuring MC. Why	It is not necessarily true that all biochars are hygroscopic. Biochar fired at lower temperatures (~350C), contains significant residual labile hydrocarbon and as a result is fairly hydrophobic, with occluded volumes from which water is excluded (Webber et al 2012). We have revised section 7.3 (see response to A1.11 below) to address the issue of moisture prior to elemental analysis. We have revised section 7.2 to allow the analyst to choose the method for grinding biochar.	All biochars that emerge from a carbonizer are dry if the carbonizer operates at 1 bar and water is not employed to cool the charcoal in the carbonizer. Upon exposure to air the biochar quickly gains weight by adsorption of moisture, oxygen and other compounds. In my lab the biochar equilibrates at about 10 wt% MC. If the biochar is subsequently dried to measure MC, it will regain weight upon exposure to air by again adsorbing moisture from the air. Thus it is true that all	Indeed, biochar samples can adsorb atmospheric moisture during sample preparation and storage, although based on the recent literature, this tends to be more accentuated in carbonized materials produced in the 250-400°C – and mainly those that did not fulfil the definition of biochar. This is shown in the figure below where the average spectral absorbance (and standard error) of biochar samples grouped based on target heating temperatures of production is represented (Kusumo et al. 2014). The authors suggested the contribution of hydroscopic material such as cellulose in low- 

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	reinvent the wheel?	In 7.2, the moisture content is reported "as received" i.e., on a wet basis. The procedure outlined is simply a way to calculate MC, not a method in and of itself.	dry biochars are hygroscopic and the response is wrong. Section 7.2 is still flawed. ASTM D1762-84 recommends a measured weight loss of 0.0005 g or less. The recommended 0.01 g in section 7.2 is too crude. I am sending ASTM D1762-84 to the American Carbon Registry to enable them to know the standard practice.	temperature biochars as the plausible explanation. Kusumo et al. 2014. *J. Near Infrared Spectrosc.* 22, 313–328 This however does not preclude the need for measuring the moisture content of biochars. We have revised section 7.2 to address the issue of moisture prior to elemental analysis following the suggested measured weight loss of 0.0005 g or less.
A1.11	Concerning elemental analysis. • Commercial laboratories may report elemental analyses on an "as received" (i.e. moist) as opposed to the conventional dry basis. The basis must be clearly stated in the analysis. Analysis on an "as received" basis greatly	We agree with the reviewer that analysis conducted on an "as received" (wet) basis is an issue. To address this, we have revised section 7.3 to ensure that analyses are conducted on a dry basis. Two different issues	The Dumas combustion procedure measures N content of a substrate. As far as I know there are no round-robin studies of C, H, and O content of charcoals by combustion methods, especially when O is measured by	no comment

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	complicates the use of such analyses. • As noted in section 9.1 no round robins have been conducted to estimate precision and bias. In our experience, the determination of C and H content is not as precise as would be expected. For example, we obtained elemental analyses of identical oak wood samples from two of the best known commercial laboratories in the USA. One reported a C content of 49.05 wt%; whereas the other reported 51.02 wt% for the same sample of red oak. The standard deviations of analyses of many different oak woods were 0.74 wt% and 0.25 wt%.3 • After the precision of elemental analysis has been established, propagation of error is	have been intermingled in this comment: (i) the different C contents of different oak samples (or biochar samples), and (ii) the different C contents obtained from two different laboratories of the same oak sample (biochar sample). For this discussion, only the second point is useful. We agree that sample analyses using any method can be quite different when using different laboratories. Usually, for ring trials and tests measuring lab variability, many more than two laboratories need to be used, and all these laboratories have to adhere to standard practices of quality control. What is important is that the reproducibility of measuring carbon of	difference. We agree that a comparison of results from 2 laboratories is not a definitive round-robin. The number of labs was limited by the high cost of the study: thousands of $ were invested to merely obtain C, H, O analyses of many different woods. Nevertheless, the labs were among the best in the USA and the comparison was instructive. The revision to section 7.3 is an improvement.	

