



Bringing Biochar Projects into the Carbon Marketplace

An introduction to biochar science, feedstocks and technology.

By John Gaunt and Keith Driver
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Note to Reader

This primer document supports an initiative from Carbon Consulting and Blue Source, along with founding sponsors Carbon War Room and ConocoPhillips Canada, to create a protocol for the development of projects and the quantification of greenhouse gas emission reductions across a variety of biochar projects and technologies. The primer is not intended to be comprehensive, but rather to serve as a common basis and framework to facilitate discussion as we move forward. This initiative will ultimately utilize industry expertise to develop a comprehensive, broad-scope framework for a biochar methodology.

This protocol development project is being completed in the public domain, including resource materials and events to solicit input from the biochar and carbon finance communities on the science and policy implications behind biochar. We encourage all interested stakeholders to become involved, and we ask that you take the time to read this document in its entirety. This will build an educated constituency to support the biochar protocol development process and ensure that your valued input is most effectively utilized.

Our goal is simple: to open carbon markets to biochar and pyrolysis technologies.

For more information on this initiative, please visit our website at: www.biocharprotocol.org.

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Glossary

Additionality

Measure of whether a project is incremental to the business-as-usual case. Often used as a key measure of whether a project should be considered eligible for the creation of carbon offset credits. This term has different definitions and uses across carbon offset systems.

AFOLU

Used under the VCS and otherwise to describe Agricultural, Forestry and Other Land Use projects. These projects involve processes and practices that impact the carbon and nitrogen cycles across a landscape.

Aggregation

The practice of bundling small offset projects to overcome the economies of scale associated with carbon offset documentation, certification, and commercialization.

AOS

Alberta Offset System, the regulatory regime for offset credits in Alberta.

Baseline

The emission of greenhouse gases that would occur without the contemplated policy intervention or project activity.

C

Carbon.

CaCO₃

Limestone used to compensate for effects of soil acidity.

CaO

Quicklime used to compensate for effects of soil acidity.

Carbon offset or credit

Generic units used to describe the verified and certified reduction or sequestration of one ton of carbon dioxide equivalents (CO₂e).

Carbon offset system

Voluntary or compliance-based program for the certification and recognition of carbon offsets. These programs are typically broadly scoped across project types with codified rules designed to accommodate a diverse set of interests.





CDM

Clean Development Mechanism, the carbon offset certification body established under the Kyoto Protocol for projects implemented in developing nations.

CH₄

Methane a greenhouse gas with a global warming potential 25 times greater than CO₂ over a 100-year period.

CO_{2e}

Carbon dioxide equivalents.

Double-counting

The attribution of a GHG emission reduction or sequestration benefit multiple times. This is a significant concern for ensuring the integrity of carbon offset systems.

Emission Reductions (ERs)

The measurable reduction of release of greenhouse gases into the atmosphere from a specified activity or over a specified area, and a specified period of time.

GHG

Greenhouse gas, typically including the six common gases of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). All GHGs can be related back to a common unit of CO_{2e} by multiplying the emissions of a given gas by its global warming potential.

Leakage

Term used to describe a situation where an emission reduction measured in one instance results in a measurable increase in emissions elsewhere.

Methodology

A quantitative approach to analyzing the emission reductions from a given project. Methodologies are embedded within a protocol and may otherwise lack the overlay of the applicable carbon offset system guidelines.

N₂

Nitrogen gas. Produced in soil through denitrification, where heterotrophic denitrifying aerobic bacteria cause respiratory reduction of nitrate or nitrite to N₂O and N₂ under anoxic conditions.

N₂O

Nitrous oxide, a greenhouse gas with a global warming potential 310 times greater than CO₂ over a 100-year period. Produced in soil through denitrification, where heterotrophic denitrifying aerobic bacteria cause respiratory reduction of nitrate or nitrite to N₂O and N₂ under anoxic conditions.





NH₄

Ammonium is a positively charged polyatomic cation – a form of nitrogen found in soil as a result of the breakdown of organic matter and/or addition of fertilizer.

NO₃

Nitrate is a negatively charged polyatomic anion – a form of nitrogen found in soil as the result of a biological process called during nitrification (i.e. conversion of NH₄ to NO₃) or the addition of fertilizers.

Offsets

See Carbon offset above.

Permanence

A measure of whether the carbon emission reduction or sequestration has a lifespan greater than or equal to the lifespan of a GHG in the atmosphere. Permanence of reversible emission reductions or sequestration opportunities is assessed differently across carbon offset systems.

Protocol

A codified quantification methodology approved by a carbon offset system suitable for use as a carbon market access mechanism. Protocols include a quantification methodology and the overlay of carbon offset system guidelines, within a given document format. Each carbon offset system has a development and approval process for protocols.

VCS

Voluntary Carbon Standard, an international standard for use in the voluntary carbon markets. Largely viewed as a pre-compliance standard in the United States.





1. Biochar Protocol Development's Vision

The responsible deployment of biochar will make a significant positive impact in the fight against global climate change by offering a strategy to draw down carbon dioxide from the atmosphere. To accelerate the delivery of this impact, we will open up carbon markets to biochar and pyrolysis technologies by creating a protocol for the development of projects and

quantification of greenhouse gas emission reductions and removals. This public-domain protocol will be applicable across a wide variety of biochar projects and technologies, enabling even small-scale projects to be rewarded for their contribution to withdrawal of carbon dioxide from the atmosphere.

2. Introduction

Human-induced carbon emissions are in the order of 25 billion tons (gigatons (Gt)) carbon dioxide (CO₂e) annually. Current atmospheric CO₂ levels are approximately 392.94 ppm or 3,144 Gt CO₂ (1 ppm CO₂ equates to approximately 8 Gt CO₂ in the atmosphere), exceeding what is generally regarded as a safe limit of 350 ppm CO₂ by 344 Gt.

If we accept that levels of CO₂ in excess of 350 ppm in the atmosphere pose a threat to our environment, then the dual challenges that face us are 1) to remove CO₂ from the atmosphere and stabilize it against re-release, and 2) to reduce the rate of release of CO₂ to the atmosphere.

Growing plants draw down 440 Gt CO₂ annually as they grow to produce carbon-containing biomass. Of the CO₂ captured by growing plants through photosynthesis, 50% is retained in plant biomass and 50% is released as CO₂ through autotrophic plant respiration. During plant death, and the decomposition of organic material, carbon stored in biomass is re-released to the atmosphere within a matter of months to years, dependent on various factors. Thus the

annual flux of C from soil to the atmosphere is estimated at 220 Gt CO₂.

