> Hello Dave and colleagues,
>
> There is an aspect of the OCP that I'd like to bring to the
> Committee'sattention, which needs updating and clarification.
> This is subject of
> residential use of trailers and mobile homes. The context for my
> comment, in
> the current OCP, is section 3.1.4 Affordable Housing, Rental Housing,
> Special Needs Housing (Objectives and Policies). The type of
> trailer I'm
> speaking of here is not the smaller "camper" or "motor home"
> variety, but
> the larger towable units.

> Trailers are already in use on Bowen Island as permanent
> residences or as
> part of a cluster of buildings dedicated as a whole for
> residential use.
> They represent a form of affordable housing that is not
> addressed in the
> current OCP. As a result, those uses are technically illegal or
> non-compliant in spite of representing a very affordable form of
> housing.
>
> On the subject of trailers, the current OCP states only:
>
> Tourist Commercial Policies
>
> 3.7.21 Campgrounds for recreational vehicles and trailer parks
> shall not be permitted on Bowen Island;
>
> Similarly, the LUB states:
>
> PROHIBITED USES OF LAND, BUILDINGS AND STRUCTURES
>
> 3.3 The following uses are prohibited in all zones, except as
> otherwise specifically stated in this Bylaw:
>
> .2 Campgrounds for recreational vehicles and trailer parks;

> .6 A use located partially or totally in a tent trailer, motor
> home, camper, or other recreation vehicle, without a permanent foundation
or permanent service connection, except when a tent trailer, motor home or

> camper, or
>
> other recreation vehicle:
>
> - is otherwise permitted by this Bylaw; or
>
> - is used for temporary sleeping accommodation for non-paying visitors for a period not exceeding 90 days in any 360 day period.
>
> NUMBER OF DWELLINGS ON A LOT AND DWELLING USE
>
> 3.9 Despite Subsection 3.3.6, where a building permit has been issued for the construction of a building or structure for a permitted use, the owner or builder may use one travel trailer or camper on the lot for temporary accommodation during the construction, for a period not to exceed one year from the date of issuance of the building permit, subject to approval of the sewage disposal system by the Medical Health Officer.
>
> Based on my reading and understanding of these documents, there is no prohibition of the use of a trailer as a residence if it is placed on a permanent foundation. However, this is not explicitly stated anywhere and must be interpreted from the bylaws.

>
>
> There is a well and long-recognized need for affordable housing
> on Bowen.
> This need is explicitly identified in the current OCP. However,
> the lack of
> clarity has had some unfortunate results in the past. For
> example, it is my
> understanding that the lack of clarity in the current OCP and
> LUB concerning
> the use of trailers as residences has resulted in at least one family
> ultimately being ordered to not use a trailer as a residence or
> as a
> mortgage helper rental suite while slowly building their
> permanent home on a
> small lot. This family ultimately decided to move away from
> Bowen because an
> other than a trailer was not affordable at the time. Their
> departure from
> the island was a significant loss to the community. The OCP
> Update needs to
> ensure that this kind of impact in not repeated.
>
>
>
> My request is that:
>
> 1)   This issue (residential use of
> trailers) be examined during the OCP
> Update and that the Objectives and Policies for Affordable
> Housing trailers
> be updated to allow for residential use of trailers as a form of
> affordablehousing. Understandably, this would be subject to
> compliance with health,
> safety and other regs. regarding power, water and sewer connections,
> building code, development permit conditions and other aspects, as
> appropriate.
>
> 2)   The use of a trailer on a
> permanent foundation be allowed as a
> permanent residence. And
>
> 3)   The time period for temporary

> residence in a trailer during
> construction of a building (i.e. LUB Section 3.9) be extended
> (e.g., to
> three years instead of the current one year) in order to
> acknowledge that
> some residents will only be able to afford building their permanent
> residence at a slower pace than they would otherwise be forced
> to do under
> the current LUB.
>
>
>
> Thank-you for the opportunity to provide input. Please feel free
> to contact
> me about this matter if you have any questions about this
> submission.
>
>
>
> Regards, and Best wishes during the remainder of the OCP Update
> process.
>
>
> Alan
> Whitehead

Biochar: A Soil Amendment that Combats Global Warming and Improves Agricultural Sustainability and Environmental Impacts

Introduction to Biochar

Biochar and bioenergy co-production from urban, agricultural and forestry ***biomass*** can help combat ***global climate change*** by displacing fossil fuel use, by sequestering carbon in stable soil carbon pools, and by dramatically reducing emissions of nitrous oxides, a more potent greenhouse gas than carbon dioxide.[1,2] As a soil amendment, biochar helps to improve the Earth's soil resource by increasing crop yields and productivity, by reducing soil acidity, and by reducing the need for some chemical and fertilizer inputs.[3,4] Water quality is improved by the use of biochar as a soil amendment, because biochar aids in soil retention of nutrients and agrochemicals for plant and crop utilization,[5,6] reducing leaching and run-off to ground and surface waters.

Biochar production and utilization systems differ from most biomass energy systems because the technology is ***carbon-negative***: it removes net carbon dioxide from the atmosphere and stores it in stable soil carbon "sinks".[7] Other biomass energy systems are *at best* carbon-neutral, resulting in no net changes to atmospheric carbon dioxide.