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	needed to determine its impact on the evaluation of H/C_{org} and ER (eq. 39).	oak wood is not different than that of biochar made from oak. And there is ample information about C measurements of all sorts of biomass (charcoals, activated carbons, etc.) that can be used to give the measurement errors of the Dumas combustion method, therefore there is no need to repeat this process for biochars. If peer reviewed papers that establish the error from Dumas combustion of organic materials including charcoals and activated carbons can be identified, it may be useful to include that in the equations as the reviewer suggests.		

Appendix 2: Justification for the "Standard Test Method for Estimating Biochar Carbon Stability (BC_{+100})

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A2.1	Chemical analysis on black carbon found in sediment have provided a range of H/Corg of 0.2 to 0.74, whereas the O/C ratios were 0.11 to 0.24 (Song et al., 2002). The authors of these studies indicated that the O/C was more sensitive to indication of weathering than the H/C. The authors of the proposed guidance suggested the use of a H/Corg ratio of less than 0.7 as the fundamental chemical screening criteria for the classification of a material as a "stable" biochar. Aromaticity is defined the property that describes the phenomenon in which a conjugated ring of unsaturated bonds, lone electron pairs, or empty atomic orbitals gain bond strength and thus the stabilization exceeds what would be predicted by the conjugation alone (Vollhardt and Schore, 2011). There is no requirement for a particular ratio of H/Corg. In fact, in one examines the simplest two aromatic carbon ring compounds – benzene (C6H6) and naphthalene (C10H8), the ratios do not fall within the "aromatic biochar" definition set forth by the H/Corg ratio of <0.7. There have been numerous	Our overall response to this lengthy and interesting comment is that the lower cost and greater availability of the H/C_{org} test far outweighs whatever incremental advantage in chemical significance measurements of molecular structure might offer. Below we respond to specific elements of this comment (converted to bold font by us). A certain degree of polyaromaticity would be required for the material to fall below the threshold of $H:C_{org}$ ratio of 0.7. A single benzene ring would not be sufficiently polyaromatic (it is not polyaromatic at all)	The purpose of this was to caution the authors that the use of H/Corg is solely an empirical and correlative property - there are no supported mechanisms. Other research in black carbon stability and coal degradation has been evaluating mechanisms – and they have found the O/Corg to be problematic as a classification tool. That was the point of the comment.	We disagree with the referee that the H/Corg value has no functional relationship with persistence. In fact, H/Corg ratios are indicators of the degree to which a charred organic material consists of so-called fused aromatic ring structures. This has been well documented (McBeath and Smernik, 2009; McBeath et al., 2011, 2014; Wiedemeyer et al., 2015). The most relevant supportive mechanism is the stability of high molecular weight PAHs. We agree with the referee that

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	attempts at utilizing the proximate and ultimate results for a quick classification system for condensed aromatic carbon compounds. However, there are a number of potential pitfalls, with moisture content and cation presence exerted significant control over the pyrolysis processes and compound outcomes (Saiz-Jimenez and De Leeuw, 1986; Ahmed et al., 1989; Hshieh and Richards, 1989; Raveendran et al., 1995; Agblevor and Besler, 1996; Alén et al., 1996; Di Blasi et al., 1999). Even though this ratio was justified across the biochars used in the research in the Appendix and text, these are a very small subset of all potential biochars that are produced from the pyrolysis of biomass. The authors did not critically evaluate the range of biochar products that would be possible, since a majority of these pyrolysis units are solely laboratory scale units, with very few large industrial scale units currently in operation. The most scientific supported route of calculating the aromatic index of an organic compound is to first assess the "double bond equivalence" (DBE) to carbon ratio. This is a common practice	which follows the logic of the method. We have added a requirement that biochars be dried prior to elemental analysis. We agree with this statement; one cannot easily predict the material properties from feedstock properties. A feedstock with higher metal contents will have a higher H/C_{org} ratio. The range of biochars used to create this ratio are the main biochars that have been used in studies to date. The production conditions are irrelevant for the definition of biochar or its classification according to		challenges may arise with the O/C ratio, which was the reason to adopt the H/Corg ratio in this methodology. The O/C ratio can be problematic for two reasons: (i) inorganic carbon may decrease the ratio without reflecting fused aromatic ring structures, but carbonates that can dissolve in slightly acidic soil solution; (ii) the presence of oxygen as part of metal oxides and carbonates may bias the results and organic-carbon bound oxygen is more difficult to quantify than hydrogen, as proposed here. **References**:

