U.S.-FOCUSED BIOCHAR REPORT

ASSESSMENT OF BIOCHAR'S BENEFITS FOR THE UNITED STATES OF AMERICA

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Edited by | Jonah Levine
Contributing Authors | Christoph Steiner, PhD, Hugh McLaughlin, PhD, PE, Andrew Harley, PhD, Gloria Flora, Ronal Larson, PhD, Adam Reed, JD
Formatting by | Annie Dore, BeeSpring Designs
Printing by | Centennial Printing

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Biochar is a charcoal carbon product derived from biomass that can enhance soils, sequester or store carbon, and provide useable energy.[1] Lessons learned from Terra Preta (an ancient human-created soil type in Brazil) suggest that biochar will have carbon storage permanence in the soil for many hundreds and possibly thousands of years.[2] Biochar is produced by subjecting biomass to elevated temperature, extracting energy in the form of heat, gases, and/or oils while retaining a large portion of the original biomass carbon in a solid form (charcoal or char). The relative percentage of solid carbon retained vs. the amount and form of energy produced is a function of the process conditions. The resultant solid carbon becomes biochar when it is returned to soils with the potential to enhance mineral and nutrient availability and water holding capacity, while sequestering carbon for on the order of a thousand years. Economic drivers bringing biochar to practical application include:

- Agricultural value from enhanced soils
- Renewable energy produced
- Permanent carbon sequestration
- Waste mitigation
- Environmental remediation
- Concurrent economic value from reduced nitrous oxide and methane release.[3]

Well designed renewable energy (RE) technologies such as energy efficiency, solar, wind, geothermal, hydroelectric, and biomass driven projects are needed to ensure a diverse portfolio of sustainable solutions to meet our energy demands. These RE technologies offer opportunities to produce energy that is carbon neutral, whereas biochar offers the potential to be carbon *negative*.[4] Biochar as a method of carbon management is also widely scalable in size and flexible across soil type and usage making biochar deployable worldwide. While technologically ready, research and development is needed for consistent production, material improvement and assessment of biochar's impact on soil ecology and processes. Biochar development is a vibrantly growing field.

Biochar presents the ability to produce usable energy during its production while concurrently creating a solid carbon product, which has many value-added uses. This carbon product can function to both sequester carbon and enhance agriculture, forestry, remediation and other processes. The political and business climate that allows renewable energy generation, agroforestry improvement, waste mitigation and carbon storage mechanisms to accelerate would be wise to take notice of past work, tune in to current work, and position themselves for future work on biochar.

The following report addresses six critical topics:

1. Agroforestry
2. Energy Co-Products
3. Reclamation
4. Sustainability
5. Green House Gas Accounting
6. Green House Gas Markets

Each of these areas will continue to develop over time with research and application but the information presented in this report serves as a resource for those becoming involved or continuing to be involved in the exciting development of biochar. USBI encourages readers to consider how they might add to this body of biochar knowledge and contact us for suggestions and contributions

It will take a community to raise the biochar baby – biochar needs project champions, YOU are that champion.

Jonah G Levine
Research Faculty University of Colorado
Center for Energy and Environmental Security (http://cees.colorado.edu/)
Jonah.Levine@Colorado.Edu

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The overall purpose of the report is to provide U.S. decision-makers with a compelling vision of the significant potential benefits of biochar application with respect to the sections described below.

BIOCHAR IN AGRICULTURAL AND FORESTRY APPLICATIONS IN:
BIOCHAR FROM AGRICULTURAL AND FORESTRY RESIDUES – A COMPLIMENTARY USE OF "WASTE" BIOMASS

CHRISTOPH STEINER
christoph.steiner@biochar.org

As society embarks into a new era of sustainable practice energy efficiency and conservation are a top priority, in addition the world needs a permanent carbon sink, which will not compromise the productivity of agricultural land and is affordable. Biochar carbon sequestration may offer such opportunities. Pyrloysis with biochar carbon sequestration would return nutrients and a significant proportion of the original feedstock's carbon back into agricultural fields. A large proportion of the feedstock energy is still in the biochar and its non-fuel use holds a cost, but offers the following advantages over other forms of bio-sequestration:

1. Reduced competition between different land use purposes such as carbon sequestration, food or energy production.
   a. Carbon and nutrients are returned to the fields and establish a permanent carbon sink.
   b. Biochar is a beneficial soil amendment improving soil fertility.
   c. The technology can be deployed at various scales and this may allow the utilization of a broad spectrum of otherwise wasted biomass.
2. The issues of permanence, additionality and leakage are less prohibitory for biochar projects than for other land use, land-use change and forestry (LULUCF) projects.
   a. If biochar is applied once it is highly unlikely that changes in management, environment or wildfire would increase the vulnerability of this carbon sink.
   b. Biochar carbon sequestration is additional as its non-fuel use competes with energy production.
   c. Monitoring of biochar carbon should be easier than estimating biomass carbon gains or balancing gains and losses in soils.
3. More carbon can be sequestered when biochar is used as soil amendment than when used for fossil fuel substitution.

However, as long as fossil energy is consumed wastefully, carbon credits will remain low and biochar carbon sequestration depends on a carbon trade.

Biomass Abundance in the U.S.

Biomass currently provides 3% of the total energy consumption in the U.S. To meet the goal of a 30% replacement of the current U.S. petroleum consumption with biofuels would require approximately 1 billion Mg (megagram = dry tons) of biomass feedstock per year (Perlack *et al.* 2005). A study conducted by DEO and USDA (Perlack

et al. 2005) estimated that over 1.2 billion Mg (1.3 billion dry tons) could be generated in the U.S. forestry and agricultural sector per year. They assume that about 336 million Mg (370 million dry tons) of sustainable biomass could be produced on forestlands and about 900 million Mg (one billion dry tons) could come from agricultural lands. According to these authors forestland and cropland have the potential to provide seven times more biomass resources than the amount currently consumed. Andrews (2006) estimated that the eight leading U.S. crops produce more than 450 million Mg (500 million tons) of residue each year, where corn (Zea mays) and wheat is receiving most attention for biofuel production due to its concentrated production area and its relatively high residue production. The amount of biomass currently available for bioenergy and bioproducts is about 170 million Mg (190 million dry tons) annually. In order to supply one billion Mg of dry biomass from U.S. cropland major changes in crops, agricultural praxis, yield increases and more efficient harvest technology would be necessary (Perlack *et al.* 2005).

The forest resources potentially available for bioengery production include residues produced during the harvesting of forest products, fuel-wood extracted from forestlands, residues generated at primary forest product processing mills, and forest resources that could become available through initiatives to reduce fire hazards and improve forest health. Currently, about 60 million Mg (97 million dry tons) of residues are generated annually from these activities (cited in Perlack *et al.* 2005) and about 37 million Mg (41 million dry tons) of this biomass material is potentially available for bioenergy. These estimates take into consideration factors affecting access to residues, equipment recovery limitations, economic and ecological considerations. The limitations for crop and forestry residue use are mainly due to conflicts between food or biofuel production, carbon sequestration and maintenance of soil fertility.