Biochar represents an opportunity to harness the natural C cycle, using growing plants to effectively drawn down CO₂ from the atmosphere.

2.1 Background on Biochar

Pyrolysis is a thermo-chemical process where biomass is heated in the absence of oxygen (or partially combusted in the presence of a limited oxygen supply). All pyrolysis systems produce some char as a product; additional pyrolysis co-products include energy products such as liquid fuels, heat, and electricity.¹

The char material is thermally transformed, or modified, from its original structure. Brown² defined *char* as "any carbonaceous residue from pyrolysis including natural fires"; *charcoal* was

¹ Yaman, S. (2004) Pyrolysis of biomass to produce fuels and chemical feedstocks. *Energy Conv. Manage.* 45, pp 651-671.

² Brown R. 2009. *Biochar Production Technology*. In.

Lehmann, J. and Joseph, S (2009) *Biochar for Environmental Management*. pp 127-146.



defined as “char produced from animal or vegetable matter for use in cooking or heating”; and *biochar* as “carbonaceous material produced specifically for agricultural or environmental management.”

When added to soil, biochar continues to store carbon and enhance soil quality. Using biochar on farm fields can increase agricultural production without increasing cropped area, all the while reducing fertilizer and water inputs.

Biochar has a significant positive impact on the fight against global climate change, which even surpasses the importance of its agricultural benefit.

During the conversion of biomass to biochar, about 50% of the original carbon is retained in the biochar.

Carbon contained in biochar is believed to have long mean residence times in soil, ranging from 1,000 to 10,000 years, with 5,000 years being a common estimate.^{3,4} Without thermal stabilization, the same biomass will release all the C it contains to the atmosphere in a short period with much of the C being lost within a few months and with the majority of the C being lost within 10 years.

Thus where prior management for biomass includes incorporation in soil, agricultural burning, composting, or even biofuels, biochar represents an opportunity to lock in and

stabilize the carbon that decomposing plants would otherwise release into the atmosphere.⁵

Although stabilisation of C in biochar represents an important sequestration pathway, overall, biochar combats climate change through:

- avoided emissions when biomass residues are diverted as feedstocks for pyrolysis;
- enhanced C storage in biochar resulting from the thermal transformation of C contained in feedstocks and the application of biochar to land;
- avoided fossil fuel emissions where pyrolysis is deployed as a bioenergy technology;
- reduction in agricultural emissions of N₂O and CH₄; and
- savings in fertilizer and other inputs associated with the application of biochar to land.

From available published and peer-reviewed literature, it can be shown that not all biochar is created equal. Key chemical and physical properties of biochar are greatly affected both by choice of feedstock (crop waste, energy crop, wood chip, municipal waste, manure, etc.) and process conditions (rate of heating, final temperature of pyrolysis, and residence time).

The influence of the highest treatment temperature on biochar structure is represented schematically below (Figure 1). As physical structures change, so do the micro-chemical, organo-chemical, nutrient, and biological properties of biochar.

³ Cheng, C., Lehmann, J., Thies, J., and Burton, S. (2008). Stability of black carbon in soils across a climatic gradient *J. Geophysical Res.* Vol 113. G02027, 10 PP

⁴ Warnock, D. D. Lehmann, J. (2007). ‘Mycorrhizal responses to biochar in soil – concepts and mechanisms’ *Plant & Soil.* vol 300. pp9-20

⁵ Lehmann, J.; Gaunt, J.; Rondon, M. (2006) Biochar sequestration in terrestrial ecosystems – a review. *Mit. Adapt. Strat. Global Change*, 11, pp 403-427.



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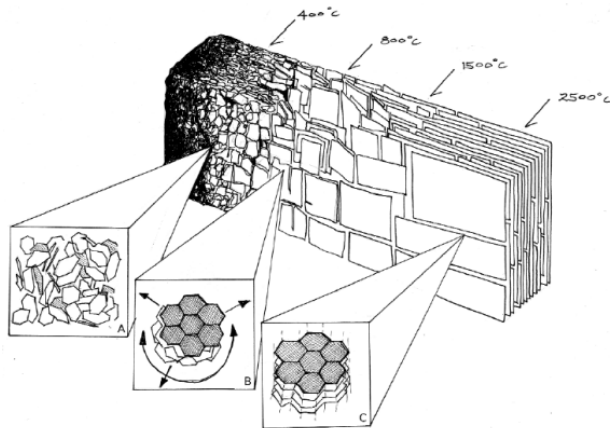
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The influence of process conditions on the characteristics of biochar have recently been thoroughly reviewed and summarized, and we do not repeat this material here; rather readers are referred to the publication edited by Lehmann and Joseph.⁶

Figure 1 Development of biochar structure with highest treatment temperature.



Source: Downie et al. 2009.⁷
 © Johannes Lehmann and Stephen Joseph

The properties of biochar determine how it influences soil characteristics as well as its permanence when added to soil.

While there is much to be learned about how the properties of biochar can be managed to maximize agricultural and environmental performance, the factors that determine the C stability of biochar are understood and it is clear that charcoal produced from conventional

animal and vegetable feedstocks is very stable compared to uncharred biomass.

When used as a soil amendment, biochar continues to store carbon and act as a soil quality enhancement. Using biochar on farm fields can increase agricultural production without increasing cropped area, while reducing fertilizer and water inputs. It is believed that biochar works as a soil conditioner by providing habitat for soil microorganisms, which in turn may aid in making some nutrients available to crops, reducing leaching of nutrients, improving overall soil structure, and enhancing soil moisture retention.

A number of authors have reported significant yield increases when biochar is applied to agricultural soils (see Table 1 for a selection of representative results from field trials), and field trials are currently under way across the globe, including in the U.S. under the guidance of the U.S. Department of Agriculture.

Table 1 Yield increases reported for selected field trials with biochar			
Crop	Yield	Biochar	Reference
Beans	+46%	90g/kg	Rondon, 2007
Carrots	+100%	30 t/ha	Rondon, 2004
Cowpea	+150%	67 t/ha	Steiner, 2002
Maize	+30%	20t/ha	Rondon, 2006
Maize	+51%	10t/ha	Van Zwieten, 2008
Maize	+50%	15t/ha	Yamato, 2006
Maize	+91%	n.a.	Oguntunde, 2004
Maize	+100%	6t/ha	Kimetu, 2008
Rice	+>100%	8t/ha	Nehis, 2002

⁶ Lehmann, J. and Joseph, S (2009). *Biochar for environmental management: science and technology*. Earthscan, UK

⁷ Downie, A, Crosky, A and Munroe P. (2009). Physical properties of biochar in J. Lehmann and S. Joseph (eds) *Biochar for environmental management: science and technology*. Earthscan. UK.