Biochar Production

Bioenergy and ***biochar*** can be co-produced from thermal treatment of biomass feedstocks. The thermal conversion of biomass, under the complete or partial exclusion of oxygen, results in the production of biochar and bioenergy or other bioproducts. Biochar production processes can utilize most urban, agricultural or forestry biomass residues, including wood chips, corn stover, rice or peanut hulls, tree bark, paper mill sludge, animal manure, and recycled organics, for instance.

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[1] Yanai et al., 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***, 53:181-188.

[2] Rondon, M., Ramirez, J.A., and Lehmann, J.: 2005, Charcoal additions reduce net emissions of greenhouse gases to the atmosphere, in ***Proceedings of the 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration***, Baltimore, USA, March 21-24, 2005, p. 208.

[3] Glaser, B., Lehmann, J. and Zech, W., 2002, Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal --- a review, ***Biology and Fertility of Soils***, 35: 219-230.

[4] Lehmann, J. and Rondon, M., 2006, Biochar soil management on highly weathered soils in the humid tropics. In Uphoff N (ed.), ***Biological Approaches to Sustainable Soil Systems***, CRC Press, Boca Raton, FL, pp. 517-530.

[5] Lehmann, J., et al., 2003, Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments, ***Plant and Soil***, 249: 343-357.

[6] Steiner, C., et al., Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil, ***Plant and Soil***, 291: 275-290.

[7] Lehmann, J., Gaunt, J., and Rondon, M., 2006, Bio-char sequestration in terrestrial ecosystems – a review. Mitigation and Adaptation Strategies for Global Change, 11:403-427.

Under controlled production conditions, the carbon in the biomass feedstock is captured in the biochar and the bioenergy co-products. Theoretically, the ***biochar*** co-product will retain up to 50% of the feedstock carbon in a porous charcoal structure; and the remaining 50% of the feedstock carbon will be captured as ***bioenergy.*** While it is technically infeasible to capture 100% of the biomass carbon, since energy is invariably used and lost in the production process, the optimal biochar production process can capture roughly half the biomass carbon in biochar and half as bioenergy.

Biochar can be produced by ***pyrolysis*** or ***gasification*** systems. ***Pyrolysis*** systems produce biochar largely in the absence of oxygen and most often with an external heat source. There are two types of pyrolysis systems in use today: ***fast pyrolysis*** and ***slow pyrolysis*** systems. ***Gasification*** systems produce smaller quantities of biochar in a directly-heated reaction vessel with air introduced. Biochar production is optimized in the absence of oxygen.

Gasification and pyrolysis production systems can be developed as mobile or stationary units. Small scale gasification and pyrolysis systems that can be used on farm or by small industries are commercially available with biomass inputs of 50 kg/hr to 1,000 kg/hr. The bioenergy produced from these systems, which can be in the form of a synthetic gas, or ***syngas***, or ***bio-oils***, can be used to produce heat, power or combined heat and power. At the local or regional level, pyrolysis and gasification units can be operated by co-operatives or larger industries, and can process up to 4,000 kg of biomass per hour.

Biochar

Biochar is a fine-grained, porous charcoal substance that, when used as a soil amendment in combination with sustainable production of the biomass feedstock, effectively removes net carbon dioxide from the atmosphere.[8] In the soil, biochar provides a habitat for soil organisms, but is not itself consumed by them to a great extent, and most of the applied biochar can remain in the soil for several hundreds to thousands of years[9],[10] (see also ***Terra Preta soils***). The biochar does not in the long-term disturb the carbon-nitrogen balance, but holds and makes water and nutrients available to plants. When used as a soil amendment along with organic and inorganic fertilizers, biochar significantly improves soil tilth, productivity, and nutrient retention and availability to plants.[11]

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[8] Ibid.

[9] Pessenda, L.C.R., Gouveia, S.E.M., and Aravena, R., 2001, Radiocarbon dating of total soil organic matter and humin fraction and its comparison with ^{14}C ages of fossil charcoal, ***Radiocarbon***, 43: 595-601.

[10] Schmidt, M.W.I., Skjemstad, J.O., and Jager, C., 2002, Carbon isotope geochemistry and nanomorphology of soil black carbon: Black chernozemic soils in central Europe originate from ancient biomass burning. ***Global Biogeochemical Cycles***, 16: 1123.

[11] Glaser, B., Lehmann, J. and Zech, W., 2002, Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal --- a review, ***Biology and Fertility of Soils***, 35: 219-230.

Bioenergy

The ***bioenergy*** produced during biochar production may be in the form of thermal energy, a synthesis gas, aka ***syngas,*** or a ***bio-oil***. The syngas or bio-oil can be used to heat the pyrolysis unit for continued production, and surplus syngas or bio-oil can be used to provide additional energy for on-site uses, such as heat and electricity. ***Syngas*** is rich in hydrogen, methane and carbon monoxide and in addition to its use for heat or power, it can be converted to ***liquid fuels*** or industrial ***chemicals.*** The bio-oils can also be used for on-site power and heat generation, or converted to ***liquid fuels*** or industrial ***chemicals***.

Economics of Biochar Systems

The co-production of biochar from a portion of the biomass feedstock reduces the total amount of bioenergy that is produced by the technology, but even at today's energy and fertilizer prices the net gain in soil productivity is worth more than the value of the energy that would otherwise have been derived from the biomass feedstock. As the cost of carbon emissions rises and the value of CO_2 extraction from the atmosphere is also considered, the balance becomes overwhelmingly attractive in favor of biochar co-production.