Biofuels, Soil Fertility and Carbon Sequestration

The interest in domestic production of biofuels and other biomass energy stimulated the debate on crop and forest residue utilization and its consequences on soil erosion, fertility and carbon sequestration. Crop residue utilization can be challenged by concerns about soil degradation mainly caused by a decline in soil organic carbon (SOC). Numerous researchers warn of deleterious effects on soil fertility if crop residues are removed for bio-energy production (Lal 2005, 2007; Lal 2007; Lal and Pimentel 2007; Blanco-Canqui and Lal 2007; Sauerbeck 2001). Blanco-Canqui and Lal (2007) found that an annual corn stover removal rate of > 25% reduces SOC and soil productivity. However none of these authors considered the returning of carbon and nutrients in the form of biochar. Most studies consider complete combustion, gasification or ethanol production from lingo-cellulosic feedstock. These options remove carbon from the fields in form of crop residues; oxidize the carbon to carbon dioxide (CO_2) and consequently reduce SOC with important implications on soil fertility. Proposals resulting in crop residue removal without returning nutrients and carbon to agricultural fields might either overestimate the rate of sustainable crop residue supply or underestimate the negative consequences of crop residue removal on soil fertility. It is imperative that residue removal be considered only when soil conservation will not suffer as a result. Proposals for agricultural and forestry biomass utilization typically focus on only carbon sequestration (Seifritz 1993; Strand and Benford 2009; Zeng 2008) or bioenergy production – but not both. The main focus on bioenergy is ethanol production from lingocellulosic biomass. While others suggest maximizing carbon sequestration by either the burial of crop residues in the deep ocean (Strand and Benford 2009) or the storage of wood underground (Zeng 2008). The burial of crop residues in deep ocean sediments was criticized by Karlen *et al.* (2009). The authors call attention to the multiple functions of crop residues for sustainable and well-functioning agricultural systems. Storage of carbon rich biomass in sediments and soil without ecological function, would not only remove carbon but also nutrients. The costs and carbon footprint associated with replacing these nutrients (fertilization) needs to be considered. Strand and Benford (2009) argue that as long as fuels exist with higher energy yield-to-carbon content (E/C) ratios than biomass, it will always be more energy efficient and less carbon polluting to sequester the biomass in the deep oceans, and use those fuels with higher E/C ratios for power generation, rather than burn biomass for power generation. The authors justify biomass ocean sequestration with an estimated efficiency of 92%, while according to the authors fossil fuel replacement with bioenergy has only

an efficiency of 32% and conventional soil carbon sequestration in soils is about 14%. The U.S. 2007 Energy Independence and Security Act states that cellulosic biofuels (such as ethanol made from cellulose) must, when both direct and indirect emission are taken into account, offer at least a 60% lifecycle greenhouse gas (GHG) reduction relative to conventional gasoline (cited in Tilman *et al.* 2009). According to Strand and Benford (2009) the burial of crop residues in the deep ocean is the only method to process large amounts of carbon, be repeatable, sequester carbon for thousands of years, be practical, economical (337.5 US$ Mg^{-1} of carbon) and be implemented soon. Carbonization of biomass and the storage of carbon in the form of charcoal (biochar) was suggested by Seifritz (1993). However these proposals neglect the removal of essential nutrients contained in the biomass and the beneficial effects of carbon on soil fertility. Seiftiz did not know about the beneficial effects of charred plant material on soil fertility and that a significant proportion of SOC in Chernozems or Mollisols consists of such carbonized plant matter (Skjemstad *et al.* 2002). The recalcitrance of carbonized plant matter makes it needless and therefore wasteful to protect this form of carbon in ocean sediments or landfills. Pyrolysis of waste biomass generates fuels and biochar recalcitrant against decomposition. Returning the carbon and nutrients to the land in form of biochar would offer unique options to address issues emerging from the conflicting and complimentary positions of cultivated crops including; energy, CO_2 sequestration; or, for food and fiber. The residual biochar still contains a significant proportion of the energy contained in the feedstock. Not utilizing the charcoal for energy generation but instead using it as biochar (non-fuel use) holds an opportunity costs. Some of the values added are; increased sustainability of land use, a large carbon sink, and reduced competition between different land use purposes through waste biomass utilization. Biofuels should make a positive impact on energy security, greenhouse gas emissions, biodiversity, and should not compete with food production (Searchinger *et al.* 2008; Tilman *et al.* 2009).

Biochar and Soil Fertility

Before the introduction of mineral fertilizers a complex crop rotation and fallow system was established in order to maintain SOC; nutrient cycling and SOC conservation was of prime importance. Today however even mineral fertilized fields show yield decreases, reduced nutrient cycling and reduced nutrient-use efficiency of applied fertilizer if SOC declines (Grace *et al.* 1995; Yamoah *et al.* 2002). As opposed to the traditional mineral fertilizer practice described above, soils containing charred plant materials are among the most productive soils in the world. High levels of charcoal carbon resulting from repeated historical burning of grasslands, open woodlands, and agricultural crop residues have been reported in soils from Australia and Germany. As the SOC pool declines due to cultivation, the more resistant charcoal fraction increases as a portion of the total carbon pool (Zech and Guggenberger 1996; Skjemstad 2001; Skjemstad *et al.* 2002). In U.S. agricultural soils charcoal constitutes up to 35% of the total SOC (Skjemstad *et al.* 2002). However only a small percentage of the original carbon remains in the form of charcoal after a forest fire (Fearnside *et al.* 2001).

Most impressive is the transformation of one of the world's most infertile soils into one of the most productive ones in the Brazilian Amazon. If either anthropic (unintentionally formed) or anthropogenic (intentionally formed), these dark soils are the product of human activities and termed Terra Preta de Índio. The deposition of nutrient-rich materials and charcoal within the zone of habitation and associated garden areas created these soils (Woods 1995). The resulting soil contains high concentrations of charcoal (Glaser *et al.* 2001); significantly more plant available nutrients than in the surrounding Oxisols (Lima *et al.* 2002). Terra Preta soils still contain elevated carbon contents, despite their age of 500 to 2,500 years (Neves *et al.* 2003) and intensive cultivation. With certainty charcoal was intentionally used in U.S. and European agriculture. The book "Brief Compend of American Agriculture" published in 1847 mentions multiple uses of charcoal mainly for nutrient (nitrogen) conservation purposes (Allen 1847). The author recommends the mixing of nutrient rich materials such as guano with charcoal in order to absorb ammonia. Even human excrements were mixed with charcoal dust and used to replenish nutrients in the field. It is mentioned that a dressing of charcoal has been found so beneficial that it has been extensively introduced in France. Probably the oldest description of charcoal use in agriculture comes from Japan. In 1697 Yasusada Miyazaki termed it "fire manure" and described roasting organic wastes and mixing with

nutrient rich manures (Miyazaki 1697). Rice husk biochar has been used since the beginning of rice cultivation in Asia (Ogawa 2008). Rice husk biochar was also mixed with nutrient rich materials in order to increase its fertilizing efficiency. A mixture of human waste and charcoal powder was called "haigoe" and was frequently used to fertilize crops (Ogawa 1994). As a result of experience and research, carbonized materials are formally authorized for use as soil amendment material in Japan, which is using 27% of its national charcoal production for purposes other than fuel, more than 30.6 percent of which is used in agriculture (Okimori, Ogawa, and Takahashi 2003). Also the recalcitrance of carbonized materials was well known and utilized to increase the durability of wood.

In an attempt to recreate Terra Preta, initial biochar research was conducted in the humid tropics. Tropical land use systems provide unique conditions for biochar carbon sequestration. The humid tropics produce more biomass than anywhere else and the abundance of "waste" biomass is huge. Decomposition of labile SOC is fast and in strongly weathered tropical soils, SOC plays a major role in sustaining soil productivity. Therefore both, the conditions to produce biochar as well as the benefits of soil biochar applications appear greatest in the humid tropics. As a result slash-and-char was described as an alternative to slash-and-burn (Steiner 2007). Lehmann and Rondon (2006) reviewed 24 studies with soil biochar additions and found improved productivity in all of them ranging from 20 to 220% at application rates of 0.4 to 8 Mg carbon ha^{-1}. Such increases in productivity were explained by improving soil chemical, biological and physical properties. Iswaran, Jauhri, and Sen (1979) used biochar as carrier material for Rhizobium. The biochar provides favorable reaction and aeration and enhances the longevity of these bacteria. Ogawa (1994) also found increased abundance of nitrogen fixing bacteria in soil amended with biochar. Rondon *et al.* (2007) found increased biological nitrogen fixation by common beans through biochar additions and Gehring (2003) increased occurrence of nitrogen-fixing nodules in plants in forests on Terra Preta compared to adjacent soils. Also the colonization rates by mycorrhizal fungi was enhanced in the majority of experiments conducted (Warnock *et al.* 2007). The effects on soil biology seem to be essential as biochar has the potential to alter the microbial biomass (Steiner, Das *et al.* 2008; Steiner *et al.* 2004) and composition (Birk 2005) and the microbes are able to change the biochar's properties (Glaser *et al.* 2001). Increased microbial biomass was also found in temperate soils in the U.S. after biochar application (Kolb, Fermanich, and Dornbush 2008). Wardle, Zackrisson, and Nilsson (1998) found that biochar stimulated active soil microbial biomass and the presence of biochar increased nitrogen uptake in a boreal forest ecosystem and concluded that biochar provides a major contribution to the rejuvenating effects of wildfire on forest ecosystems.