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Gaunt and Cowie⁸ signal the importance of establishing a value for biochar as a product and the potential for a wide range of markets. At this stage it is too early to define these. However, it is already clear that they will likely extend beyond field crop agriculture to include sectors such as horticulture, turfgrass, land remediation, and restoration. In some situations, biochar will enter retail channels. Biochar may also be used as a constituent of animal feed by blending or substituting for traditional rations, thereby reducing rumen emissions and also reducing emissions from faeces.

It can also be anticipated that rather than being used as biochar, charcoal may be used itself as an energy product, “green coal,” or as a densified and stabilized waste that could be returned to landfill or used as a construction material. Economics will determine the outcome and final uses of biochar.

A net emission reduction and biochar deployment must also be supported by a sustainable feedstock supply and environmentally and socially responsible practices. There is an important role for efforts to establish best practice within the emerging biochar industry. The purpose of this effort is not to define these practices, nor to constrain innovation, rather to inform the development of carbon offset methodology that will enable this innovation to flourish and best practices to be established and demonstrated.

To do this we propose to facilitate the development of universally applicable biochar protocols for carbon capture and storage that will enable biochar operators of a diversity of

scales and feedstocks to meet and participate in the carbon markets, without the costs of developing a project-specific methodology.

Implementing a high-quality offset program will require transparency and credible verification. This includes clear and transparent project documentation requirements, high quality independent verification to support regulatory review, and regular program review and adjustment. Widely applicable biochar protocols will alleviate both costs and administrative burdens for future project-specific protocols.

As is described in the primer “*Bringing Biochar Projects into the Carbon Marketplace: An introduction to carbon policy and markets, project design, and implications for biochar protocols,*” there has been a general evolution of protocols toward an ISO 14064 pt II approach. The ISO 14064 standard provides a high-level approach for developing protocols based on the systematic and comprehensive identification and analysis of the sources of emissions, carbon sinks and carbon reservoirs. The Clean Development Mechanism (CDM) may be the only notable exception to the move toward ISO 14064 pt II.

Approaches for methodology development are increasingly moving toward an in-depth grounding in the relevant peer-reviewed literature as well as national and international best practice guidance. This puts increasing responsibility on protocol developers to demonstrate a thorough scientific analysis, ensuring that the quantification methodology conforms to these varied, evolving sources of information.

The purpose of this document is to frame the issues and to identify key questions that will need to be addressed as we move forward to develop a protocol.

⁸ Gaunt, J and Cowie, A. (2009). Biochar, Greenhouse Gas Accounting and Emissions Trading in J. Lehmann and S. Joseph (eds) *Biochar for environmental management: science and technology*. Earthscan. UK.





3. Mitigation Benefits of Pyrolysis for Biochar and Bioenergy

As was discussed in the sister primer: *“Bringing Biochar Projects into the Carbon Marketplace: An introduction to carbon policy and markets, project design, and implications for biochar protocols,”* we anticipate that the offset opportunity from biochar will likely be developed through a relatively small number of platforms representing distinct configurations of biomass feedstocks, pyrolysis technologies, and biochar and energy products at a range of scales. The pathways by which a platform will deliver avoided emissions were summarized above as:

- avoided emissions when biomass residues are diverted as feedstocks for pyrolysis;
- enhanced C storage in biochar resulting from the thermal transformation of C contained in feedstocks and the application of biochar to land;
- avoided fossil fuel emissions where pyrolysis is deployed as a bioenergy technology;
- reduction in agricultural emissions of N₂O and CH₄; and
- savings in fertilizer and other inputs associated with the application of biochar to land.

Each of these pathways is discussed further below and will be addressed through the protocol development process.

3.1 Avoided Emissions from Change in Feedstock Biomass Management

The conventional management of biomass often leads to release of methane (CH₄) or nitrous oxide (N₂O) as the biomass decomposes under

anoxic conditions. For example, urban green waste (tree trimmings and garden waste) deposited in landfills releases significant quantities of CH₄, while animal manures rich in both C and N often break down to release CH₄ and N₂O. CH₄ and N₂O are greenhouse gases (GHGs) with global warming potential 25 and 310 times greater than CO₂.⁹ Management strategies that avoid these emissions can therefore contribute significantly to mitigation of climate change.

As was discussed above, many types of biomass are suitable feedstocks for production of biochar. The quantity of emissions avoided depend both on the nature of the biomass resource and the management change involved, and are well covered by existing methodologies.

3.2 Fossil Fuel Displacement

The net energy output from pyrolysis will depend on the feedstock properties and pyrolysis process deployed. Energy streams can include syngas, bio-oils, and heat. These renewable energy sources can be used to displace fossil energy sources.

The mitigation benefit will depend on the application (heat, electricity), which determines

⁹ Forster, P., Ramaswamy, V., Artaxo, P., Bernsten, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prin, R., Raga, G., Schulz, M. and Van Dorland, R. 2007. ‘Changes in atmospheric constituents and in radiative forcing’ in S. Solomon, D. Qin, M. Manning, Z. Chen, M., Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK



the efficiency of conversion and emissions intensity of the fossil fuel source displaced (for example, there is greater benefit from displacing coal than natural gas due to the lower emissions intensity of natural gas).

This category would also capture situations where biochar was itself used as a source of energy.