Rural and Developing Country Applications of Biochar Systems

Biochar systems can reverse soil degradation and create sustainable food and fuel production in areas with severely depleted soils, scarce organic resources, and inadequate water and chemical fertilizer supplies. Low-cost, small-scale biochar production units can produce biochar to build garden, agricultural, and forest productivity, and bioenergy for eating, cooking, drying and grinding grain, producing electricity and thermal energy, for instance.

Biochar Misconceptions and the Science

IBI has prepared this document in response to various press releases and reports issued by the groups EcoNexus and Biofuels Watch, including a report titled: *Agriculture and climate change: Real problems, false solutions*. This report states that it was prepared for the June 2009 climate talks in Bonn. It is not a peer-reviewed scientific paper and the qualifications of the authors are not stated. Nevertheless, they bring up questions that are good to ask.

We provide answers below that draw from the published scientific literature. IBI believes that while no answer in science is final, there is sufficient evidence in hand to justify pursuing proper use of biochar as a valuable tool for enriching Earth's soils with stored carbon. We look forward to the continued progress of biochar research and development.

For more information on the questions below, see the resources on the IBI website, www.biochar-international.org. Visit our FAQ section and our IBI Publications page where you will find basic fact sheets, white papers and research summary papers.

Response to questions raised by Biofuels Watch/EcoNexus

The questions and answers below are in response to statements on pages 17-20 of *Agriculture and climate change: Real problems, false solutions,* by EcoNexus and Biofuels Watch, and also from some previous reports and statements by Biofuels Watch.

1. Does IBI promote large monoculture tree plantations, as Biofuels Watch claims, that will decimate native forests and drive indigenous people from their land in order to make enough biochar to meet climate targets?

No. The IBI promotes the use of waste biomass for the production of biochar. Large amounts of agricultural residues, municipal green waste and forestry biomass are currently burned or left to decompose and release CO_2 and methane back into the atmosphere. IBI has produced a preliminary analysis titled, *How Much Carbon Can Biochar Systems Offset -- and When?*, that assumes only biomass from waste streams would be used. This analysis concludes that even a conservative scenario, using only 27% of the world's crop and forestry wastes for biochar, could sequester 0.25 gigatons (Gt) of carbon a year by 2030 with biochar alone. If the energy co-product of biochar production is used to offset fossil fuel use, then the carbon offset potential of biochar more than doubles to 0.6 Gt of carbon a year by 2030.

IBI, like many organizations and individuals, is also concerned about forest preservation. Many people falsely associate biochar production with the historical deforestation that has occurred to provide wood for inefficient, traditional charcoal production for fuel. This is not the strategy that IBI promotes or believes should be implemented for modern biochar production and utilization systems.

The promise of biochar technology as IBI envisions it is to improve soil fertility and reduce emissions, taking into consideration the full life cycle analysis of the biochar systems, including indirect land use change. Logging primary forests to produce biochar would defeat the purpose of biochar, which is to reduce the amount of carbon dioxide in the atmosphere. Properly implemented, biochar production and use will serve the interests of local people and protect native forests while reducing carbon emissions and enhancing the world’s soils.

2. Is it true that biochar will soon be patented by big corporations that will prohibit small farmers and gardeners from using it?

While some biochar producers may be able to patent a specific biochar production process or method, there exist a number of open-source, low-cost, clean technologies that can make biochar at the home or village level, and more are in development.

3. Does IBI advocate adding carbon derived from coal, old tires or municipal solid waste to soils as Biofuels Watch alleges?

No. Coal is not a renewable resource. Biochar refers specifically to materials made from present-day biomass, not fossil carbon. Tires and other potentially toxic waste materials are not appropriate as sources of biochar for soil improvement.

4. Is it true, as EcoNexus and Biofuels Watch claim, that there are no significant field trials showing that biochar really benefits soil fertility? Without better information, are the risks too great to consider large scale biochar use at this time?

Field trials using biochar have been conducted in the tropics over the past several years. All showed positive results on yields when biochar was applied to field soils and nutrients were managed appropriately. Large scale field trials have recently begun on highly fertile Iowa Mollisols by the US Department of Agriculture’s Agricultural Research Service (USDA-ARS). First year results are positive, yet it will take several years before definitive results are available (Laird, D., 2009)

In addition, we cannot, as Biofuels Watch would have us do, discount the evidence from thousands of years of traditional use of charcoal in soils. The most well-know example is the *Terra Preta* soils in Brazil, but Japan also has a long tradition of using charcoal in soil. This tradition is now being revived and even exported as in the case of a commercial biochar fertilizer production facility that has been operating along Japanese principles in Costa Rica for the last 20 years.

The Japanese tradition is described in this paper from Ogawa, M., Osaka Institute of Technology, Charcoal Use in Agriculture in Japan, Keynote address, Asia Pacific Biochar Conference, 17-20 May 2009:

> "…use of charcoal dwindled to 30,000 t/year by the 1980s but in the 1970s scientists began promoting its production and use, and in 1986 a technical group was established to study carbonization technology, soil amendment in agriculture and revegetation, activation of microorganisms and water purification. In 1990 the research results were published and widely distributed, and charcoal and wood vinegar were authorised for soil amendment by the Ministry of Agriculture, Forestry and Fishery."

The Brazilian and Japanese traditions together provide long-term evidence of positive biochar impact on soils.

Recent research also documents the nearly ubiquitous occurrence of biochar-type materials in soils globally (Skjemstad et al., 2002; Hammes et al., 2008; Krull et al., 2008; Lehmann et al., 2008; Laird et al 2008). While these were generated from wildfires, they share the basic properties with biochar generated from woody and grassy feedstock. In fact, soils high in natural biochar found in fire-prone grasslands like the North American Prairie are some of the most fertile soils in the world.