Decreased acidity, exchangeable aluminum and increased mineral nutrition on acidic tropical soils was found by Steiner *et al.* (2007; Topoliantz, Ponge, and Ballof (2005); and Major *et al.* (2010). But also mineral nitrogen fertilization was more efficient on soils containing biochar. Lehmann *et al.* (2003) found significantly reduced leaching of applied fertilizer nitrogen in biochar containing pots. This was corroborated in a field experiment by Steiner, Glaser *et al.* (2008). The recalcitrant nature of biochar makes it rather unlikely that nitrogen immobilization caused this increased nitrogen retention. Terra Preta soils show not only a doubling in the organic carbon content but also a higher cation exchange capacity (CEC) than would be expected from the sum of the colloidal activity of the organic matter and the kaolinitic clay minerals individually (Sombroek, Nachtergaele, and Hebel 1993). In Terra Preta soils it appears the oxidation of the biochar that creates carboxylic groups on the edges of the aromatic core, which are responsible for the increased CEC and reactivity of biochar in the soil (Glaser *et al.* 2001). The high specific surface area, oxidation of the biochar itself and adsorption of organic matter to biochar surfaces may contribute to the high CEC found in soils containing biochar (Liang *et al.* 2006). This raises hope that the beneficial effects of charcoal amendments increase over time. Increased fertilizer use efficiency was also found in Australia (Chan *et al.* 2007) and the UK (Gathorne-Hardy, Knight, and Woods 2009). Similar to the studied tropical soils agricultural soils in the southeastern U.S. Coastal Plain have meager soil fertility characteristics because of their sandy textures, acidic pH values, kaolinitic clays, low cation exchange capacities, and diminutive SOC contents. Biochar additions to such soils significantly reduced acidity and improved soil fertility (Novak, Busscher *et al.* 2009; Novak, Lima *et al.* 2009). Laird *et al.* (2010) assessed the impact of biochar amendments on the quality of a typical Midwestern agricultural soil. This soil is not considered meager; however the authors report significantly increased CEC, and extractable plant nutrients. The supply of nutrients largely depends on the feedstock used for biochar production. Depending on pyrolysis temperature, most nutrients (with excep-

tion of N and S) get enriched in the biochar with increasing losses of oxygen, hydrogen and carbon (Gaskin *et al.* 2008). The nutrient contents of biochars may be enriched by co-composting with nutrient rich materials. Such applications were already recommended by Allen (1847). The production of biochar does not compete with composing but could be a supplementary approach. In general nutrient rich materials or materials with a low carbon-to-nitrogen ratio (C:N) and high moisture content make a good compost whereas materials with a high C:N ratio (>30) are less suitable for composting. Woody materials are rather resistant to decomposition, require long composting times and additional nitrogen fertilization. Available carbon (wood waste) may also negatively influence compost stability and quality (N-immobilization). Therefore such biomass waste is frequently burned or is deposited in landfills. These biomass sources are ideally suited for biochar production and can either be mixed with compost or used as a bulking agent during composting. Due to its recalcitrance, the use of biochar as a bulking agent does not result in the addition of readily available carbon, and thus its use does not increase the effective C:N ratio. Recent research has shown that co-composting of biochar with nitrogen rich manures reduces nitrogen losses due to ammonia (NH3) volatilization by up to 50% (Steiner *et al.* 2010).

Asai *et al.* (2009) found improved soil water permeability and soil water holding capacity and thereby plant water availability in rice plantations after biochar amendments. This was also found in temperate soils (Briggs 2005) but might depend on soil properties such as clay content (Glaser, Lehmann, and Zech 2002). A 2% switchgrass biochar addition to a sandy Norfolk soil in the southeastern U.S. could significantly improve soil water retention (Novak, Lima *et al.* 2009) and was also found in the Midwestern soil by Laird *et al.* (2010).

As other organic matter, biochar additions may influence the environmental fate and performance of pesticides. Sheng *et al.* (2005) found that wheat char was highly effective sorbent for the pesticides, and its presence (1% by weight) in soil contributed 70% to the pesticide sorption. It is advantageous if adsorbed pesticides are not carried downward through the soil profile with percolating water. Thus application of biochar, may offer an important strategy for reducing pesticide leaching. The nature of organic matter in soil plays a key role in the performance of applied pesticides (Gevao, Semple, and Jones 2000). However, if biochar affects herbicide sorption in soil, it may in turn affect herbicide persistence (Spokas *et al.* 2009; Yu, Ying, and Kookana 2009). Despite greater persistence of the pesticide residues in biochar-amended soils, the plant uptake of pesticides decreased markedly with increasing biochar content of the soil in a study by Yu, Ying, and Kookana (2009). Yet charcoal was reported to prevent fungus disease (rust in wheat, and mildew in other crops) (Allen 1847) and thus might reduce pesticide requirements. Recent research showed that relatively small (1% by weight) biochar additions to soil and potting medium induced a systemic resistance against two foliar fungal pathogens (*B. cinerea* and *L. taurica*) in both pepper and tomato plants, and to a pest (*P. latus*) in pepper plants (Elad *et al.* 2010).

Carbon Sequestration

Carbon dioxide is removed from the atmosphere through photosynthesis and stored in organic matter. When plants grow they utilize sunlight, CO_2 and water (H_2O) to synthesize organic matter and release oxygen (O_2). This accumulated carbon is returned to the atmosphere by decomposition of dead plant tissue or disturbances, such as fire, in which large amounts of organic matter are oxidized and rapidly transferred into CO_2. Eighty to ninety percent of the carbon from crop residues in the field is lost due to decomposition in the first 5 to 10 years (Lehmann, Gaunt, and Rondon 2006). Humus enrichment follows a saturation curve, approaching a new equilibrium level after some 50 to 100 years. The new SOC level drops rapidly again, as soon as the required careful management is no longer sustained (Sauerbeck 2001). Baker *et al.* (2007) reviewed literature on conventional plowing and conservation tillage and did not find consistent accrual of SOC due to conservation tillage. He assumes that root growth and distribution might be affected by conservation tillage leading to increased SOC in surface horizons but SOC depletion in subsoil horizons. Furthermore the addition of degradable crop residues and reduced tillage systems is not always beneficial. Increases in nitrous oxide (N_2O) and methane (CH_4) emissions, increased susceptibility for pests and diseases, and nitrogen immobilization are among the observed negative effects. These adverse ramifications of accumulating crop residues are one reason why many farmers

burn crop residues in the field. Agricultural fires were found to account for 8-11% of the annual global fire activity. In U.S., agricultural burning contributed 9-16% of all fires (Korontzi *et al.* 2006). Burning crop residue before and/or after harvest is a common farming practice. The highest rates were found in Florida with 34% of reported harvest area burned. In 2003, crop residue burned areas in the continental U.S. equaled 79% of the area burned by wildland fires (excluding prescribed fires), suggesting that crop residue burning is a major fire activity for the U.S. (McCarty *et al.* 2009).

Conventional bio-sequestration options (in biomass) are challenging and complex due to uncertainties in biological systems affected by climate change such as increased temperatures, altered precipitation patterns, and changes in disturbance regimes (fire, insects, and disease). Leakage, permanence and additionality are issues of particular concern in LULUCF projects (involving no-till agriculture). The permanence and vulnerability of these sinks are likely to change in a warming climate and potential future losses must be compensated (Gaunt and Cowie 2009). Therefore carbon sequestered by LULUCF projects is generally considered only temporarily sequestered from the atmosphere (Kollmuss, Zink, and Polycarp 2008). The Clean Development Mechanism (CDM) board and Gold Standard deals with these challenges by either excluding or strictly limiting LULUCF projects. One hundred years is the maximum time forestation projects guarantee to keep carbon sequestered. The storage of biomass in landfills is associated with CH_4 production and might in view of the relatively large global warming potential of CH_4, even be counterproductive in mitigating climate change (Reijnders 2009).