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	in mass spectrometry studies. As shown in Figure 1, there are compounds that are condensed aromatic structures [shown here as a DBE/C >0.65; shown with a light green, yellow, orange, and red] that possess an H/Corg ratio of >0.7. Just as quick examples, the simplest form of a condensed aromatic species is naphthalene (C10H8). A partial oxidized lignin subunit (C26H28O10; H/Corg = 1.08), would also be excluded based on this definition. Therefore, there are compounds that are aromatic and would have slow microbiological mineralization rates, but would be excluded by this criterion of H/Corg<0.7. These aromatic compounds would then not be considered biochar by the protocol, even though they are aromatic structures that have reduced mineralization rates compared to original biomass materials and might be produced for carbon sequestration purposes. This can be observed However, the DBE/C ratio alone does not solve the problem –since some of the aromatic structures also can contain non-carbon atoms (O, N, S, and P). One of the most applicable studies to this methodology is the work Koch and	$H:C_{org}$ ratios, which is based on the final biochar product. It is worth mentioning here that the $H:C_{org}$ ratio is not meant to be a proxy for aromaticity (even though it may correlate with aromaticity). Rather, it is meant to be used as an indicator for persistence of the biochar when placed in soils. Lignin is not particularly persistent in the environment (Schmidt et al 2010) which is in line with its classification of having a $H:C_{org}$ ratio above 0.7 (indicating rapid turnover). Not everything that has a reduced mineralization rate		McBeath, A. V., & Smernik, R. J. (2009). Variation in the degree of aromatic condensation of chars. *Organic Geochemistry*, *40*(12), 1161-1168. McBeath, A. V., Smernik, R. J., Schneider, M. P., Schmidt, M. W., & Plant, E. L. (2011). Determination of the aromaticity and the degree of aromatic condensation of a thermosequence of wood charcoal using NMR. *Organic Geochemistry*, *42*(10), 1194-1202. McBeath, A. V., Smernik, R. J., Krull, E. S., & Lehmann, J. (2014). The influence of feedstock and production

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	Dittmar (2006), where they proposed a correction to the DBE, which is similar in concept to the correction proposed by (Brodowski et al., 2005) for EDS composition data: DBE_{AI} = 1 + C – O – S - (0.5)*H; and CAI = C – O – S – N – P, results in: $AI = \frac{DBE_{AI}}{C_{AI}} = \frac{1 + C - O - S - 0.5H}{C - O - S - N - P}$ Thereby, this represents the minimum number of C-C double bonds plus rings in a common molecular structure (Koch and Dittmar, 2006). As one can see from the formula, with biomass feedstocks that can contain a large percentage of N, S, Cl, and P, the presence of these elements need to be directly accounted for in the estimation of the chemical character of the biochar. In fact, if the authors reviewed the literature from the classification of coal, humic and other condensed forms of organic matter, one would find a wealth of information that could have been used to improve this index.	is a biochar or is as persistent as biochar. Again, lignin is not particularly persistent in soil, in fact, it has been shown to be less persistent than many lipids; see Schmidt et al (2010). For a method to be useful in the context of this methodology it should be robust, simple and inexpensive. Spectroscopic techniques of the type suggested by this reviewer are neither easily obtainable nor affordable, but can be used to strengthen the routine methods, as described in the appendix for NEXAFS, NMR, and other gamma methods.		temperature on biochar carbon chemistry: A solid-state< sup> 13</sup> C NMR study. *Biomass and Bioenergy*, *60*, 121-129. Wiedemeier, D. B., Abiven, S., Hockaday, W. C., Keiluweit, M., Kleber, M., Masiello, C. A., ... & Schmidt, M. W. (2015). Aromaticity and degree of aromatic condensation of char. *Organic Geochemistry*, *78*, 135-143.