While the larger questions concerning overall biochar benefits to soils have been answered in the affirmative, significant questions remain, including the need for a better understanding of some of the details of biochar production and characterization. Work is ongoing to develop methods for matching different types of biochar to soils for the best results. IBI is working with private and public researchers around the world to develop protocols to answer these questions.

5. Biofuels Watch and EcoNexus question whether biochar will last long enough in soil to be counted as a carbon offset. They also speculate that at some point in the future it could all be released into the atmosphere at once in a devastating "carbon time bomb." Do we really know that biochar will be stable in soils?

Biochar is not a single material, and its properties vary according to how it is made and from what it is made. The prevailing scientific understanding of biochar degradation in soil is that some portions of it are quite readily decomposable (termed "labile"), while the core structure of the material is highly resistant to degradation (termed "stable"). Analyses of biochar will indicate the relative amounts of labile and stable materials in each biochar material. Depending on how the material is made and from what, the size of these fractions varies.

The degradable portion of biochar (composed of condensates, bio-oils, etc) is usually small and its size can be managed in the production process. Once this portion degrades in the years following application, the leftover will remain in soil for very long periods of time. There is variation in the exact composition of biochars, but basically a charred material will always be more recalcitrant (resistant to degradation) than its uncharred counterpart.

Biochar carbon in *Terra Preta* soils of the Amazon has been dated up to several thousand years old. The Amazon is a tropical climate where organic matter degradation is very rapid due to constantly high temperatures and moisture levels. In Australia, estimates of mean residence time for naturally occurring biochar carbons are 1,300 – 2,600 years (Lehmann et al., 2008). Organic matter decomposition rates in temperate regions are slower and the carbon resides in the soils for much longer periods of time.

Controlled experiments where biochar decomposition is monitored are underway, but results extending over long periods of time are not now available. However, applying scientifically robust mathematical models to describe the degradation of organic matter in soil, and using data available to date, multiple independent estimates show that biochar has a mean residence time in soils on the order of 1,300 to 4,000 years (Cheng et al. 2008, Liang et al. 2008, Kuzyakov et al. 2009).

Soil tillage is known to cause sudden release of CO_2 from soils and to accelerate decomposition of soil organic matter. This is one of the downsides of using reduced tillage to sequester carbon in soils: if the soil is ploughed, a portion of soil carbon that has accumulated over several years can be lost very quickly. Due to the chemical nature of biochar, it is a lot more resistant to degradation than other forms of organic matter. Thus, we expect events such as tillage to cause negligible loss of biochar carbon compared to carbon in biogenic soil organic matter. Biochar is intimately mixed with soil, interacts with its constituents and is stable in that environment. It does not depend on any form of containment.

In summary, a good deal is known about the stability of biochar in soil. Certainly there is enough information to make conservative estimates in most cases that are suitable for basic carbon accounting.

6. EcoNexus and Biofuels Watch attempt to show that large fractions of biochar can be lost over short periods by quoting studies that look at black carbon left by fires. Are these studies relevant?

Some references have reported that large pieces of charcoal left on forest floors after a forest fire may be burned when subsequent fires move through the same forest. This is true, but is not relevant for biochar-amended soils. Fires may burn surface vegetation but will not oxidize biochar that has been thoroughly mixed with the mineral soils. The term “loss by oxidation” in these reports refers to carbon losses from burning in subsequent wildfires – not to microbial oxidation of carbon, as may be concluded.

One work by Nguyen et al. (2009), reports on carbon dynamics in agricultural soils in Kenya following land clearing by fire. This was not biochar that was prepared by modern pyrolysis methods and then purposefully incorporated into soil, but rather black carbon left from clearing of forests for cultivation. The temperature at which this black carbon was produced probably varied significantly and a substantial fraction was likely formed at lower temperatures than in a modern biochar pyrolysis facility. This study reports a loss of 70% of black carbon from the topsoil over 20-30 years. The change likely involved a number of processes, including decomposition of the labile fraction of the black carbon, lateral erosion away from the site, and transport below the sampling depth in the soil by tillage, earthworms and water leaching. The authors found that after the initial phase of unattributed rapid carbon movement and/or loss, the black carbon fraction in the soil remained stable for 70 years, up to the present. It is important to acknowledge that even if black carbon or biochar changes location or is leached into the subsoil, very little of the carbon is lost to the atmosphere, i.e., it is still sequestered. Further research is warranted to determine how much carbon loss in this situation was attributable to decomposition and how much to physical transport.

7. Biofuels Watch and EcoNexus warn that if biochar was applied to large areas of land, carbon-eating microbes might multiply and break down black carbon more easily, leading to increased carbon emissions.

There is no evidence for this concern. The fact that *Terra Preta* soils contain so much black carbon after so long a time in a diverse tropical environment that highly favors microbial activity and decomposition indicates this is very unlikely to occur.

8. These critics also cite a study of charcoal in boreal forests as evidence that "adding biochar to soil could actually worsen climate change due to potential losses of soil organic carbon."