Biochar carbon sequestration is fundamentally different to other forms of bio-sequestration. The issues of permanence, land tenure, leakage, and additionality are less significant for biochar projects than for projects that sequester C in biomass or soil though management of plant productivity. Biochar carbon sequestration might avoid difficulties such as accurate monitoring of soil carbon which are the main barriers to inclusion of agricultural soil management in emissions trading. Using the turnover rate and the quantity of carbon has been suggested as a method to be used in assessment of the carbon sequestration potential (Gaunt and Cowie 2009) and that could be done independently from biochar's use as soil amendment or other non-fuel purposes.

Biochar formation decelerates the carbon cycle with important implications for carbon management. Carbon dating of charcoal has shown some C material to be over 1500 years old, fairly stable, and a permanent form of carbon sequestration (Lal 2003). Kuzyakov *et al.* (2009) assessed a half-life of 1400 years for carbonized plant materials. Spokas *et al.* (2009) could not find mineralization of biochar in an incubation experiment. Assuming a constant supply of biomass and conversion to biochar and energy a difference in half-life of 100 or 1000 years would result in a negligible difference in the carbon sequestration potential (Gaunt and Lehmann 2008). Lenton and Vaughan (2009) rated biochar as the best geo-engineering option to reduce CO_2.

An observed reduction on N_2O and CH_4 after biochar applications deserves particular attention due to the much higher global warming potentials of these gases compared to CO_2. Rondon, Ramirez, and Lehmann (2005) observed a 50% reduction in N_2O emissions from soybean plots and almost complete suppression of CH_4 emissions from biochar amended (20 Mg ha^{-1}) acidic soils in the Eastern Colombian Plains. Yanai, Toyota, and Okazaki (2007) observed an 85% reduction in N_2O production of rewetted soils containing 10% biochar compared to soils without biochar. A significant reduction in N_2O production was also found by Spokas *et al.* (2009) in a Minnesota agricultural soil. Such additional GHG reductions may have an enormous potential and the mechanisms of CH_4 and N_2O reduction needs to be discerned in more detail. A potential impact of biochar soil additions on N_2O production and fertilizer efficiency may outweigh the use of biochar for energy (Gaunt and Lehmann 2008).

The existence of Terra Preta may be the best proof that SOC enrichment beyond the maximum capacity (determined by environmental factors) is possible if done with a recalcitrant form of carbon such as biochar. These soils still contain large amounts of biochar derived SOC in a climate favorable for decomposition, and CO_2 respiration is lower than that found adjacent soils (Steiner *et al.* 2004).

Benefits of Biofuels and Potential of Biochar

The net benefit of bioenergy production is discussed very controversially. Most evaluations assume a maximization of biofuel production compromising soil fertility and carbon sequestration (Lal and Pimentel 2007; Tilman *et al.* 2009; Vries *et al.* 2010) and competing with food production (Pimentel, Marklein *et al.* 2009; Searchinger *et al.* 2008). This applies particularly to bioenergy crops. Grain- and seed-based biofuels provide modest GHG mitigation benefits (Cherubini *et al.* 2009) and raise major nutritional and ethical concerns, as nearly 60% of the world population is currently malnourished (Pimentel, Gardner *et al.* 2009). Others proposed maximizing carbon sequestration and waive benefits from renewable energy production and disregard the importance of SOC to maintain soil fertility (Seifritz 1993; Strand and Benford 2009; Zeng 2008). Site-specific parameters and too many uncertainties make it very difficult to provide values for greenhouse gas emissions and fossil fuel substitution of bioenergy systems. Afforestation, reforestation or revegetation of degraded land, in combination with future bioenergy production has been described as a synergistic way to produce bioenergy and sequester carbon (Cherubini *et al.* 2009). Biochar carbon sequestration may offer similar synergies with the greatest carbon sequestration and economical potential if crop residues or waste biomass is used rather than purpose grown crops (Roberts *et al.* 2010). Furthermore the revegetation of degraded land might require inputs such as biochar and fertilizers. Pyrolysis with biochar carbon sequestration allows cycling nutrients back into the agricultural soils and sequestering carbon in a recalcitrant form. A biorefinery processes biomass into a spectrum of marketable products and energy. One such product could be biochar. However there is an opportunity cost attached to biochar carbon sequestration. This is the cost of energy still contained in the carbonized biomass. If pyrolysis gears for maximizing biochar production (roughly 30 to 35% of the feedstock is converted to biochar), approximately 50% feedstock energy is contained in the biochar. However, more than 60% of the emissions reductions of biochar production with energy co-generation are realized from C sequestration in the biochar (Roberts *et al.* 2010). Therefore the price of carbon is critical to the cost-effectiveness of biochar projects (Pratt and Moran 2010; Roberts *et al.* 2010). However even the most expensive biochar projects revealed cost-effectiveness superior to other carbon negative technologies such as carbon capture and storage (Pratt and Moran 2010). Gaunt and Lehmann (2008) evaluated a sequestration cost of U.S. $9-16 Mg^{-1} CO_2 for biochar projects and concludes that potential revenues from C emission trading alone can justify the maximization of a pyrolysis plant for biochar production. A strategy that combines pyrolysis for bioenergy production with biochar carbon sequestration is more effective than producing solely bioenergy (Gaunt and Lehmann 2008; Roberts *et al.* 2010). About 30% more GHG emissions can be reduced when the biochar is applied to soil (-864 kg CO_{2e} Mg^{-1} dry corn stover) rather than combusted for energy generation (Roberts *et al.* 2010). However if the corn stover is directly combusted (and not biochar) as a substitution for natural gas the result would be comparable in GHG reductions (Roberts *et al.* 2010). Nevertheless only the biochar option can address issues emerging from SOC depletion and carbon sequestered in soil actually removes CO_2 from the atmosphere, whereas avoided fossil fuel consumption only reduces the speed of GHG concentration increase. Avoided fossil fuel emissions today are not avoided forever, particularly when only part of the world undertakes carbon policy. Avoided emissions today, may mean higher emissions in the future, due to a lower price path of fossil fuels (Herzog, Caldeira, and Reilly 2003).

The capture of CO_2 and storage in depleted oil and gas fields or saline aquifers is an option which requires vast capital inputs and large scale projects and would therefore be even more expensive for bioenergy projects due to the lower energy and bulk density of biomass compared to coal. One of the main advantages of biochar carbon sequestration is that it can be implemented with or without additional energy production on a small scale (improved kilns, stoves, gasifiers) as well as a large scale (e.g., biorefinery). This option would certainly expand the quantity of available biomass. Biomass from invasive species, dead trees or biomass generated from fuel reduction treatments might be pyrolysed. It is estimated that 11 million ha (28 million acres) of forest could benefit from fuel reduction treatments in the western U.S. alone, with a total biomass treatment of 313 million Mg (345 million dry tons) (USDA 2003). Vegetation treatments to regulate density and species mix, inhibit insect and disease outbreaks, or reduce wildfire risk (Morgan, Johnson, and Piva 2009). Prescribed fires are the least expensive option, but limited by restrictions on air pollution, weather conditions and a lack of resources. From the 160 million ha (400 million acres) surveyed in 2006, about 2.1 million ha (5.3 million acres) had tree mortality detected

by aerial survey. The mountain pine beetle is responsible for 50 percent of the detected mortality. It was estimated that more than 23 million ha (58 million acres) will have more than 25% of the standing live volume at risk of mortality within the next 15 years (Oswald and Campbell 2009). Conner and Thompson (2009) estimated the total mortality for trees in the U.S to be nearly 221 million m^3 (7.8 billion cubic feet) in 2006. The Rocky Mountain region showed a decline in net growth since 1996, with mortality 3.5 times higher than the annual rate of growth. In 2006, more than 127 million m^3 (4.5 billion cubic feet) of logging residues was created in the U.S. and left in the forest in the process of harvesting timber. A further unutilized 1.2 million Mg (1.3 million tons) of wood residues are generated by the timber-processing facilities in the U.S. (Morgan, Johnson, and Piva 2009).