3.3 Enhanced Carbon Storage

Non-transformed biomass C added to soil decomposes rapidly through the actions of soil fauna and microorganisms. In this decomposition process, soil microbes digest organic matter, respiring CO₂ back to the atmosphere and simultaneously releasing plant nutrients. The pattern of breakdown of organic matter in soil and associated release of CO₂ is well-understood: The majority of organic matter is composed of labile fractions that decompose rapidly, over one to five years; the very small amounts of more stable organic matter fractions break down over decades to centuries; while the most recalcitrant fractions turn over in several hundred to a few thousand years.¹⁰ The net result is that the bulk of C added as biomass is rapidly released back to the atmosphere as CO₂ within 10 years.¹¹

There is considerable interest in storing or sequestering C in soils. Fundamental to whether or not a change in management has added to the total terrestrial C stocks is the need to demonstrate that the sequestration is real. This

requires one of the following conditions to be met:

1. The proportion of the organic matter added to soil that is resistant to decay has been changed due to a manipulation of the characteristics of biomass, e.g. *through plant breeding to change lignin content of biomass or thermal transformation of biomass by pyrolysis*
2. Soil environmental conditions have been altered in a way that slows the rate of release of CO₂ from biomass added to soil, e.g. *adoption of reduced cultivation or no-till practices that change the soil environment to reduce the rate of decay*
3. Increased production of biomass per unit area due to enhanced productivity, e.g. *improvements to soil fertility, replacing existing biomass species that capture more C*

Due to the complex nature of soil systems and the need to demonstrate permanence of C sequestered, many of the current claims of soil C sequestration may in time be shown to be flawed. For example, it is argued that application of compost to soil leads to C sequestration. Unless evidence is presented that conditions 1 or 2 are met, the apparent increase in soil C is not sequestration, rather the result of the transfer of organic matter from one location to another. This is an example of leakage.

We discuss the potential for biochar to result in C storage further below.

Stabilization of Biomass C Directly in Biochar

Pyrolysis of biomass creates a real increase in terrestrial C stocks because it stabilizes biomass C. As discussed above, the thermal conversion of biomass to biochar fundamentally alters the decomposition of the feedstock biomass.

¹⁰ Davidson, E. A. and Janssens, I. A. (2006) 'Temperature sensitivity of soil carbon decomposition and feedbacks to climate change', *Nature*, vol 440, pp165-173

¹¹ Jenkinson, D. S. and Ayabana, A. (1977) 'Decomposition of carbon-14 labelled plant material under tropical conditions', *Soil Science Society of America Journal* vol 41, pp912-915



Pyrolysis releases a portion of the C contained in the biomass immediately. This initial release is more rapid than would occur during natural decomposition of the biomass feedstock. However, the energy associated with this release of C can be used for the production of bioenergy, offsetting traditional energy sources. The remaining thermally stabilized material is resistant to decomposition.

The decomposition characteristics of biochar do not mimic other forms of non-thermally transformed biomass. There is an initial rapid phase of breakdown as the volatile and easily accessible organic matter components are broken down. While the transformed organic matter is not inert, evidence to date suggests that the mean residence time is in the order of hundreds to thousands of years. Given the non-transformed feedstock has a mean residence time significantly less than 10 years, it can be appreciated that thermal conversion of biomass leads to a net and real stabilization of biomass C.

Indirect Stabilization of C in Soil

When added to soil, biochar alters the properties of soils and acts to render non-biochar C in soil more stable. Lehmann et al.¹² refer to evidence suggesting organic matter interacts with biochar surfaces increasing stabilization; they further speculate that this stabilization would impact biochar turnover and the stabilized soil C. However, the magnitude and mechanisms of this impact on C turnover has yet to be documented.

¹² Lehmann, J., Czimczik, C., Laird, D., and Sohi, S. (2009) 'Stability of Biochar in Soil' J. Lehmann and S. Joseph (eds) etc.

C Sequestration Due to Enhanced Biomass Production

Biochar has been shown to enhance agronomic efficiency, that is, yield of harvested product per unit of fertilizer input. In high productivity situations, this benefit may be manifest as fertilizer savings; whereas in low-yield situations, crop yields may be increased.

In situations where greater plant growth results from biochar application, there will be greater C sequestration in growing biomass. This may result in increased returns of organic matter to soil. Given that this represents an enhanced capture of CO₂ from the atmosphere, the resulting increase in soil C reflects a genuine sequestration of C, as discussed above.

3.4 Avoided Emissions of N₂O and CH₄ from Soil

Because CH₄ and N₂O are potent GHGs, reduction in these emissions from soil through application of biochar could significantly contribute to mitigation of GHG emissions. This is particularly important in situations where N₂O emissions are greatest, such as in intensively fertilized, irrigated agriculture. Nitrogen (N) fertilizers, biological N fixation by legumes species, and the urine and dung of grazing animals are all potential sources of N₂O emissions. Nitrous oxide is produced in soil during nitrification (i.e. conversion of NH₄ to NO₃) and through denitrification, where heterotrophic denitrifying aerobic bacteria cause respiratory reduction of nitrate or nitrite to N₂O and N₂ under anoxic conditions.¹³

¹³ Wrage, N., van Groeningen, J.W., Oenema, O. and Baggs, E. M. (2005) 'Distinguishing between soil sources of N₂O using a new ¹⁵N- and ¹⁸O- enrichment method', *Rapid Communications in Mass Spectrometry*, vol 19, pp3298-3306





Rondon et al.¹⁴ found that CH₄ emissions were completely suppressed and N₂O emissions were reduced by 50% when biochar was applied to soil. Yanai et al.¹⁵ also found suppression of N₂O when biochar was added to soil. A recent review suggests biochar application may significantly reduce N₂O and CH₄ emissions from soil.¹⁶

We consider two mechanisms by which biochar may impact these losses, first by displacing or reducing the inputs required per unit of production and secondly by impacting the processes that lead to the production of the GHG emissions.

3.5 Displaced Fertilizer and Agricultural Inputs

The use of biochar may displace fertilizer use in two ways: 1) by substituting directly for other sources of fertilizer (e.g. where biochar is produced from nutrient-rich feedstock) and 2) by increasing the efficiency with which fertilizer is used because biochar increases the soils' nutrient retention capacity.

Manufacture of nitrogenous fertilizer is an emissions-intensive process due to the

consumption of natural gas as a hydrogen and energy source. Emissions range from 3-10kg CO₂e kg⁻¹ N, depending on the manufacturing process.¹⁷ Therefore, where the use of biochar reduces the requirement for fertilizer, biochar displaces the emissions associated with manufacture of fertilizer.

The high pH of many biochars and biochar's potential liming ability have been widely recognized. This is important because agricultural soils typically require liming to compensate for the acidifying effect of fertilizers over time. Further, some soil types, for example oxisols, require liming to be productive for agricultural purposes.

Limestone (CaCO₃) and quicklime (CaO) are typically used to increase soil pH. Both result in significant release of CO₂. Limestone breaks down to release CO₂ when applied to soil, and significant emissions arise during the manufacture of quicklime.