There is no evidence or research indicating that biochar could trigger additional carbon releases from soil. This concern stems from the results of a study by Wardle et al (2008). The study placed mesh bags of charcoal in the humus layer (consisting of needles and litter, usually called an organic or O horizon, not a mineral soil) of a forest and observed a subsequent loss of carbon. Increased microbial respiration is one possible mechanism for the observed carbon loss, but the investigators did not measure the physical transport of carbon to areas outside the mesh bags they used in the experiment. Organic carbon that is leached into deeper, mineral layers of soil has repeatedly been shown to become stabilized by interactions with minerals, and thus to remain within the soil system.

A recent study testing this very same interaction between litter, char and soil organic matter in a laboratory incubation (Bruun, et al, 2009) found no evidence that biochar increases the decomposition of soil organic matter. The authors conclude: "There is thus no indication the carbon sequestered in the biochar will be offset by an increased release of carbon dioxide because of increased decomposition of soil organic or recently added plant litters. All of this supports the assertion that biochar presents a potentially very effective method for soil carbon sequestration." The same conclusion was drawn from two further studies (Liang et al., 2009; Spokas et al., 2009) that used more comprehensive approaches than the study by Wardle et al. (2008).

Finally, the effect of biochar on plant growth was not captured in the system studied by Wardle et al. (2008) and this can make a significant difference in the total carbon accounting. A study by Major et al. (2009) showed a net gain in soil organic carbon beyond the biochar additions that was caused by greater plant productivity and accumulation of dead roots and other organic matter in the soil. Consequently, with more organic matter available to microbes, soil respiration was greater. Such greater carbon cycling should not be identified as a loss of soil carbon caused by biochar additions. The Major study stresses the fact that the effect of biochar on non-biochar soil carbon must be studied in the field, at a scale that includes plant reactions to the presence of biochar.

9. Could biochar worsen climate change through changes in albedo or impacts from airborne black dust?

After centuries of agriculture, soils globally have become depleted of carbon, compared to pre-agricultural conditions. Agricultural development goals include restoring carbon to carbon-depleted soils. Adding any form of carbon to soil, not just biochar, changes soil albedo (a measure of sunlight reflectance). Fortunately, darker, carbon-rich soils are more fertile and will be more easily re-vegetated. Vegetation has a lighter albedo, so the albedo problem is neither specific to biochar nor a simple cause and effect but requires detailed study.

Small particles of black carbon are produced from the incomplete combustion of fossil and biomass fuels. When deposited on snow and ice, they are able to absorb heat and energy. The smallest black carbon particles associated with biochar production and application are much larger, in the millimeter range, than the particles associated with global warming, in the nanometer range. Thus application of biochar would result in little opportunity for long-range transport and deposition into the sensitive Arctic and mountain regions.

Dust is a certainly a concern with biochar application, but best practices require that biochar applications be done during periods of low wind to prevent the blowing of fines. Agricultural techniques already exist to apply powdered fertilizers and other amendments. Several techniques are available to help keep wind losses to a minimum: biochar can be pelleted, prilled, mixed into a slurry with water or other liquids, mixed with manure and/or compost, or banded in rows. The optimization of biochar application to soil is important, and the farm technology and methods are available.

10. Biofuels Watch and EcoNexus cite uncertainty about biochar’s ability to retain soil moisture.

More studies are needed on the question of water retention, but the results so far consistently show benefits in sandy soils where this function is most needed. The Australian national science agency, CSIRO, released a comprehensive review (*Biochar, climate change and soil: A review to guide further research*) of biochar in February 2009, co-authored by Rothamsted Research and Newcastle University in the UK. The CSIRO review looked at work done on biochar impact on soil moisture retention. While it found few studies that directly addressed soil moisture retention with biochar, it found that "Many studies where the effect of biochar on crop yield has been assessed have cited moisture retention as a key factor in the results."

CSIRO cited a study (Gaskin et al., 2007) that found water retention doubled in a loamy sand soil, and a study of *Terra Preta* (Glaser et al., 2002) that showed an 18% higher water retention than adjacent soil.

A case study in Ghana illustrates the significance of biochar augmented water retention in a dryland crop:

> Case Study 5 – Example of highly diverse cropping system (maize, yam) with secondary forest in Ghana managed with biochar over 20 years. Farmer reports 100 percent increase in yields. "Her perception is that the underlying mechanism for the effects she sees is entirely physical, citing two factors: enhanced rainwater infiltration and enhanced soil moisture retention. In drought-susceptible sandy soils – prevalent in most parts of Ghana – crop performance is considerably governed by the timing and extent of rainfall, and its effect on crop establishment and maturation."
>
> From: Lehmann, C.J. and Joseph, S., 2009. Biochar systems. In: Lehmann, C.J., Joseph, S. (Eds.), Biochar for environmental management: science and technology. Earthscan.

11. Biofuels Watch and EcoNexus say biochar could introduce toxic compounds to soil

In its report titled *Biochar, climate change and soil: A review to guide future research*, the Australian science agency CSIRO states, "…the apparent success and longevity of the civilization that created the *terra preta* provides some reassurance as to the long-term safety of biochar incorporation to soil…Nonetheless, a critical and non-prescriptive experimental analysis of risks that might arise from the deployment of biochar has not been undertaken according to modern criteria…" Below is a brief summary of the potential toxic compounds that could be associated with biochar:

Heavy metals. Some feedstocks that could be used for biochar might contain heavy metals, however, these are unlikely to be present in harmful concentrations in agriculture and forestry wastes. Caution is necessary in choosing feedstocks to avoid those containing toxic compounds. Treated lumber is an example of biomass that should never be used to produce biochar. There are rules for metal contents in soil-applied materials like composts and sludges, and biochar should be subject to such rules. The IBI is able to provide the expertise through its members to advise in the development of guidelines that would meet environmental standards.