Apart from soil fertility improvements, decentralized production and utilization would reduce costs and GHG emissions associated with biomass and biochar transport and has therefore an advantage to co-firing biochar in coal power plants or sequestration of biomass carbon the deep ocean. Currently, most calculations for proposed biofuel plants limit their collection radius to 65 km (40 mi), a distance more than twice that currently considered economical for sugar cane processing (Karlen *et al.* 2009). However, costs of collection, pyrolysis and transportation are also a significant hurdle to the economic profitability of larger biochar-pyrolysis systems (Roberts *et al.* 2010).

Considerations

Issues of SOC and nutrient cycling, crop yield, available water and drought resistance can be addressed with biochar (Laird *et al.* 2010; Novak, Busscher *et al.* 2009). However, any practice that involves removal of crop residues, leaving soil unprotected even for a short duration, would increase risks of accelerated erosion (Lal 2008). According to Andrews (2006) crop residues incorporated into the soil (which would apply for biochar) do not provide the same protection against soil erosion as crop residues left on the soil surface. The relationship between residue removal weight and resulting soil cover is not linear and needs to be assessed to determine appropriate removal rates. A 30% removal rate resulted in 93% soil cover after residue harvest (Soil Quality National Technology Development Team 2006). If 70% of surface residues remain in the field crop residue utilization (without considering biochar carbon sequestration) would not increase erosion or runoff (Andrews 2006). The issues of soil erosion and runoff can effectively be addressed with a cover crop, which is considered to be 2.5 times more effective then crop residue in reducing wind erosion (Soil Quality National Technology Development Team 2006). However the recommended precautions for crop residue removal by Andrews (2006) should be considered with or without biochar carbon sequestration. These involve determination of sustainable crop residue removal rates and additional conservation practices such as contour cropping, conservation tillage and cover crops.

Research has shown that biochar has significant effects on pesticide sorption (Sheng *et al.* 2005; Spokas *et al.* 2009; Yu, Ying, and Kookana 2009). This may reduce pesticide leaching into surface and ground water, but the influence of biochar on pesticide function and effectiveness might require further assessments.

A definition of biochar as carbon rich material should make a clear distinction between biochar and ash. Some mineral rich raw materials (e.g. manures) produce a biochar with high ash content. The impact on SOC is negligible if such biochars are applied at agronomic fertilization rates (based on phosphorus and potassium requirements). On the other hand, applied at rates to increase SOC levels, the applied phosphorous might negatively impact water resources. Losses of nitrogen during pyrloysis of nitrogen rich materials (Gaskin *et al.* 2008) may increase nitrogen fertilization requirements. However nutrient rich materials can be co-composted with biochar in a synergistic way (Steiner *et al.* 2010). Maximizing nutrient use efficiency would also contribute to reducing carbon emissions from agricultural systems. About one-third of the energy requirement in U.S. crop production is caused by nitrogen fertilization (Pimentel, Gardner *et al.* 2009).

Competition with food production and induced land use change would diminish the carbon sequestration potential even for a strategy as promising as biochar. Roberts *et al.* (2010) calculated a small net increase in GHG emissions if switchgrass is purposefully grown for biochar production and the indirect consequences on land

conversion were taken into account. Strategies leading to deforestation would deplete terrestrial carbon stocks. Therefore the biomass source is important in determining the sequestration potential, highlighting the importance of waste biomass use which would alternatively decompose or be burned. As biochar carbon sequestration depends on revenues from carbon trading (Pratt and Moran 2010; Roberts *et al.* 2010) projects depleting the terrestrial carbon stocks would also have reduced economic viability. All potential emissions, including those caused by induced land use change need to be considered in all biofuel scenarios.

Energy efficiency and conservation are certainly top priority. As long as energy is consumed wastefully, the price for carbon offsets remains low. Compensating wasteful fossil fuel use with biochar carbon sequestration would consequently imply wasteful biomass management. Pimentel, Gardner *et al.* (2009) showed many ways to reduce energy consumption in the U.S. However bioenergy cannot sustain the current energy consumption and biochar carbon sequestration not sequester the current GHG emissions. Each year, the U.S. population uses three times more fossil energy than the total solar energy captured by all harvested US crops, forests, and grasses (Pimentel, Gardner *et al.* 2009). Biochar production and utilization can be an effective tool if partnered with efficiency, conservation and other renewable and sustainable approaches.

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BIOCHAR AND ENERGY LINKAGES IN:
BIOCHAR AND ENERGY CO-PRODUCTS

HUGH MCLAUGHLIN, PHD PE
hmcLaughlin@alternabiocarbon.com

Biochar's potential benefits for the United States in the topic area of Energy Co-products are:

- providing a renewable resource with significant GHG emission benefits
- providing economic value and local opportunity to create and use biochar
- while making biochar, displace fuel oil and natural gas in domestic heating applications
- promoting distributed local agriculture productivity and energy production

The specific issues discussed are:

- Calculating the impact on Carbon Dioxide Emissions by using biomass as fuel
- Valuing Energy Co-products compared to traditional Fossil Fuels
- Estimating the cost of Biochar in Combined Heat and Biochar (CHAB) applications
- Valuing Biochar in the Soil – the importance of Yield and Adsorption Capacity
- The energy potential of a large amount of biomass – displacing Fossil Fuels
- Biochar properties and CHAB production processes – balancing tradeoffs
- Process-dependent Energy Co-product properties

Introduction

Biomass represents the renewable resource with the largest potential to affect energy-related greenhouse gas emissions. There are many possible scenarios by which biomass could influence the current energy consumption options and this analysis will attempt to put those options in perspective. In general, biomass can replace fossil fuels in energy consuming applications (electrical generation, transportation, heating), where the biomass fuel is considered "carbon-neutral", but the overall application is actually "carbon-negative" if one includes the fossil fuels displaced, as discussed below. Alternately, biomass, in the form of biochar, can be used to sequester carbon dioxide when used in agriculture, also considered "carbon-negative". One can also create the linkage between the consumption of fossil fuel, being "carbon-positive", and a corresponding offset by carbon-negative biochar, resulting in a carbon-neutral combination. The combinations are endless, but ultimately, society has to meet its energy consumption requirement and manage the impact on the level of greenhouse gases in the atmosphere.

This analysis seeks to put in perspective the various predominate biomass conversion technologies. While there are many variations of every technology, and the emergence of new approaches cannot be precluded, the focus will be on slow pyrolysis, fast pyrolysis and gasification biomass conversion technologies. All of these technologies are mature in the sense that they have extensive technical histories and have been implemented at pilot

and commercial installations, thereby developing the necessary basis to evaluate their potential if proposed for large-scale applications.

Calculating the impact on Carbon Dioxide Emissions

Unique to this analysis is the valuation of the solid residue from any biomass conversion process as "Biochar". Biochar, when utilized in agriculture, is carbon-negative, since it contains carbon atoms that were removed as carbon dioxide from the atmosphere as the biomass grew and now securely reside in the soil. As will be seen, all biomass conversion processes invariably generate additional energy co-product streams. The carbon in these energy co-product streams is carbon-neutral, having come from the atmosphere, and offers the potential to replace fossil fuels in many applications. When carbon-neutral biomass energy co-products displace carbon-positive fossil fuel in an existing application, the net effect is considered carbon-negative, by virtue of avoiding that portion of carbon-positive fuel consumption. If the energy co-product is not used to displace fossil fuels, then that portion of the biomass conversion process is carbon-neutral.

For example, suppose a biomass conversion process produces 30 tons of biochar, 20 tons of bio-oil and 50 tons of combustible vapors that are either used within the biomass conversion process or flared (combusted to carbon dioxide and water vapor and discharged). The 30 tons of biochar would be carbon-negative in the soil by the amount of elemental carbon in the biochar that is calculated and predicted to be stable in the soil, converted to the carbon dioxide equivalent (CO_2e). If the biochar were used to substitute for a fossil fuel, typically coal, it would be carbon-negative by the amount of carbon dioxide emissions avoided by not using the fossil fuel. The 20 tons of bio-oil would be used to displace a fossil fuel application, perhaps industrial fuel oil, and would be carbon-negative by the amount of fossil fuel carbon dioxide emissions avoided, which depends on the specifics of the fossil fuel displaced. The 50 tons of combustible vapors, as used in this case, would be carbon-neutral upon being returned to the atmosphere. If some of the combustible vapors were diverted to a local generator and electrical power sent offsite, then the combustible vapors would be carbon-negative by the amount of fossil fuel displaced by the electrical power exported to the "Grid".