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	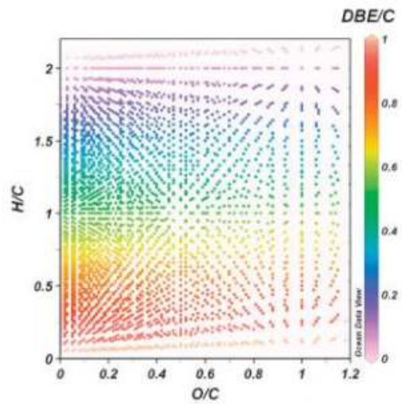 **Figure 1.** Molecular H/C vs. O/C ratios for all possible molecular formulae of the artificial data matrix containing C, H, and O in the mass range of 400–500 Da. Color scale represents the DBE/C ratio. However, in order to properly assess the long-term carbon sequestration impacts of biochar additions to the management of SOC a detailed long-term field data is unfortunately needed before this methodology could be recommended (van Wesemael et al., 2010), due to the difficulty in extrapolating the laboratory observed rates to field rates.	It is not clear what this reference should prove. This paper is on agricultural management, in general, not about biochar or pyrogenic organic carbon. This paper does support the claim that laboratory assessments cannot be automatically transferred to field conditions but in the context of soil management, mainly conversion of cropland to grassland. However, addition of organic material is a much more easily constrained system than the very complex interactions that take place when converting cropland to grassland. The behavior of charred organic matter in soil is still complex, but the increase in residence time between the charred and uncharred organic matter is a very robust effect, much more robust than land use changes described in this		

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		paper.		
A2.2	The theory that translocation into marine sediments results in stable carbon appears to be based on assumption and not a clear scientific basis ("It is reasonable to assume that mobilized Biochar does not decompose"). This could be a particular concern for application of very fine particle sized biochar, which may be more liable to runoff into watercourses or released to air than biochar of a large particle size. Unless there is a robust justification and demonstration that there is a low risk of translocation, this should be considered in a leakage assessment.	We have revised the text in the methodology to address this concern as follows: "It is reasonable to assume that mobilized Biochar does not decompose at a greater rate than Biochar in the soil environment…" Further, it is important to consider that burial of eroded biochar at depositional sites is likely to lead to its enhanced preservation due to unfavorable conditions for microbial activity (Lal, 2003; Berhe et al, 2012). Preservation would be particularly enhanced at oxygen-deprived depositional sites such as lake sediments, river and coastal sediments and ocean sediments (Rumpel et al 2014).	Accepted – no further comment	
A2.3	Concerning Mean Residence time (MRT) of biochar across studies. • The range from decadal to millennial is not comforting. Skeptics will have	• Yes, but this is a scientific reality: biochars have different mineralization rates	We agree that the MRT data is very widely scattered.	We cannot verify and refute anecdotal evidence without proof or reference. In

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	a field day with this Table. • Relevant data exists regarding the shipment of charcoal across oceans, but currently this data is confidential to the industries involved. I am able to reveal the following. During a period of about 6 weeks that the charcoal is in the ship's hold where it is covered and well isolated, about 14 kg of charcoal is lost to oxidation per 100 kg of charcoal shipped. The arrival of carbon is about 75 kg per 100 kg of carbon shipped. During shipment the volatile matter (VM) content of the charcoal, as represented by hydrogen, almost doubles; and the VM content, as represented by oxygen, more than doubles. Thus at ocean temperatures (<20 C) charcoal fixed-carbon is "rapidly" (i.e. over 6 weeks) converted to volatile matter accompanied by overall weight loss and loss of carbon as CO2. This chemistry is strongly affected by the humidity of the environment. • The large range of MRT displayed in Table A2-1 may in part reflect variations in the moisture content of the soil and its effect on biochar	(some of this is a result of different material properties, some of it is a result of different experimental conditions). • This is an interesting but essentially anecdotal scenario and we thus cannot review and respond to factors that may have led to this result. For example, we do not know whether this material is pyrolyzed wood or coal, nor what the starting H:C_{org} ratio of the material was? The oxidation of charcoal in a ship's hold is vastly different from that of biochar in soil. We do not find this a useful comparison.	The "material" is low VM wood charcoal that would be expected to be very stable in the soil. We plan to report our findings at the forthcoming EUBCE 2014 meeting. Our paper will include the starting H:Corg ratio. A ship's hold is a very benign environment relative to the soil. The charcoal was exposed to nothing but charcoal and humid air. This comparison is useful because it indicates the need for improvements in our knowledge of charcoal stability. Charcoal is not stable under conditions where it ought to be stable.	addition, they are in contrast to any published evidence and multiple studies and would need to be provided to be useful as a discussion point. We request that such arguments are not utilized in a review process.