PAHs. Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds that are produced as byproducts of fuel burning (whether fossil fuel or biomass). Some PAHs are carcinogenic to humans, but many are not. PAHs are found naturally in soils as a result of wildfire and many microbes are able to metabolize them. An investigation by M. Jones, et al (2008) found PAHs in biochar amended soils to be at levels similar to or below PAH concentrations found in many unamended soils. One analysis of PAH profiles in biochar samples found a lower concentration of PAHs than in char formed by a prescribed burn in pine forest (Brown, 2006).

Dioxins. Dioxins are predominantly formed at temperatures above 1000 degrees C. Most pyrolysis technology operates well below that temperature. Dioxins should not be a concern with biochar, but any proposed high temperature pyrolysis technology should be assessed and monitored for possible dioxin production.

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International Biochar Initiative

Biochar Pathways for Different Environments

	Feedstock	sustainability challenges	Production technology	additional process steps	potential co-products	biochar point of use	economic challenges	social challenges	Advantages
1. Restoration Site (forest, wetland, etc.)	thinning slash, noxious weeds		mobile pyrolysis, charring piles in situ		biochar, bio oil, heat for drying feedstock	soil and watershed reclamation site	labor intensive, need to value ecosystem restoration	accepting the need to pay for restoring ecosystems services	restored ecosystems store more carbon
2. Managed Forest	thinning slash, logging slash	overcutting diminishes ecosystem services, transportation footprint	mobile pyrolysis, hog fuel for co-gen, feedstock for pellets or briquettes	produce pellets or briquettes to use in home or district heating pyrolysis appliances	biochar, bio oil, process heat, electricity, home heat	commercial fertilizer, home garden	forest thinning is labor intensive, low density slash is expensive to haul	need to train workforce for ecological thinning	can improve forest health, cheap fuel source, provides long term employment
3. Forest product processing waste	sawdust, shavings, hog fuel	overcutting diminishes ecosystem services	co-gen pyrolysis or gasification, feedstock for pellets or briquettes	produce pellets or briquettes to use in home or district heating pyrolysis appliances	biochar, bio oil, process heat, electricity, home heat	commercial, home garden	supply dependent on economic growth and housing starts, resource is already fully utilized	competition for resource	already in widespread use
4. Biomass Plantation	trees, grass, hemp, algae, kudzu	could displace native ecosystems & people, water use, monoculture problems, GM species	co-gen pyrolysis or gasification, feedstock for pellets or briquettes	produce pellets or briquettes to use in home or district heating pyrolysis appliances	biochar, bio oil, process heat, electricity, home heat	plantation soils, commercial fertilizer, home garden	large capital investment and pressure to adopt unsustainable practices	need to strengthen land tenure rights of poor people	Could be used for afforestation of degraded land
5. Urban Forestry and landscaping	thinning slash, logging slash, weeds, grass clippings		co-gen pyrolysis or gasification, feedstock for pellets or briquettes	produce pellets or briquettes to use in home or district heating pyrolysis appliances	biochar, bio oil, process heat, electricity, home heat	commercial fertilizer, home garden	new capital investment	need to train workforce for ecological thinning	avoids disposal cost
6. Ag Waste - Industrial	straw, cobs, orchard trimmings	need to leave some decomposing organic matter in soil	mobile pyrolysis, co-gen pyrolysis or gasification, feedstock for pellets or briquettes	produce pellets or briquettes to use in home or district heating pyrolysis appliances	biochar, bio oil, process heat, electricity, home heat	farm soils, commercial fertilizer, home garden	new capital investment		avoids disposal cost

	Feedstock	sustainability challenges	Production technology	additional process steps	potential co-products	biochar point of use	economic challenges	social challenges	Advantages
7. Ag Waste - Subsistence	straw, cobs, orchard trimmings, kernels, peels, hulls, pulp, offal	need to leave some decomposing organic matter in soil	stoves, kilns, feedstock for briquettes	pyrolyze briquettes in home or district heating appliances	biochar, process heat, home heat and cooking	farm soils	new capital investment	need to learn new technologies and agricultural systems	locally produced soil amendment enhances food security
8. Industrial Food Processing Waste	kernels, peels, hulls, pulp, offal		co-gen pyrolysis or gasification		biochar, bio oil, process heat, electricity	commercial fertilizer	new capital investment		avoids disposal cost
9. Animal Feedlots	pig, chicken, steer manure	large CAFOs have many impacts - water, disease, animal rights	co-gen pyrolysis or gasification		biochar, process heat, electricity	farm soils, commercial fertilizer	new capital investment		avoids disposal cost
10. Municipal Sewage	solids, urine	contamination by toxics and heavy metals	co-gen pyrolysis or gasification		biochar, process heat, electricity	commercial fertilizer - non food crops	new capital investment		avoids disposal cost
11. Municipal Solid Waste	trash, paper	pollution, losing resources that could be recycled	co-gen pyrolysis or gasification		biochar, process heat, electricity	suitable for use as carbon sink only	supply dependent on economic growth, consumption		avoids disposal cost
12. Household and District Heating	pellets and briquettes from 1-7	need to invest in building efficiency to reduce fuel needs, transportation cost to distribute to users	pyrolysing cookstoves, furnaces and boilers		heat, biochar, possibly electricity	home garden, landscaping	new capital investment	learning to use new appliances and building heating systems	efficient energy use, integrated home systems for fuel and food

How Much Carbon Can Biochar Systems Offset -- and When?