How accurate is "semi-quantitative"

This analysis will seek to establish clear distinctions wherever possible, with semi-quantitative trends and predictions at all times. Quantitative accuracy can become the enemy of clarity when drawing conclusions. As such, calculations will be accurate to within about 10 percent and numbers will be rounded by similar amounts to clarify the parallels. English units will be used most of the time and approximate metric equivalents provided in parentheses. For example, within 6%, one (1) million British Thermal Units equals one (1) gigajoule (exactly 1.055 GJ), which would be depicted as 1 MMBtu (1 GJ) in the text. One very accurate equivalence is 1 GJ / metric tonne * 0.43 = 1 thousand Btu / pound.

Valuing Energy Co-products

Fundamentally, all biomass conversion processes start with some form of biomass, and likely either supplemental air or thermal energy, and discharge a solid, which is designated the "char", and one or more vapor streams, which are the potential Energy Co-products. The objective for Energy Co-products is to utilize the chemical and thermal energy contained in the vapors that exit the biomass conversion process. The exiting char represents another product from the biomass conversion process, and the valuation of that solid will be taken up next.

The vapors created during biomass conversion are a combination of non-condensable gases and condensable liquids that can be isolated by lowering the vapor stream temperature. Biomass conversion processes distinguish themselves by the manner that they partition and recover the vapor stream(s) into one or more product streams

of value. Depending on the process, the condensates, often referred to as "bio-oil", demonstrate a wide variety of physical and chemical properties.

Co-products are valued on the basis of the amount and value of the fossil fuel they can displace in an existing application. For example, if a non-condensable pyrolysis gas steam can be co-fired in an industrial boiler with natural gas, and the boiler requires half as much natural gas when co-firing at an established steam production rate, then the value of the Energy Co-product is the value of the natural gas avoided. By the same logic, the carbon dioxide savings is equal to the carbon dioxide that was avoided by displacing a portion of the natural gas fuel, since the non-condensable pyrolysis gas steam is considered carbon-neutral, as discussed previously.

It is important to tie the value and emission benefit of the Energy Co-product to the fossil fuel displaced for three reasons: fossil fuels vary significantly in cost per million Btu (GJ); each fossil fuel has a conversion efficiency to useable energy depending on the end use (electrical generation, transportation, heating); and the carbon dioxide emissions per unit of energy varies with each type of fossil fuel (see http://www.engineeringtoolbox.com/CO_2-emission-fuels-d_1085.html). For all these reasons, it is not acceptable to compare or value Energy Co-products on an "energy-equivalence" basis, unless the alternate fuel and the fossil fuel are essentially interchangeable. One rare example of this is biodiesel and fossil diesel, but this broad compatibility occurs with virtually no other fuel combinations.

It is useful to identify benchmark values for various standard fossil fuels, which will be used in pricing the value of energy byproducts. Since all fossil fuels are subject to volatile pricing, especially in the spot market, these benchmark prices will be used as a point of reference and the reader should always take local circumstances into account when assigning a value to any energy co-product application. A recommended site for current and projected short-term energy prices is http://www.eia.doe.gov/emeu/steo/pub/contents.html.

Natural gas is most reasonably benchmarked at $5 per million Btu (GJ) and is a very useful fuel for both electric power generation and industrial heating applications. The only real drawback is transportation, in that it usually has to be supplied by pipeline on an as-needed basis.

Coal is the other fossil fuel that dominates electrical power generation and industrial heating, and coal prices can be quite variable depending on the quality of the coal and restrictions on consumption, such as sulfur dioxide emission limits, etc. Most coal trades for $1 to $3 per million Btu (GJ), with $2 per million Btu (GJ) representing a reasonable benchmark.

Once one moves from raw sources of energy to refined energy streams, such as transportation fuels and electricity, or to the retail energy market, such as residential fuels, the price increases significantly. Transportation fuels (gasoline, diesel, etc.) at $2 per gallon (corresponding to crude oil at $75 per barrel and before taxes) correspond to about $15 per million Btu (GJ) and electricity at $0.10 per kilowatt hour equals about $30 per million Btu (GJ).

Even wood pellets, representing an engineered wood product for residential consumption, at $200 per ton corresponds to $12.50 per million Btu (GJ), with each pound costing $0.10, but providing only 8000 Btu of useable energy. Cord hardwood, typically priced around $240 per cord and weighing about two tons, still costs $7.50 per million Btu (GJ).

The lowest cost clean biomass is probably "Forestry Residues" from pulp and paper or lumber sawmills. This excess biomass is often exchanged within the immediate vicinity of its creation, since it is too heavy and bulky to move significant distances. The open market price is typically on the order of $25 per ton, but is very dependent on local supply and demand. If excess "fiber", as it is known, is generated locally, it may be available for free or burned in a "Beehive Burner". Unfortunately, if the fiber supply tightens up, the cost of "hog fuel" may swing widely, with the upper limit being reached when it becomes economically attractive to chip whole trees to create additional residual fiber.

Irrespective of origin, all woody biomass averages about 8,000 Btu/# or 18.6 GJ/metric tonne on a dry weight

basis. Thus, if available for $25/ton and one ton equaling 16 million Btus (17 GJ), the raw energy cost of biomass is on the order of $1.56 per million Btu ($1.48 per GJ), which is competitive with coal. Notably, wood is a much cleaner fuel than all grades of utility coal, with a much lower ash level and negligible sulfur and nitrogen content.

In some situations, biomass may be available for less than free, or received with payments known as "tipping fees". Construction and demolition debris is one example, as would be many contaminated biomass sources that normally require more expensive disposal options. While it may seems lucrative to be paid to take the biomass, then convert it into energy and biochar, the contamination concerns generally preclude utilization of the solid residue as biochar. As such, contaminated biomass streams are not considered further in this discussion.

Estimating the cost of Biochar

Biochar is a new product and a new application. As such, its value in a given agricultural application is hard to predict and quantify. It is helpful to define the value that biochar will have to attain in the long run to be successful: it has to sell for more than it costs to make. However, many factors can contribute to satisfying this criterion.

The specific breakeven point for production varies widely with local circumstances, but it is convenient to think of the selling price as being composed of raw material costs, transportation to the conversion plant and from the plant to the customer(s), production costs and profit margins. Of all these factors, only raw material costs are external to individual production facility and the markets it is servicing. Thus, we need to take a closer look at what drives raw material costs for biochar producing processes.

While virtually all biomass sources can be converted into biochar of varying quality, wood residues and agricultural crop residues dominate the biomass landscape. Both biomass sources have other markets; wood residues being converted into wood pellets and corn stover being used as animal feed, especially in the dairy industry. In the future, both biomass sources may serve as raw materials for cellulosic ethanol production, although when and at what cost remains to be seen.

Of the two major biomass sources, wood residues are the larger player in the current biomass-to-energy applications and we will focus on that application as a case study. Let us consider a simple example of the tradeoffs involved in biochar production, which might be called the "biochar versus Btu" tradeoff.

Imagine a homeowner with three wood pellet home heating device choices: 1, burning the pellets to ash, 2, producing 12.5% byproduct biochar by weight of wood pellets and 3, producing 25% biochar. Both biochar options 2 and 3 produce high temperature high quality biochar, with low levels of ash. Furthermore, the baseline cost of the wood pellets is $200 per ton, corresponding to $0.10 per pound, and the homeowner needs 48 million Btu per heating season.

Wood pellets, as currently manufactured and marketed, contain about 8,000 Btu/# of usable heat, so the stove that burns the wood pellets to ash will need 6000 pounds of wood pellets, or three pallets of one ton each, or $600 per heating season. The biochar, when produced, also represents heating value, but this fuel content is lost when the biochar is removed from the stove. Because biochar contains more carbon than wood, each pound of biochar represents 12,000 Btu of foregone heating value.