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	oxidation. In my opinion, more research is needed to understand the MRT of biochar in soils. This understanding is likely to include an understanding of the charcoal oxidation chemistry that occurs in a ship's hold as described above.			
A2.4	Concerning the content of volatile matter (VM). • Raw wood can have a VM content of 80% or somewhat less. Figs. A2-6 and A2-7 span a range from 80% to 0% VM, thus they span a range from raw wood to biocarbon. In Appendix 1, section 4 biochar is said to have increased stability relative to wood, but these Figures incorporate raw wood into their data. Thus the use of these figures is self-contradictory to the interests of the methodology. • Fuel scientists require a VM content of <40% to <30% (varying from country to country) to characterize "biochar" as charcoal. In my opinion the data in Figs. A2-6 and A2-7 should be restricted to VM < 40%. • If the data is restricted in this way, all the biochars had a half-life of 100 years or more, and most had a half-life of 1000 years or more.	• Only Fig A2-6 incorporates "biomass and natural black C" (not necessarily "raw wood") data (open circles). It can be assumed that the data with low VM content and O:C ratios are the natural black C portion of those data. So the figures are not self-contradictory. • Both figures are illustrative of why VM is not used as a method to predict biochar C stability. The cut-offs of VM <40% are thus not relevant. • Agreed, but VM is not	So we don't know the actual identity of the data in Fig A2-6 and we must assume it is "natural black C"?? In any case, data in Fig A2-6 span a range from raw wood to biocarbon. The breadth of this range obscures the desirable behavior of charcoal and biocarbons. Engineers are well acquainted with correlations based on non-dimensional numbers. Often the first correlation that comes to mind is not the most effective. Persistence is needed. The correlation based on	The suggestion from this reviewer is to use the ratio %fC/%VM as an indicator of stability and "hone in" on biochars having a %VM <40%. However, as discussed in numerous sections in this 2nd response, we maintain that the scientific body of evidence adequately supports H/Corg as a predictor of biochar carbon stability.

	1st review	Response	2nd review	Response
	• In my opinion, proximate analysis has been "short-changed" in this work. More attention needs to be given to the use of fC and VM in the prediction biochar half-life.	the chosen methodology for measuring biochar C stability. • The panel of experts that reviewed biochar C stability test methods compared numerous different methods including proximate analysis using existing datasets and published papers (i.e., not opinion based) and selected $H:C_{org}$ as the most appropriate method.	H:Corg is not good, and a correlation based on VM (alone) would be expected to be unsatisfying. I suggested a promising correlation, which employed VM as well as other measurements, to one of the "experts". My suggestion was ignored. So this is the problem: the definition of "biochar" is too all encompassing, and not enough effort has been made to find a convincing correlation.	
A2.5	Concerning H/C_{org}. • As correctly noted above Fig. A2-6, VM is well correlated to H/C ratios (especially for VM<40%). If VM is not correlated with biochar half-life, how can H/C expected to be correlated with biochar half-life? • As above, in my opinion the range of H/C_{org} is too large to be representative of stable charcoal addition to the soil. Because this range does not represent true	• Within certain ranges of VM, they are correlated (see Enders et al 2012), but not for the entire range of VMs. We do not argue that VM is not correlated with biochar persistence (i.e., half-life). Many papers have shown it e.g., Zimmerman 2010, Whitman et al 2013. But	This is an insightful response. The methodology attempts to include too many waste products (e.g. "manure biochar") under the umbrella of "biochar" and thereby incurs poor correlations and dubious results.	Inclusion of a wide variety of different biochars with different properties strengthens the approach, as it allows quantification of biochar properties (here, the H/Corg ratio) to be used to conservatively predict biochar persistence.