Biochar production and utilization systems differ from most biomass energy systems because the technology is ***carbon-negative***: it removes net carbon dioxide from the atmosphere and stores it in stable soil carbon "sinks." Biochar and bioenergy co-production from urban, agricultural and forestry biomass residues can help combat global climate change by a number of different pathways that include the following:

- Direct sequestration of biochar in stable soil carbon pools
- Displacement of carbon-positive fossil fuel energy
- Increase in global Net Primary Production (NPP) from increased soil fertility
- Reduction of nitrous oxide emissions

There are additional pathways to reduced emissions that may result when biochar is added to soil. These include savings in energy and emissions from fertilizer production as the need for fertilizer is reduced and potential reductions in methane emissions when biomass is charred rather than allowed to decompose.

Because there are many complex factors involved in estimating the total impact of biochar systems on climate, the IBI has developed a model to predict the carbon removing potential of sustainable biochar systems. We expect these answers will change as more is learned about the impacts of biochar, but the model gives a sense of what is possible. The rest of this paper explores the results of this preliminary model using a question and answer format.

1. What are the basic assumptions used in the IBI model?
We developed four scenarios using a simple model (Amonette et al., 2007, 2008) that accounts for modern biochar technology, availability of biomass and land for storage, and for the stability of the biochar when placed in soil. Of all of the carbon offset pathways described above, we considered only the ones with the greatest impact: direct sequestration, displacement of fossil energy, increase in NPP, and nitrous oxide reduction. We also analyzed the impact of applying carbon capture and sequestration (CCS) to biochar energy co-production.

2. What is IBI's goal for carbon removal from the atmosphere?
IBI is focusing presently on the feasibility of one "wedge," which equals one gigaton of carbon per year. The term "wedge" comes from an often-quoted analysis (Pacala and Socolow, 2004) showing a need to have seven gigatons of carbon per year (seven wedges) of reduced carbon emissions by 2054 just to keep emissions at the 2004 level.

3. Is a one gigaton per year biochar wedge achievable by 2054?
Yes. In the four basic scenarios we have examined, we found several ways to create at least one wedge by 2054.

4. What are the four scenarios you developed?
We developed scenarios that differed primarily in the amount of biomass that was available in a sustainable way from global Net Primary Production (NPP), using residue data compiled by Krausmann et al. (2008). The "Conservative" scenario assumed that only biomass from cropping and forestry residues that otherwise had no use (about 27% of the total residues) was available. The "Moderate" and "Optimistic" scenarios considered that 50% and 80%, respectively, of all the cropping and forestry residues was available to make biochar. For each base scenario, we estimated the amount of biochar produced, as well as the amounts of fossil fuel carbon emissions replaced by the energy generated during biochar production. And we estimated the additional amount of carbon that could be sequestered if CO_2 emissions generated during biochar production were captured and sequestered in the same manner as proposed for coal combustion facilities. For the "Optimistic Plus" scenario, we added in generous feedbacks related to potential increases in NPP (25%) and potential decreases in N_2O emissions (50%) stemming from biochar amendments to soil. Our N_2O emissions scenario relied on the data and as-

sumptions of Crutzen et al. (2007) and Galloway et al. (2004). All scenarios assumed that slow pyrolysis, which has a carbonization efficiency of about 40%, was used to produce the biochar. Other factors such as the stability of biochar in soils and the length of time required to reach maximum production levels were also varied. The parameters used to develop each scenario are summarized in Table 1.

5. Is biochar production sustainable from an ecological perspective?
In our scenarios, we took biomass from the residues of existing agricultural and forestry practices and used modern high-yield pyrolysis technology. No new land was cleared or converted to biochar plantations. The maximum amount of global NPP used in our scenarios is 3.2%. Estimates of the fraction of global NPP that can be used for sustainable bioenergy production go as high as 13% (e.g., Sims et al., 2007, using the assumptions of Amonette et al., 2008). The higher estimates in that paper assume dedicated bioenergy plantations. Because there are doubts about the sustainability of some biomass plantations, we have excluded plantations from this analysis, giving a result that is conservative overall.

6. How much carbon do your scenarios predict can be removed from the atmosphere? The results of the scenarios show that most conservatively, the carbon in biochar alone can account for about 1/4 of a wedge (0.25 Gt) by 2030. Our Optimistic Plus scenario reaches one full wedge around 2040 (Fig.1). When we count carbon emissions from coal combustion that is avoided by substitution of energy generated by biochar production, three of the scenarios predict more than a wedge of impact on atmospheric CO_2 by 2025 (Fig. 2). Perhaps most intriguing is the positive feedback shown in the Optimistic Plus scenario, where the impact of biochar is shown to continue to increase after the other scenarios have leveled out. The cumulative impact of the four biochar scenarios is shown in Fig. 3 where as much as 60 gigatons of carbon could be sequestered or offset in just the 40 years to 2050 with the Optimistic Plus scenario.

7. Is there anything special in the manner that you have modeled the paths from 2010? No. We have used a standard sigmoidal growth function to model the increase in biochar production from 2010 (Row 1) to the peak (Row 3), with specified spans shown in Row 2.

