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, a model has been developed 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. 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 storage (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 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. We also 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 assumptions 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, producing an overall conservative result.

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. Biochar additions can potentially 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.

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 the 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 storage (CCS). This potential is captured in rows 7b and 8b of Table 1.

11. How can one learn more about these projections?
Detailed assumptions, calculations, descriptions and references, along with updated versions of this paper, are available on the IBI website (www.biochar-international.org).

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

Row	Parameter	Units	Conservative	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

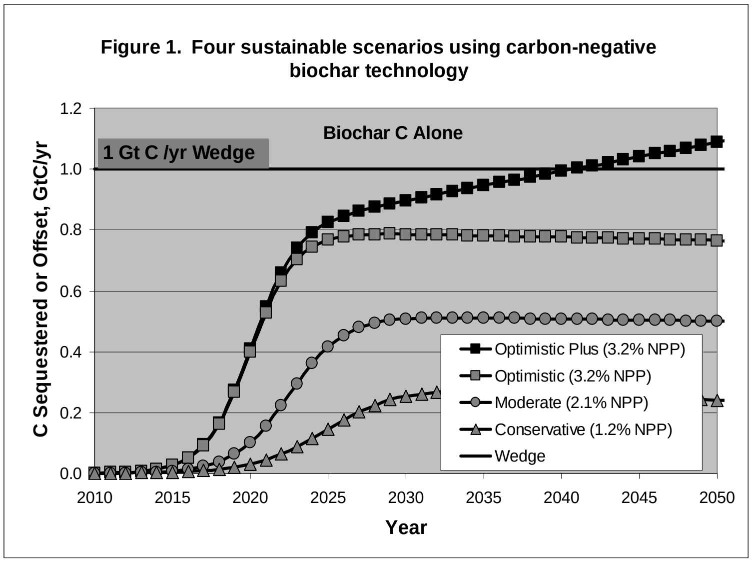

Figure 1. Four sustainable scenarios using carbon-negative biochar technology
Biochar C Alone
1 Gt C /yr Wedge
Optimistic Plus (3.2% NPP)
Optimistic (3.2% NPP)
Moderate (2.1% NPP)
Conservative (1.2% NPP)
Wedge
C Sequestered or Offset, GtC/yr
Year

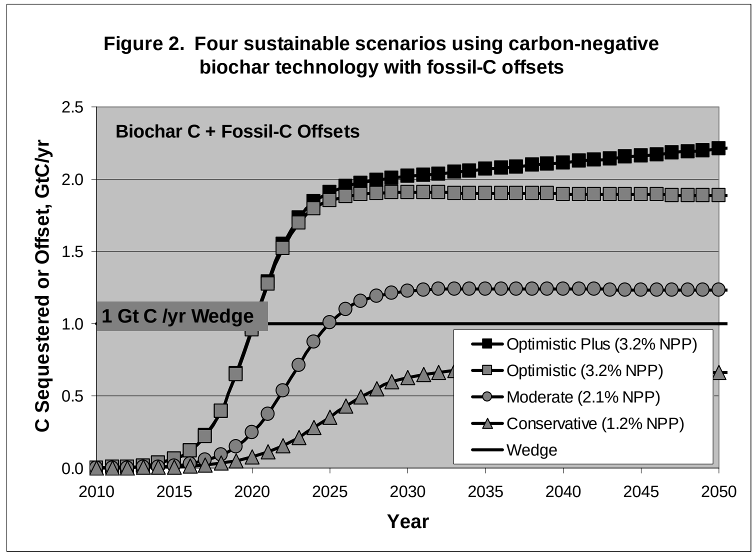

Figure 2. Four sustainable scenarios using carbon-negative biochar technology with fossil-C offsets
Biochar C + Fossil-C Offsets
1 Gt C /yr Wedge
Optimistic Plus (3.2% NPP)
Optimistic (3.2% NPP)
Moderate (2.1% NPP)
Conservative (1.2% NPP)
Wedge
C Sequestered or Offset, GtC/yr
Year

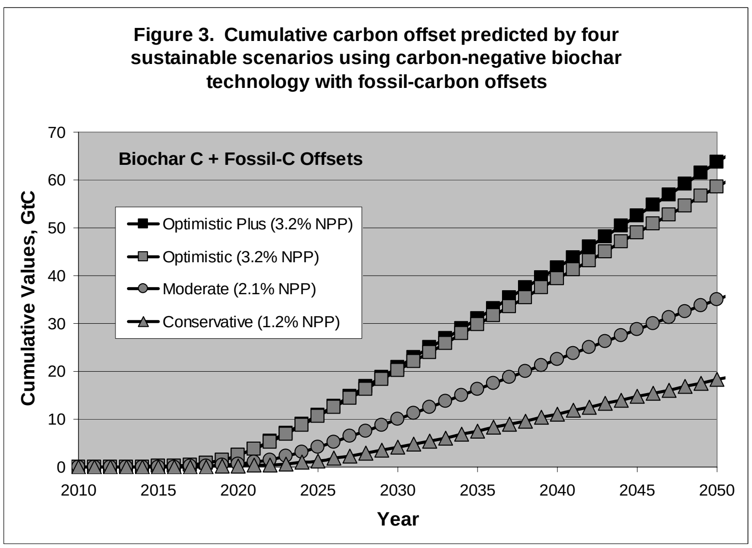

Figure 3. Cumulative carbon offset predicted by four sustainable scenarios using carbon-negative biochar technology with fossil-carbon offsets
Biochar C + Fossil-C Offsets
Optimistic Plus (3.2% NPP)
Optimistic (3.2% NPP)
Moderate (2.1% NPP)
Conservative (1.2% NPP)
Cumulative Values, GtC
Year

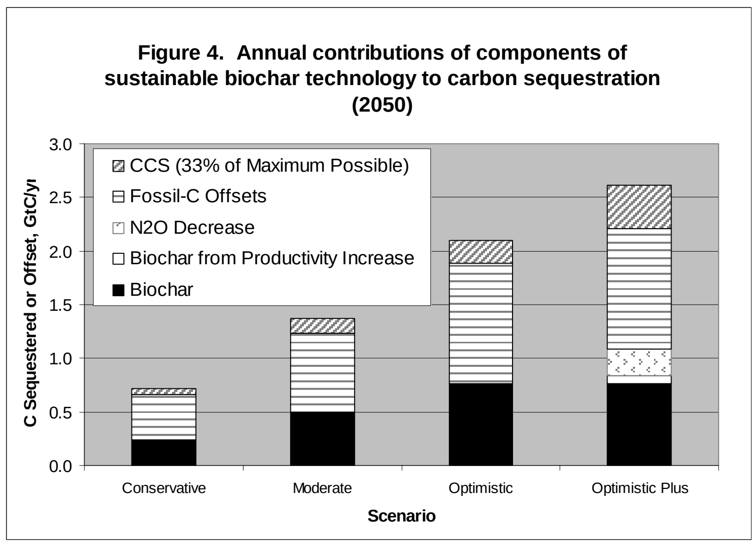

Figure 4. Annual contributions of components of sustainable biochar technology to carbon sequestration (2050)
CCS (33% of Maximum Possible)
Fossil-C Offsets
N2O Decrease
Biochar from Productivity Increase
Biochar
Conservative
Moderate
Optimistic
Optimistic Plus
Scenario
C Sequestered or Offset, GtC/yr