<table>
<tr><th></th><th>1st review</th><th>Response</th><th>2nd review</th><th>Response</th></tr>
<tr><td></td><td>charcoal, it obscures the values of BC_{+100}.
The metallurgical industry uses charcoals with low VM=7.3%, fC=89.7%, and H/C_{org}=0.17 (not accounting for inorganic carbon), to medium VM=14.8%, fC=82.2% and H/C_{org}=0.31. These charcoals, of which hundreds of thousands of tons are produced for metallurgical applications each year, span a range of values that are not even represented in Fig. A2-9 (the values are too far to the left to appear). This observation reveals my chief point: this methodology lacks a focus on true charcoal.
Note that Fig. A2-4 does not correctly represent the elemental composition of charcoal employed by the metallurgical industry.
I remark that, because the use of charcoal in the metallurgical industry replaces coking coal as a reductant, this use of charcoal effectively fights climate change. The ACR would be well advised to give credits to the metallurgical industry when it employs charcoal as a reductant.</td><td>across all biochars, including manure biochars, the $H:C_{org}$ ratio produces better results.
There are no data to back up this opinion.
This is true because it is not a methodology that caters to charcoals made as fuels, but rather to biochars made as soil amendment. Metallurgical charcoal would fall in the range of very persistent biochar as per the classification scheme proposed here.
This methodology does not focus on charcoal for the metallurgical industry.
This may be an appropriate approach but we cannot comment on it as it falls outside the scope of the proposed methodology.</td><td>This is a truly disappointing response. The authors admit that metallurgical charcoal would be a very persistent biochar; yet its composition is not well represented in the methodology. Why neglect the most promising biochar? The methodology encompasses too wide a range of “biochars” and thereby overlooks the most promising candidates for carbon sequestration.</td><td>We agree with the referee that the regressions are poor, but only to a small extent due to variations in biochar properties (which are captured as the H/Corg ratio), but to a greater extent due to different soils, organic carbon of soils, different moistures and fluctuating vs constant moisture and temperature regimes. Therefore, this methodology adopts a conservative approach and does not utilize the mid-point (i.e., a regression) but the lowest points below which biochar remaining after 100 years is unlikely to fall (using a statistical approach).</td></tr>
</table>

	1st review	Response	2nd review	Response
A2.6	Concerning Gamma methods. • From a purely scientific perspective these methods are interesting, but an enormous effort would be required to relate these methods to BC_{+100}. • In particular, researchers with the Hungarian Academy of Sciences (HAS) have been using Py GC/MS for nearly 30 years to study biomass, charcoal, and coal pyrolysis and oxidation (Varhegyi et al, 1988; Varhegyi et al, 1988b; Varhegyi et al, 1989; Szabo et al 1990; Jakab et al 1991; Szabo et al, 1996; Varhegyi et al, 1998; Varhegyi et al, 1999; Tam et al, 2009; Meszaros et al, 2007). As far as I know, no Py GC/MS results have been successfully correlated with biochar lifetimes in the soil. An enormous effort would be needed to accomplish this goal. • It seems to me that this discussion of gamma methods could mislead the non-expert into believing that we are closer to using biochar molecular properties to predict biochar lifetimes than we actually are. A very costly effort will be required to realize this goal.	• Agreed, it is stated in Appendix 2 that the Gamma methods "are not expected to be used by Biochar producers for determining Biochar C stability." Instead Gamma methods are used by researchers to validate Alpha and Beta methods to improve on more readily accessible methodologies for predicting biochar C persistence. • No comment We maintain that gamma methods are critical support for alpha methods (in this case $H:C_{org}$), which are low-cost methods.	We agree that gamma methods are desirable. Readers of the methodology need to understand the enormous effort that will be required to make these methods useful.	Indeed, and there is ongoing research to develop gamma methods that support this work. It is the intention of the methodology developers to incorporate relevant advances in science into the methodology as they are validated and published in the literature.