Biochar can influence soil structural properties such as the capacity of a soil to withstand stresses without failing (soil strength), soil moisture holding capacity and infiltration. Chan et al.¹⁸ reported that the incorporation of biochar at 50 t ha⁻¹ improved soil moisture holding capacity and reduced soil strength. As fuel used in cultivation is directly related to soil strength

¹⁴ Rondon, M. Ramirez, J. A. and Lehmann, J. (2005) 'Charcoal additions reduce net emissions of greenhouse gases to the atmosphere', in *Proceedings of the Third USDA Symposium on Greenhouse Gases and Carbon Sequestration*, Baltimore, MD, 21-24 March 2005, p208

¹⁵ Yanai, Y., Toyota, K. and Okazaki, M. (2007) 'Effects of charcoal addition on N₂O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments', *Soil Science and Plant Nutrition*, vol 53, pp181-188

¹⁶ Van Zwieten, L., Singh, B., Joseph, S., Kimber, S., Cowie, A., and Yin Chan, K. (2009) 'Biochar and Emissions for Non-CO₂ Greenhouse Gases from Soil' in J. Lehmann and S. Joseph (eds) *Biochar for environmental management: science and technology*

¹⁷ Wood, S. and Cowie, A. (2004) *A Review of Greenhouse Gas Emission Factors for Fertilizer Production*, IEA Bioenergy Task 38, <http://www.ieabioenergy-task38.org/publications/>

¹⁸ Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2007) 'Agronomic values of greenwaste biochar as a soil amendment', *Australian Journal of Soil Research*, vol 45, pp629-634





(e.g., McKenzie and So¹⁹), in situations where biochar application leads to a reduction in soil strength, a reduction in fuel use and associated emissions will result.

Understanding the specific mechanism that biochar exerts on water-holding capacity or water retention, macroaggregation and soil stability is of importance in climate change adaptation, where mitigating drought, nutrient loss and erosion are critical to productive agriculture.

Biochar enhances soil moisture holding capacity and infiltration in some soils,²⁰ which may lead to a reduction in the frequency and duration of irrigation. Therefore, application of biochar to irrigated crops and pastures may reduce the emissions associated with energy use in irrigation.

4. Status of Methodologies

In this section we focus on the challenges associated with establishing a methodology. As is discussed above, a biochar-based project can potentially generate avoided emissions and C sequestration via a number of pathways. Whilst some of these are distinct to biochar, other aspects are already well established, and a protocol for biochar-based projects can utilize these existing methodologies.

The status of existing methodologies is summarized below (Table 2). Methodologies that can be used to capture changes in feedstock management are generally well established, likewise for the production of renewable energy. In many situations, the renewable energy output would be counted as a reduction in GHG emissions from the energy sector in national-level emissions accounting. At the project scale, if implemented outside a capped sector, it could generate a credit for avoided GHG emissions, calculated from the displacement of fossil fuel energy.

¹⁹ McKenzie, D. C. and So, H. B. (1989) 'Effect of gypsum on vertisols of the Gwydir Valley, New South Wales. 2. Ease of tillage', *Australian Journal of Experimental Agriculture*, vol 29, pp63-67

²⁰ Major, J., Steiner, C., Downie, A. and Lehmann, J. (2009) 'Biochar Effects on Nutrient Leaching' in J. Lehmann and S. Joseph (eds) *Biochar for environmental management: science and technology*





Table 2 Emission Reduction Mechanisms

Mechanisms	Description	Key issues	Analogues	Strategy
Waste diversion	Organic materials diverted from situations where they would degrade anaerobically, producing methane and or N ₂ O emissions.	Various models exist for predicting CH ₄ emissions from these sources. Proving diversion can be challenging, thus adding complexity to establishing the baseline.	Considered in a range of protocols across a range of carbon policy frameworks and markets.	Use existing methodologies
Avoided waste combustion	Organic materials that would otherwise have been combusted, producing carbon dioxide emissions.	Various models exist for predicting GHG emissions from these sources. Emissions from combustion of organic materials are considered as a biogenic source of emissions.	Contemplated as a project condition for incineration projects.	Use existing methodologies
Carbon accumulation	Conversion of biomass to biochar sequesters carbon. Incorporation of biochar within the soil matrix can lead to the enhanced sequestration of soil carbon.	Concerns that carbon sequestration in soil is not permanent are being applied to biochar where risks are significantly lower. Soil C sequestration is difficult to measure.	Carbon sequestration considered broadly in forestry and agriculture protocols. No biochar protocol exists.	Review and propose new or revised methodology
Fertilizer efficiency	Biochar may improve fertilizer usage efficiency relative to yield, resulting in lower N ₂ O emissions from fertilizers and reduced CH ₄ production.	Changes in input uses established. Difficult to measure changes in CH ₄ and N ₂ O emissions at a field scale. Modelling of N ₂ O can be resource intensive.	Considered in other agriculture protocols, including a number of fertilizer efficiency protocols under development.	Review and propose modifications if needed
Electricity displacement	Electricity produced from biochar projects may offset electricity produced from fossil fuels.	This is an indirect emission reduction and may not be considered under all programs.	Considered in other projects where there is electricity output, such as landfill gas and energy from biomass combustion projects.	Use existing methodologies
Fossil fuel displacement	Heat, power, and biofuels produced from the biochar projects may offset fossil fuel usage downstream.	This is an indirect emission reduction and may not be considered under all programs. There may be difficulties in direct measurement given the downstream nature of the emission reduction and conversions between equivalent units of energy.	Considered in other projects where there is heat, power, or biofuels being produced, such as landfill gas and energy from biomass combustion projects.	Use existing methodologies

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4.1 Carbon Sequestration

Due to concerns about permanence, leakage, and additionality, sequestration projects are subject to strict criteria governing eligibility, estimation, and reporting, which can escalate transaction costs and restrict participation. Difficulties in accurate monitoring of soil C due to spatial and temporal variation have been raised as barriers to inclusion of agricultural soil management in emissions trading. The Voluntary Carbon Standard (VCS), for example, proposes a method requiring monitoring that involves repeated sampling to prove the permanence of C stored in soil.²¹

However, in contrast, the Chicago Climate Exchange (CCX) has successfully monetized soil C sequestration using conservative defaults to estimate sequestration based on implementation of eligible management practices rather than monitoring soil C change.²²

An alternative approach could be taken to claiming credit for C captured and stored in biochar. Rather than focusing on the increase in soil C stock, credit could be based on the avoided C emissions due to stabilizing organic matter.