For the case of 12.5% biochar yield, the exiting biochar contains 18.75% of the fuel value of the incoming wood pellets (12.5% * 12,000 / 8,000 = 18.75%), so each pound of wood pellets only yields (100% – 18.75% = 81.25% x 8000 =) 6500 Btu toward the home heating requirement. Thus, for 48 million Btu, 7,385 pounds of wood pellets will be required (48 million / 6500), for a heating season cost of $738.50 – or an additional $138.50 in wood pellet cost. At the end of the heating season, the homeowner will have (12.5% of 7,385 =) 923 pounds of biochar, produced at an incremental cost of $0.15 per pound due to the additional wood pellets required.

Furthermore, the exiting biochar occupies roughly one half the volume of the incoming wood pellets. So the hom-

eowner will have one half of the 3.69 pallets (7,385 / 2000 = 3.69) = 1.85 pallets of biochar. In total, the homeowner has handled (7385 + 923 =) 8758 pounds of material during the heating season, an increase of 46 weight percent over the "no biochar" baseline, and handled a volume equal to 5.54 pallets of wood pellets, an 85 volume percent increase over the baseline. As such, the homeowner has added some sweat equity to the additional cost of fuel to produce biochar while providing the original heating requirement.

For the case where 25 weight percent of the incoming wood pellets is converted to biochar, the biochar contains 37.5% of the incoming fuel value and the wood pellets only yield (8000 * 62.5% =) 5000 Btu per pound. In this case, 9,600 pounds of wood pellets are needed and 2,400 pounds of biochar will be produced. While the additional fuel requirement remains $0.15 per pound of biochar, the material handling requirements of the higher biochar production scenario increase to twice the weight handled and 2.4 times the volume handled, as compared to the "no biochar" baseline.

While the incremental cost of biochar is $0.15 per pound, based on the additional wood pellets needed and the cost of the energy exiting in the form of biochar, it is interesting to calculate the value that the biochar would have to represent to underwrite the cost of the heating season. For the 12.5% yield scenario, if the biochar was valued at, or could be resold at, ($738.50 / 923 pounds =) $0.80 per pound, the homeowner could heat for free, plus the sweat equity. In the 25% case, the greater biochar yield reduces the cost to ($960.00 / 2400 pounds =) $0.40 per pound. While the value of the biochar must be significantly higher than the incoming fuel, the values calculated do not appear to be out of line with current "retail" biochar prices. In fact, most current biochar sales are transacted at $0.50 per pound or more, in addition to shipping costs

One underlying fundamental is that the raw material cost of biochar production is 1.5 times the cost of the incoming dry weight biomass. This relationship is derived by the energy ratio of wood biomass at 8000 Btu/# and biochar at 12,000 Btu/#. As such, this relationship will apply whenever both the biomass and biochar are valued on a moisture-free ash-free basis and the energy produced by the biochar generating process is used as heat. These applications are known as "CHAB" applications, standing for Combined Heat and Biochar. In CHAB applications, the cost of the biochar is tied to the cost of the incoming biomass, since a fixed heat demand is being serviced and some excess biomass is being converted to biochar. In this case, the biochar raw material cost is the incremental additional biomass cost.

If only biochar is being produced, and the available carbon-neutral heat is not being utilized, the application is known as "Biochar only". In this configuration, the raw material cost of the biochar is tied to the efficiency of converting biomass to biochar. If some heat is being utilized, but additional biochar is desired, a portion of the biochar will effectively be produced at CHAB raw material ratios and the remainder as "Biochar only" raw material costs.

The "Biochar only" case also occurs when the heat valued as "free" or when the biochar production volume results in a vast excess of unusable carbon-neutral waste heat. Then, the calculated raw material cost becomes the cost of the amount of biomass necessary to create one unit of biochar. Thus, as seen above, if the char yield is 12.5%, then 8 pounds of wood pellets are needed, as a cost of $0.80/# of biochar. Similarly, 25% yield scenario needs 4 pounds of wood pellets per pound of char, at a cost of $0.40/# of biochar.

The above examples look at an expensive biomass source, wood pellets, and the scenario of producing relatively small quantities of biochar at the residential scale. For industrial scale applications, the incremental cost of the raw materials to yield biochar becomes quite low. For example, if hog fuel is available at $25/ton, corresponding to $0.0125 per pound, then the incremental raw material cost for biochar is $0.01875/# or less than 2 cents per pound. However, the material handling issue does not disappear at the industrial scale, with 25 percent biochar yields doubling the weight handling requirements, as seen before.

In summary, any biochar production scenario will have significant amounts of thermal energy generated in conjunction with the biochar production. If the biochar is valued at higher than 1.5 times the biomass cost, in addition to the conversion cost surcharge of higher material handling costs and incremental capital and operating

costs, then the cost of the thermal energy will be decreased relative to the “no biochar” baseline. Conversely, if the biochar is worth less than the incremental cost of production, then the fuel must underwrite the cost of biochar production. This later situation is unlikely to persist on a commercial scale, unless there is an external economic benefit, such as a government subsidy or creation of a carbon trading credit of defined market value.

Valuing Biochar in the Soil

Biochar is more than a fuel and its role in soils goes well beyond anything associated with the energy released upon oxidation. In fact, since biochar’s most unique property is its ability to persist in the soil, the least relevant aspect of biochar is its fuel value.

Acknowledging that the science of biochar is just now exploring the interactions that occur between biochar and unique growing environments, biochar seems to have one property that distinguishes it from virtually all other soil materials. That property is porosity, the measure of the void spaces in a material. Porosity is the ratio of the volume of non-solid material to the total volume. The significance in soils is that the non-solid volume can be occupied by either air or water, or a combination of both to varying degrees under varying conditions. Furthermore, biochar is made up of thermally-modified biomass, which forms graphitic-like structures that exhibit adsorption capacity at the molecular scale. Thus, the porosity in biochar extends from large open voids to molecular-scale crevices. While there is a lower limit of the porosity of high quality biochars, it is at the molecular level and the porosity can conceptually be viewed as having “fractal” geometries extending from the scale of the entire particle to the scale of adsorbed molecules as small as water, methane and nitrous oxide. Because of this property, biochar can accurately be called “Mother Nature’s Nanotechnology”.

Typical biochars have bulk densities of around 250 kg/cubic meter, with some biochars having bulk densities as low at 150 kg/cubic meter. Biochar is principally composed of amorphous graphite that has a density of about 2000 kg/cubic meter (specific gravity of 2.00 or 2.00 grams per cubic centimeter). Thus, the porosity of biochar is in the range of 0.875 to 0.925. Even discounting the voids between the particles, biochars are essentially “rigid open space”.

The ability to form molecular scale crevices that exhibit adsorption capacity over a range of elevated adsorption energies is highly unusual and is one of the determining metrics for distinguishing biochar quality. Notably, this adsorption capacity phenomenon is not intrinsic in all biochars and develops under fairly narrow conditions. *Figure 1* shows the char yield and adsorption capacity for a series of chars made by the same experimental procedure except for the highest “Heat treatment temperature” reached during the thermal conversion of the biomass into biochar.

Two trends are depicted in *Figure 1*; the rapidly decreasing char yield between 250 and 350 degrees Centigrade (C), and the development of adsorption capacity between 500C and 700C. Notably, the char appears jet black everywhere above 300C, but does not develop maximum adsorption capacity until 550-600 C, only to have that property fade and almost disappear by 900C.