	1st review	Response	2nd review	Response
A2.7	Concerning biochar transport mechanisms. • Biochar is highly friable. The transportation and distribution of biochar will create much charcoal dust. Although this dust may eventually sequester carbon, it is also likely to be a health hazard. • I agree that mineralization biochar C via DOC is likely to be minor, but the moist oxidation of biochar in the soil, as mentioned in 4.2 above, should not be overlooked.	• Production of dust and particulate matter is a valid concern with biochar production and use. To this end, the IBI Biochar Standards require that users follow all relevant regulations related to emissions, transport, and worker safety, and best industry practices including the recommendation for a MSDS for the biochar (see Section 3.2 General Biochar Production and Material Handling Recommendations). When mineralization studies of biochar in soils are undertaken they are moist under field or laboratory conditions.	We hope that the standards and regulations will be enforced.	No comment
A2.8	Concerning future improvements to Alpha, Beta, and Gamma methods. • A small round-robin study of the precision of charcoal proximate analysis exists in the literature (Antal et al, 2000). More work is needed to	We agree that further research into biochar C stability including round robin studies of alpha methods will always be useful. However, we	The Discussion on p. 122 of the need for "ring trials" and other improvements, and the costs involved, is good.	No comment

	1st review	Response	2nd review	Response
	measure the true precision, and this work will be costly. • Some effort has been made to measure the precision of elemental analysis of biomass and charcoal (Wang et al, 2013), but more work is needed and this work will be very costly.	propose that current peer-reviewed data sufficiently support the use of $H:C_{org}$ as a predictor of biochar C stability.		

Appendix 3: Priming of SOC Mineralization by Black Carbon

	1st review	Response	2nd review	Response
A3.1	There is a point of confusion here. There is a statement on page 125-126 that the mineralization of dissolved biochar transported into another environment is minor. This is not consistent with the use of the 0.5 factor for DOC_f presented on page 62-63. The 0.5 factor implies that 50% of the DOC pool solubilized from biochar is degradable. The two statements should be in sync.	DOC_f as defined on page 62 refers to its use in Equation 6 used to calculate emissions from Anaerobic Decomposition in a Solid Waste Disposal Site (Alternative baseline scenario). DOC_f then pertains to the DOC in the feedstock, not in the biochar, and is assigned a default value of 0.5 according to recommendations in IPCC 2006 Guidelines for National Greenhouse Gas Inventories.	Ok.	
A3.2	On p. 126, the idea that inorganic carbon form in biochar is minor really depends	Please see Enders et al (2010) and other papers.	Ok.	

	1st review	Response	2nd review	Response
	on the pH of the biochar. Many biochars produced by high temperature pyrolysis (>500 to 700°C) have alkaline pHs. A few articles (Yuan et al., 2011; Tsai et al., 2012) have scanned these alkaline biochars using X-ray diffraction and reported minor amounts of carbonate species (calcite and dolomite). So, this finding is consistent with the wording 'IC is likely negligible…".	Inorganic C is minor (less than 5% for most biochars, some manure biochars have 20% inorganic C). Virtually all wood-based biochars have negligible amounts of inorganic C. pH can be high without appreciable amounts of inorganic C. There seems to be no disagreement, but the reviewer supports the arguments made.		

Appendix 4: Sustainable Feedstock Criteria

	1st review	Response	2nd review	Response
A4.1	The term "forestry slash" is wide open for misinterpretation. Suggest a much tighter definition, for example tops and branches not exceeding x diameter. Refer to bioenergy and forestry standards for applicable definitions. The Forest Feedstocks section would benefit from review and strengthening of requirements: Why is PEFC excluded from the list of applicable schemes? SFI	1) A review of bioenergy and forestry standards (including FSC) failed to identify a definition of "forestry slash" that included dimensions of slash. We revised the text in the Methodology according to the American Society of Foresters definition of slash http://dictionaryofforestry.org/dict/term/slash. 2) We revised the methodology to allow PEFC and other national-level forest certification programs. 3) Our review of the SFI Standard indicates that certification and auditing is a requirement;	2) PEFC encompasses national schemes including SFI, ATFS and AFS. Suggest removing text allowing any other national standards (which may not meet the PEFC/ FSC standard). If PEFC certification is required, then this limits the risk of SFI fiber which may now	We have revised the text to remove references to specific national standards. Added Chain of Custody certification to clarify this requirement to trace woody feedstocks. No minimum % content is stated