As was described above, three mechanisms are claimed for carbon sequestration:

- Stabilization of biomass C directly in biochar through thermal transformation of organic matter
- Indirect stabilization of C in soil by application of biochar to soil

²¹ VCS (Voluntary Carbon Standard) (2007) Guidance for Agriculture, Forestry and Other Land Use Projects, VCS

²² CCX (Chicago Climate Exchange) (2007) *CCX Exchange Offsets and Exchange Early Action Credits*, CCX, Chicago, IL, www.chicagoclimatex.com/docs/offsets/CCX_Rulebook_Chapter09_OffsetsAndEarlyActionCredits.pdf

- C sequestration due to enhanced biomass production

We examine each of these claims briefly below.

Stabilization of Biomass C in Biochar Through Thermal Transformation

Conversion of biomass to biochar fundamentally alters the characteristics of the organic matter. Therefore, treating biochar as a discrete “stabilized product” seems appropriate. Under this approach the requirements are to:

- establish the proportion of the C contained in biochar that is stable compared to its stability under its previous management;
- provide evidence of its long-term stability in soil; and
- confirm that there are no negative impacts on existing soil C storage when adding biochar to soil.

If this proposed treatment of thermally stabilized biomass is accepted, it will represent a major advance. It will shift the requirement to demonstrate the stability of biochar projects away from a need to monitor soil C.

Not only does this significantly reduce the cost of monitoring and verification, but it also makes it possible to monetize projects where biochar enters a retail stream.

Status of the science

The breakdown of untransformed biomass in soil is extremely well understood. Typically 80-90% (depending on soil type) of C added to soil will be lost as CO₂ after 10 years. In the schematic below (Figure 2) the red line represents the proportion of C added that remains over time.

Well-calibrated and widely applied models that describe C turnover in soil have been developed



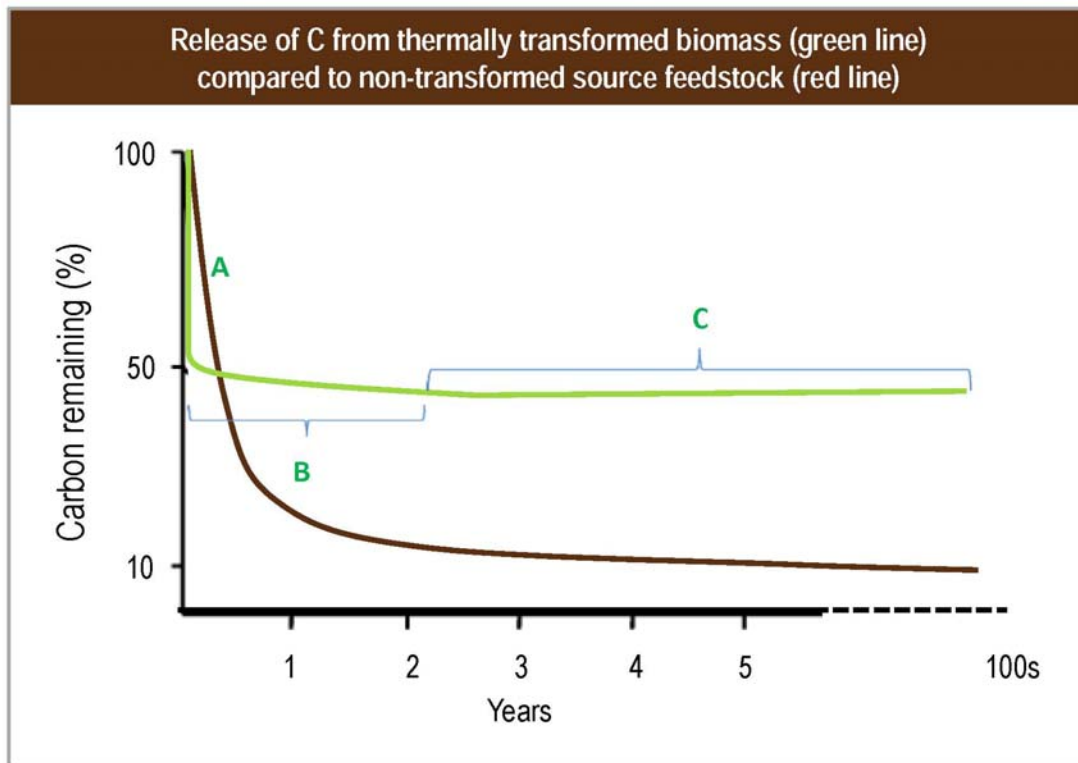


that can predict this loss of C. These models treat soil C as being comprised of discrete conceptual pools, each with different characteristic properties and a measure of reactivity (e.g. the first-order reaction constant k). Although the decomposition of plant material in soil is a complex process, such simple models have successfully described the long-term dynamics of soil C and can be used to predict the carbon that will remain from the organic matter feedstock if it is applied to soil.

Such models have informed both national greenhouse inventory assessments and proposed carbon offset methodologies.

The release of C when biomass is transformed in biochar is achieved in three distinct phases, or steps, as represented below: A) release of C during thermal transformation (i.e. during pyrolysis); B) release of labile mainly volatile C through rapid biotic decomposition; and C) long-term slow release of C due biotic and abiotic breakdown of resistant C forms.

Figure 2



The feedstock and process conditions that influence both the initial release of C during thermal transformation and initial yields of char are well understood. There is less certainty around the rapid release of C (B) and long-term release (C). However, phase B is likely to be short lived, leaving a long-term stable

component. Lehmann et al. (2009)²³ argue that understanding B (and by implication also A) is

²³Lehmann, J., Czimczik, C., Laird, D., and Sohi, S. (2009) 'Stability of Biochar in Soil' J. Lehmann and S. Joseph (eds) etc.



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important to predict the long-term stability of biochar C.

A key question and focus of the next step of the methodology development will be to examine whether sufficient data exists to establish models that predict the long-term stable C component of biochar. Given the order of magnitude difference in stability of the thermally transformed biomass compared to the original feedstock, this need not prevent us moving forward.

To claim an offset based on the stability of the biochar product, it is important to demonstrate that biochar does not lead to accelerated release of non biochar soil C when it is permanently stored in soil.

It is to be expected that CO₂ release will be enhanced when biochar is added to soil. Biochar contains labile C that acts as a substrate for biological activity. As this labile C is broken down during phase B (Figure 2), CO₂ will be released. Similar behaviour is seen when other organic materials are added to soil.

Further, it is generally understood that the addition of a labile substrate can enable the breakdown of more recalcitrant material in soil. This is called a “priming” effect.

A key question that needs to be answered is whether there is evidence that biochar stimulates the breakdown of non-biochar C to a greater extent than the addition of labile carbon in the absence of biochar.