8. When will the carbon offset potential of biochar reach an upper limit?
The positive feedback stemming from biochar's impact on land productivity indicates that an upper limit is potentially very high. Haberl et al. (2007) note that the NPP of non-irrigated cropped land is typically less than that of the native ecosystems that once prevailed. Globally NPP is about 10% less (around six gigatons of carbon per year!) than it was prior to the widespread adoption of human agriculture. Perhaps biochar additions can increase global NPP enough over time to further increase the amounts available for biochar production. There are many competing demands for NPP, which currently is about 61 Gt C/yr. Sizeable portions must be retained for natural forest and other native biomes, biofuels, forest products, and food production. Population growth will place additional demands on this limited resource. More study is needed here.

9. How do you determine the magnitude of the "Fossil-C Offsets" bar in Figure 4? Using the assumptions in Rows 7a and 8a of Table 1, much of the carbon in the co-product pyrolysis gases (the carbon not ending up in the direct biochar category) can be burned to offset fossil energy generation. This effect is about 50% greater than that of the biochar alone with the present assumptions, although the relative sizes of the biochar and fossil-offset fractions will vary by technology. For instance, charcoal-making stoves for developing countries would give more equal fractions of biochar and energy, while hydrothermal carbonization technology (Titirici et al., 2007) would yield a six-fold larger biochar fraction than fossil energy offset fraction.

10. And how about finding the magnitude of the "CCS" bar in Figure 4?
After being used for the fossil energy offset purposes in Fig. 3, the combustion products of the "left-over" pyrolysis gases might themselves be captured and placed underground in a process called carbon capture and sequestration (CCS). This potential is captured in rows 7b and 8b of Table 1.

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Table 1 – Assumptions Behind Four Sustainable Biochar "Wedge" Scenarios

Row	Parameter	Units	Conserv-ative	Moderate	Optimistic	Optimistic Plus
1	To, Start Year	yr	2010	2010	2010	2010
2	N, years to reach maximum rate	yr	30	25	20	N/A
3	Tn, year maximum rate is reached	--	2040	2035	2030	N/A
4	Global Net Primary Production (NPP)	GtC/yr	61.5	61.5	61.5	61.5
6	Fraction of Global NPP available to make biochar sustainably	%	1.2	2.1	3.2	3.2
7a	Carbonization efficiency	%	40	40	40	40
7b	Carbonization/Sequestration efficiency w/CCS	%	87	87	87	87
8a	Fossil-C (coal) Offset efficiency	%	58	58	58	58
8b	Fossil-C (coal) Offset efficiency w/ CCS	%	43	43	43	43
9	Biochar Application Rate	t C/ha	5	5	5	5
10	Impact of Biochar Application on Local NPP	% increase/ha	0	0	0	25
11	Impact of Biochar Application on N_2O Emissions	% decrease/ha	0	0	0	50
12	Half-life of Biochar in soil	yr	80	500	500	500

Figures 1 - 4.

Figure 1. Four sustainable scenarios using carbon-negative biochar technology

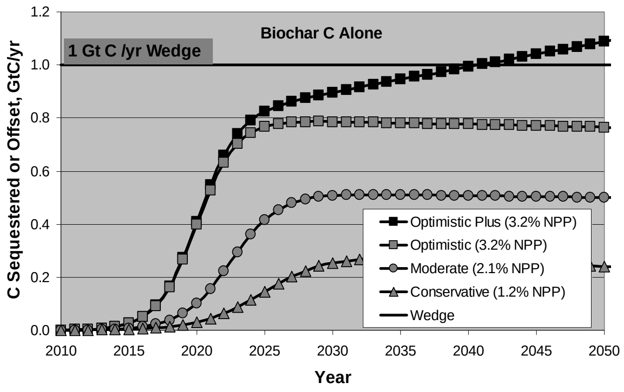

Figure 2. Four sustainable scenarios using carbon-negative biochar technology with fossil-C offsets

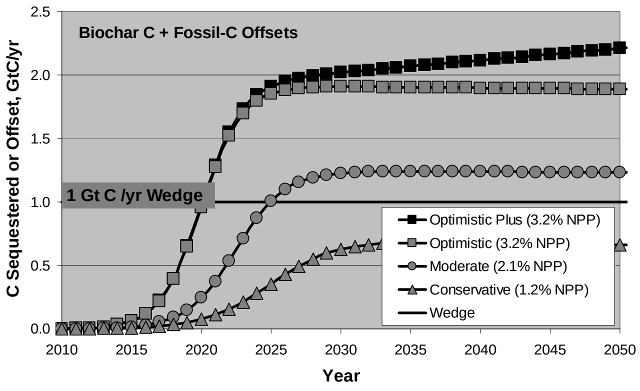

Figure 3. Cumulative carbon offset predicted by four sustainable scenarios using carbon-negative biochar technology with fossil-carbon offsets

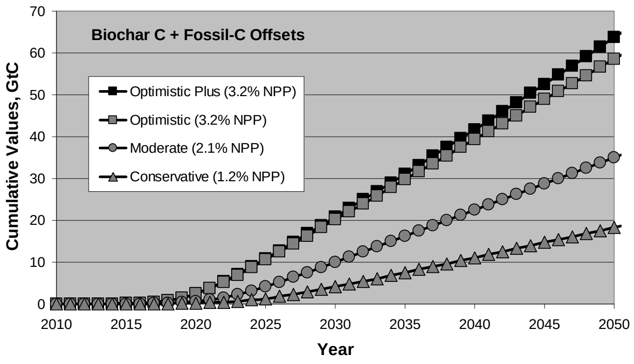

Figure 4. Annual contributions of components of sustainable biochar technology to carbon sequestration (2050)