	1st review	Response	2nd review	Response
	feedstock can be from certified forests, or 'legal and responsibly' sourced supply; the latter does not require sustainable forest management (SFI, 2010). Also, there is not a minimum % content stated for 'sustainable' forest. RSB is referenced for Agricultural Feedstocks, but this standard only requires a 'limited' level of assurance (RSB, 2011), so would not necessarily meet the ACR 'reasonable' assurance requirements. An expanded definition of what constitutes agricultural residues should be included.	in other words, there is no option receive SFI certification simply by demonstrating "legal and responsibly" sourced. Please see text from (SFI, 2010): "To meet the fiber sourcing requirements, primary producers must be third party audited and certified to the SFI Requirements: Section 2 – SFI 2010-2014 Standard (Objectives 8-20)", as well as the text contained within Section 2. 4) Revised the text to state that "all" feedstocks derived from forestry or ag residues must prove sustainable harvest. 5) RSB states that "the lead auditor appointed shall use any and all effort necessary to establish to the satisfaction of the certification body (i.e. "limited assurance level") compliance or non-compliance of the operation(s) identified in the certification scope of the participating operator with the RSB standards and the RSB certification systems. (RSB, 2011)" We contend that because the auditor is required to use "any and all effort necessary" to demonstrate compliance to the RSB standard, ACR's reasonable assurance definition in its Validation/ Verification Guideline is met. 6) Added a definition in Appendix 4 for agricultural residues.	be certified. The section should be clarified to state full chain of custody from certified forests under FSC or PEFC. Forest owners may have certified and uncertified forests, and full chain of custody requirements are the only way to ensure certified timber is used. There is still no minimum % content stated for sustainable forest materials. 5) Limited assurance does not equate to reasonable assurance – simple as that.	because the requirement is that all (100%) of forest feedstock is sustainably harvested. "All feedstocks derived from forest residues must provide substantive proof of sustainable harvest".
A4.2	Copious smoke usually accompanies the production of biochar. This smoke	We disagree that copious smoke accompanies biochar production. Thermochemical conversion of feedstocks to biochar, when	Brazil is among the world's largest producers of biochar.	The methodology requires that production

	1st review	Response	2nd review	Response
	constitutes a serious health hazard for anyone in the neighborhood of the carbonization facility (Gomes & Encarnacao, 2012). Unless the carbonizer is engineered to the environmental standards required in the USA, the production of biochar will not be sustainable.	properly executed, results in low levels of air emissions that fall below existing regulatory thresholds for air emissions. Further, this concern is specifically addressed in Applicability Condition (6) which requires biochar producers to meet all applicable local, regional, and national air quality standards.	Reference by Gomes and Encarnacao that I cited describes in detail the serious health impacts on nearby communities of smoke from biochar production in Brazil. If biochar is produced by farmers using backyard technology, emissions will be a serious problem.	technologies meet industrialized country emissions requirements, which negates the potential for emissions problems as suggested.
A4.3	Sewage sludge is mentioned as an example of "non-toxic biosolids". Actually, heavy metals (e.g. arsenic, mercury, lead, etc.) are nearly always present in sewage sludge (Yoshida & Antal, 2009), and these heavy metals can preclude the addition of sewage sludge biochar to the soil. More emphasis should be given to the environmental impacts of heavy metals contained in biochar.	The *IBI Biochar Standards* require testing of biochar for all heavy metals regulated under the US Code of Federal Regulations Title Part 503 Biosolids Rule. The Maximum Allowed Thresholds for heavy metals in the *IBI Biochar Standards* are taken directly for biosolids limits under this rule. Please see Appendix 3 of the *IBI Biochar Standards* for further information.	Sewage sludge should not be mentioned as an example of "non-toxic biosolids". Due to its heavy metal content, sewage sludge is a problematic feedstock for carbonization.	Sewage sludge has been removed from this methodology as a potential feedstock. As stated in IBI Standards, toxic materials are not qualified and testing is required to ensure potentially toxic feedstocks are non-toxic prior to

	1st review	Response	2nd review	Response
				adding to the soil. Non-toxic biosolids remains an eligible feedstock, as this term is used to describe municipal treatment plant solids which are tested and determined to be safe for land application. Non-Toxic Biosolids was added to the defined terms in this methodology.

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