Situations can also be anticipated where biochar alters the soil physical environment and moisture status or pH to such an extent that the environment is rendered more favorable to organic matter breakdown.

If either of these pathways is substantiated by literature review or if the consensus opinion of

the research community represents a significant risk, then a mechanism needs to be used to incorporate this risk in a conservative estimate.

Establishing the C Stabilized in Biochar

Three basic approaches can be considered to assess the C stabilized in biochar:

1. Measure the stability of biochar over time
2. To establish a measurement that predicts the stable component of biochar C
3. To establish predictive measurements of the labile portion of biochar.

Option 1. Involves measuring the C remaining in biochar over time in situations that are representative of where biochar is used. This has the least risk associated with it as the C storage value is claimed once it is demonstrated. However, given the evidence that biochar C is stable, this represents an approach which is unnecessarily conservative. Measurements would need to be made under conditions that represent the situation where the biochar was deployed (but would not require soil monitoring). This approach could also be designed to assess the stimulation (or stabilization, see below) of non-biochar C or GHGs.

Option 2. Measure the stable C component of biochar. Existing CDM methodologies have used the ratio of volatile to non-volatile C to predict the stability of biochar.²⁴ This

²⁴ CDM small-scale methodology AMS-III.L: Avoidance of methane production from biomass decay through controlled pyrolysis and CDM small-scale methodology AMS III.E: Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment.

http://cdm.unfccc.int/UserManagement/FileStorage/CDMW/F_AM_C7UWTIEMRJ05M3D02XWDW80JN989IP



methodology is relevant but was not used to claim C sequestered in biochar. It was used as an indicator that pyrolysis residues were inert (with respect to their potential to release methane) as part of a methodology to claim avoided methane emissions due to a change in management of the feedstock.

Others have proposed using the fixed C as a direct measure of the stable C pool. Such an approach is attractive in that it is relatively simple. International standards under ASTM (www.astm.org) exist for proximate and ultimate analysis. These methods appear flawed, as the non-volatile component (typically the material remaining after heating to a defined temperature) will also include ash. However, if the C content is measured by ultimate analysis then this approach may have merit. See McLaughlin et al.²⁵ for a useful discussion of this measure.

An important point to note here is that the method does not have to be “right,” but it does need to be “conservative.”

For example, whilst data from research and early projects are being assembled to confirm that a measure of fixed C is a reliable measure of the component of biochar that is stable when applied to soil, a conservative proportion of fixed C might be used.

The key challenge is to achieve a consensus (supported by evidence) that such a measure chosen will not overestimate C stability. Additional offsets can then be claimed over the life of the project as permanence of the stabilized C is proven.

²⁵ McLaughlin, H. Anderson, P. Shields F. and Reed T. (2009) *All Biochars are Not Created Equal and How to Tell Them Apart*. http://cees.colorado.edu/biochar_characterization.html

Option 3. As was discussed above, biochar has two distinct phases: a rapid early release of labile C and then a very slow release from a more stable component. If the labile component can be measured, either directly or through accelerated decomposition processes that seek to drive off this component, then the stable component can be established.

As decomposition profiles for biochar are obtained, it will be possible to relate the measured characteristics of biochar, or the feedstock and process conditions used to produce biochar, to the initial loss of C from biochar or measurements of fixed C.

For both options 2 and 3 it will of course take a number of years to test the relationships, but once established it will be possible to predict the stability of biochar based on an understanding of feedstock/process interaction.

4.2 Indirect Stabilization of C in Soil by Application of Biochar

This claim relates to the hypothesis that biochar may act to stabilize non-biochar C in soil.

Status of the Science

The turnover of non-biochar C in soil is well understood and can be reliably described by models of C turnover.

Research techniques using stable isotopes of C to study transformations of C in soil are used, and the advanced techniques to combine modelling and soil measurements, for example, are well suited to demonstrating this effect of biochar. At this stage it is difficult to judge from published literature whether comprehensive data to describe the mechanisms by which biochar impact on processes are available.



Option 1. To measure changes in soil C in the locations in which biochar is applied with use of techniques designed to demonstrate C stabilization, as described above.

Option 2. Include a mechanistic description of biochar interactions with non-biochar C into soil C turnover modes.

4.3 C Sequestration Due to Enhanced Biomass Production

The relationship between aboveground biomass production and belowground inputs is reasonably well understood, and both empirical

and process-based models can be used to predict the impact of increased biomass on soil C. Therefore, it is possible to estimate the increase in soil C based on changes in aboveground production.

Option 1. To measure changes in soil C in the locations in which biochar is applied

Option 2. Use existing sampling and model-based approaches to estimate increased soil C. Estimates would need to be modified for any priming effect/stabilization as described above

5. Next Steps

Since the previous primer document (*“Bringing Biochar Projects into the Carbon Marketplace: An introduction to carbon policy and markets, project design, and implications for biochar protocols”*) introduces material pertaining to protocol development, it has not been included in this document.

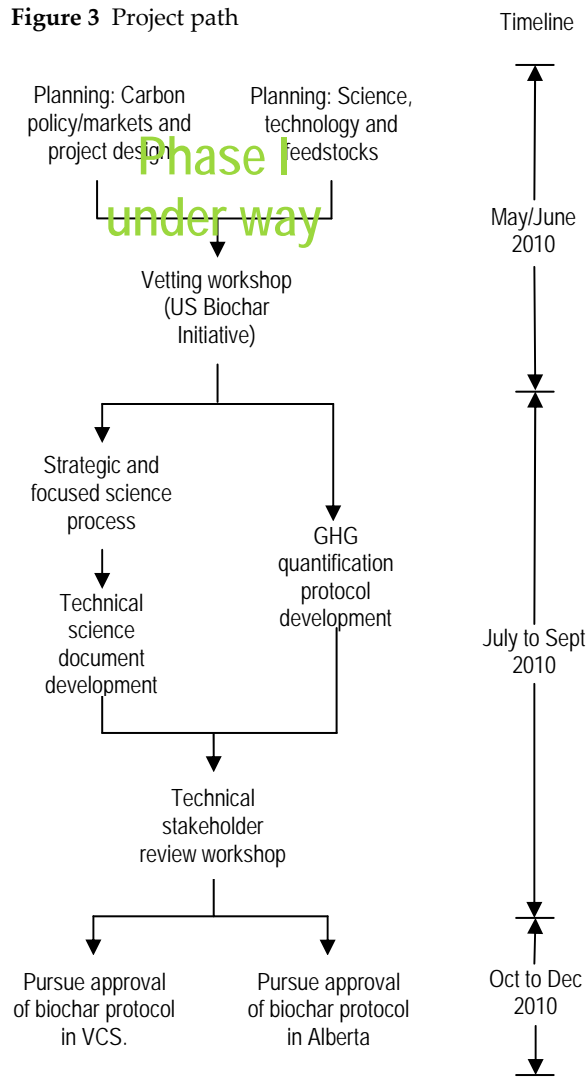
We recognize that there is prior art relevant to our proposed methodologies, and we will be reviewing this information during protocol development work, proposing modifications where required. In particular, emerging methodologies to establish nitrous oxide emissions from agriculture will need to be examined for their applicability.

The webinar scheduled for June 15, 2010 will discuss the C claims outlined and will offer opportunities for input as we begin to assess the strategy and the science upon which the methodology will draw.





Figure 3 Project path



Phase II Work plan

Building from the feedback and engagement with stakeholders, the project work plan illustrated in Figure 3 has been created to support the development of a biochar protocol. This workplan supports the development of a timely, rigorous and science-based protocol (with supporting documentation) through the balance of 2010.

The preliminary results of this work will be presented at the IBI Conference in Rio de Janeiro in September 2010 to share this work in the international realm. Further, North American stakeholder engagement sessions will be held through the fall of 2010.

Project Support

To support the activities in the work plan for Phase II, the project team is seeking financial contributions totalling between \$100k and \$150k from strategic *Sustaining Project Sponsors*. These sponsors will play a leading role in guiding the development of the protocol and ensuring applicability to their project platforms.

In-kind support is also being sought broadly from the biochar community to support the review and analysis required for this effort.

For more information on becoming a *Sustaining Project Sponsor*, please contact us at info@biocharprotocol.org.



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Summary of Phase II Work Plan Elements

Technical Science Document Development

- Bring together all the required scientific information into a document suitable for supporting protocol development and review.
- Engage with leaders in Biochar and related sciences to validate approach on key issues.
- Communicate results of the technical review to stakeholders to build capacity towards protocol review.

Deliverables: Technical Science Document, with summary slide deck, following requirements for the Alberta Offset System, supplemented to meet VCS requirements.

Cost Estimate: \$20k

Depending largely on the scope of project types being considered and the number of any project partners.

GHG Quantification Protocol Development

- Develop generic GHG emission reduction quantification protocol following the ISO 14064 pt II.
- Provide a companion document summarizing the key policy and technical issues, with particular attention to any continuing gaps in science.
- Review the quantification protocol with stakeholders to gain insights on key issues.

Deliverables: ISO 14064 pt II compliant protocol document with companion document linking to Technical Seed Document.

Cost Estimate: \$20k

Based principally on the scope of project types considered and number of any project partners.

Technical Stakeholder Review Workshop

- Facilitate web-based workshop on key and outstanding science, carbon policy and quantification issues prior to initiation of the protocol review processes.
- Incorporate feedback from the technical stakeholders into the Technical Science and Protocol documents.

Deliverables: Facilitate workshop and summarize feedback for stakeholder group review. Revise Technical Science and Protocol documents, as required.

Cost Estimate: \$10k

Per workshop, depending on scope of analysis.





Pursue Approval of Biochar Protocol under the Voluntary Carbon Standard

- Submit protocol for review under Voluntary Carbon Standard.
- Support protocol review, including engagement of third party validators as required, and/or participation in review working groups.

Deliverables: Protocol submission, revised as required to support approval. Slide decks, as required through approval process.

Cost Estimate: \$70k

Including 3rd-party costs associated with the double validation process.

Note: Protocol will be submitted for review in other regimes (CDM, CAR, Cdn. Fed., USDA / US EPA, etc) as may be relevant to the stakeholder group and the results of the work under a separately funded Phase III of the work.

Pursue Approval of Biochar Protocol in Alberta

- Submit protocol for review as part of the Alberta Offset System protocol review process.
- Support protocol through review process, providing supplemental information as required by regulator.
- Revise documentation (Technical Science and Protocol documents), as per the results of each round of review.

Deliverables: Protocol submission, revised as required to support approval. Slide decks, as required through approval process.

Cost Estimate: \$10k

In consideration of the work that will have been completed already.





How to support

To complete the protocol, we are seeking financial contributions totalling \$150,000 to cover the costs of developing the methodology and the external costs of the VCS double validation. We are not seeking to profit from this venture; only to cover the costs of creating a protocol within the public domain.

Biochar Industry Opportunities

To ensure we meet the needs of the emerging biochar industry, we are offering a range of options for Project Developers and Technology Owners to engage with and support us in this venture.

Silver Sponsor: \$5,000

For silver sponsors we will review an outline of your project and advise as to whether the protocol will meet the needs of your project. This offers an important way for us to ensure that the protocol is robust, and it provides valuable information for you. In addition to this assessment, you will receive feedback relevant to your project type at regular intervals throughout the protocol development process.

- Project review based on draft protocol
- Project-specific updates during protocol development and review period

Gold Sponsor: \$7,500

For Gold Sponsors, in addition to the assessment above, we will offer up to three, one-hour consultations to provide advice on how to proceed toward project validation against the protocol. If you choose to work with us to develop your project, up to \$2,500 of this sponsorship will be offset against future fees.

All Silver level benefits, plus:

- Consultations with the development team on implementation of approved protocol
- Can be offset against future consultancy costs

Platinum Sponsor: \$15,000+

Platinum sponsors will be recognized in all briefing and marketing materials and will be offered the opportunity to actively participate in the protocol development process via monthly calls. Participants will gain first-level knowledge and early-stage expertise regarding biochar in the carbon market. This is an excellent opportunity for carbon markets, brokers, and project financiers to get a broad understanding of the biochar opportunity, while directly helping to realize biochar's potential in the carbon marketplace.

- Direct access to protocol development team
- Participation in briefing calls
- Valuable insight into biochar evolution in the carbon markets relevant to your interests
- Recognition in all protocol materials

In-Kind Sponsorship

As we move forward, in-kind support is being broadly sought from the biochar community to support the review and analysis required for this effort.

We anticipate undertaking some tasks that will have academic merit. Contribution to this effort would not prevent publication, and such in-kind support will reduce the total funds required.

Please contact us at info@biocharprotocol.org to discuss how you can help us in this exciting venture.

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