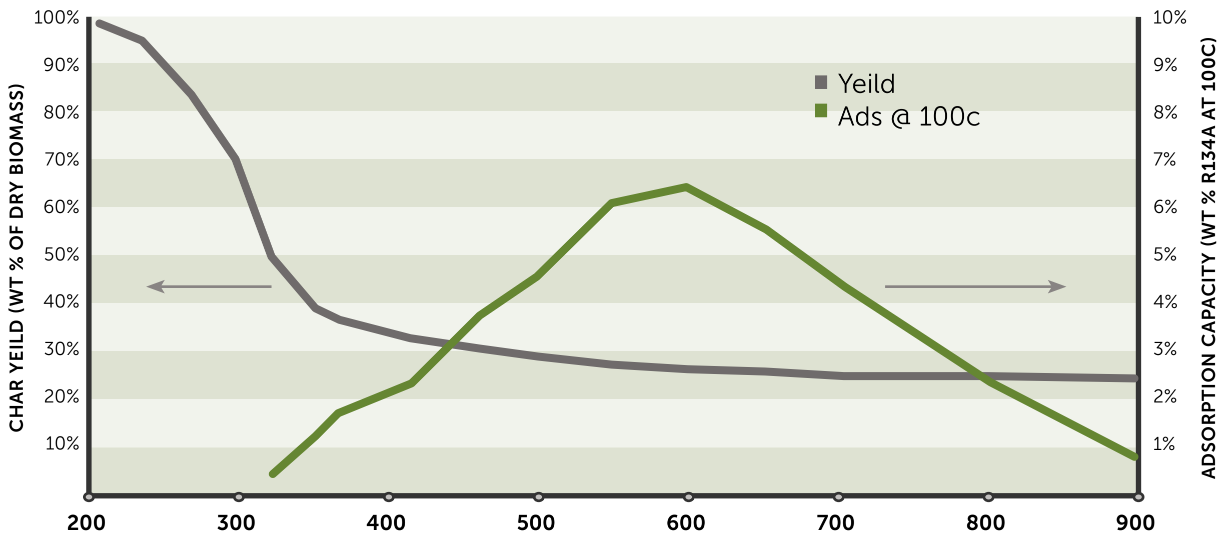

Figure 1. Heat treatment temperature Celcius

The pivotal nature of adsorption capacity relates to how biochar interacts with the rest of the soil components and the larger dynamics of soil-crop-climate interactions. Adsorption capacity directly relates to the internal surface area of the biochar, which is dominated by molecular-scale crevices within the biochar. Within these "micro-pores", two important interactions occur between the biochar and the rest of the soil; the adsorption of organic compounds and the ion exchange of soluble fertilizers, as measured by a property known as "CEC" (cation exchange capacity). The biochar takes up soluble organics and ionic plant fertilizers whenever they are in excess, stores them, and releases them slowly during periods of deficiency in the soil matrix. This buffering or moderating of the availability of soluble organics and plant fertilizer in the soil greatly facilitates both beneficial microbial activity and plant growth.

The two trends shown in *Figure 1* provide an important consideration for the production and marketing of biochar. Consider the case of starting with a fixed amount of biomass, say 100 units of dry weight, and converting it to either a 350C biochar or a 600C biochar. The 350C char will yield about 40 units of char and have an adsorption capacity of about 1.25%. The 600C char will yield about 27 units of char with an adsorption capacity of 6.50%. A measure of the productivity of a carbonization process at creating biochar, scaled by the adsorption capacity, would be the "Adsorption Yield" of (40 x 1.25% =) 50.0% at 350C and (27 x 6.50% =) 175.5% at 600C.

If the biochar is sold without any consideration being given to adsorption capacity, then the 350C char is the better product, since there are 40 units instead of 27 units to sell (50% more saleable product). In contrast, if biochar is being valued on the basis of adsorption capacity per unit weight, the 650C char would command over five times the price of the 350C char. If the biochar is valued on the basis of Adsorption Yield, the 650C char creates 3.5 times the market value of the 350C char.

In summary, in contrast with fuel application of charcoals, where fuel value is the principal concern, biochar is assessed by the performance in the soil – which depends on many things, but not on energy content. For fuels, energy content (Btu or GJ) is the main thing one looks at; in biochars, it is the only thing one ignores.

For these reasons, the International Biochar Initiative is aggressively pursuing a biochar characterization protocol to identify, measure and market biochar with labels providing measured properties including adsorption capacity and CEC (along with moisture, ash, NPK, and other metrics).

The energy potential of a large amount of biomass

When exploring the potential of the Energy Co-products associated with biochar production, it is important to compare the various available fuels and how they compare in energy density and transportation requirements.

As a basis, we will use 1 short ton (2000 pounds) of dry wood, which is about one half a full cord and a volume of 64 cubic feet. At 8,000 Btu/#, one ton of wood contains 16 million Btu (16 MMBtu or 17 GJ) and has a density of 31.25 #/ft3 (500 kg/m^3) and 0.25 MMBtu/ft3. For reference, most semi-tractor trailers are nominally 80,000 pounds gross weight, so they can carry about 25 tons of wood as a full load, for 400 MMBtu per truckload.

Diesel fuel, which is essentially identical to Heating Oil and No.2 Fuel oil, has about 140,000 Btu per gallon and a density of 7.1 pounds per gallon. Thus, storing energy as fuel oil is much easier, since it contains 53 #/ft3 and 1.0 MMBtu/ft3 (four times as dense as cord wood). A fuel oil delivery of 8,000 gallons (largest industrial tanker) represents 1120 MMBtu (2.8 times a truckload of wood).

Natural gas, as discussed, is not practical to store on site and is transported by dedicated pipeline. While reasonably priced at a benchmark $5 per MMBtu, natural gas suffers from seasonal price fluctuations, where it is a popular residential heating fuel in the winter and popular peak electrical generating fuel in the summer. However, when available, natural gas is an extremely clean, cost-effective and convenient fuel.

Coal is the mainstay of fixed site electrical production systems and the industry that has grown up around the properties and requirements of the fuel. Coal shares some properties with wood, with similar energy content per unit of weight, but is denser, burns much hotter, and contains more ash, including pollutants that are released when coal is burned. Coal, when used in large industrial and utility applications, is usually delivered by rail, providing much lower freight rates and allowing coal to be delivered over much greater distances. For example, over one third of the United States current electrical generation capacity is fueled with Powder River Basin coal from Wyoming.

In summary, biomass, and especially wood, is a low cost energy source that is expensive to move because it is typically transported by truck over small distances. Fortunately, biomass is generated over wide areas, and is, of course, renewable. As such, the prudent strategy is to use locally available and renewable biomass sources at the raw material for both biochar and energy co-product production.

Biochar properties and CHAB production processes

As noted in the Introduction, the focus of this discussion will be on slow pyrolysis, fast pyrolysis and gasification biomass conversion technologies. Slow pyrolysis will be the point for comparing biochar properties in this analysis.

Slow pyrolysis is characterized by heating biomass in an environment of controlled oxygen, with the unifying feature that the temperature gradients are gradual enough that the local char properties are determined by the biomass as it rearranges and disproportionates into a thermally modified char and exiting vapors. As the temperature rises, additional char consolidation occurs, with more and different volatiles evaporating and leaving the transforming char behind. Under these conditions, the char properties are most strongly dictated by the highest temperature the biomass experiences for a long enough period for the biomass molecules to rearrange and the volatiles to form and leave the char mass as vapors.

Note that the volatiles need to form *and* leave to complete the slow pyrolysis process. While the volatiles are formed within the biomass as it converts to char, many factors can influence the subsequent vaporization of the volatiles. It is this second step that differentiates char properties within Slow Pyrolysis chars produced at the same temperature. This is attributed to an independent char-creating process called "secondary char formation". As discussed by Antal and Grønli on pages 1627-28 "Although Klason established the key role of secondary

(vapour-phase) pyrolytic reactions in the formation of charcoal 88 years ago; today, many researchers still assume that charcoal is solely a product of primary (solid-phase) pyrolytic reactions. In reality, charcoal contains both "primary" charcoal and "secondary" charcoal that is a coke derived from the decomposition of the organic vapors ("tars") onto the solid carbonaceous solid."

Many factors influence secondary char formation, including the biomass particle size, the pressure of the pyrolysis reactor, and the relative composition of the vapors within the reactor. As such, there can be a range of resulting char yields and biochar properties produced by Slow Pyrolysis technologies at exactly the same pyrolysis temperature, depending on the extent of secondary char formation. For this reason alone, all Slow Pyrolysis chars need to have the adsorption capacity measured to establish the actual biochar quality. This variation of the char quality is a function of how much vapor leaves the pore spaces of the solid versus how much vapor stays within the adsorption sites and recondenses into those unique spaces. The presence or absence of those adsorbing spaces is a key element in the value of the biochar solid.

While slow pyrolysis chars vary over a relatively small range of yields and properties, depending on specific reaction conditions at a given temperature, the greatest changes in char properties occurs when one modifies the reaction conditions and exits the unifying envelope of "Slow Pyrolysis" conditions. The principal alternate pyrolysis regimes are called "Gasification" and "Fast Pyrolysis".

"Gasification" is pyrolysis under conditions that a portion of the char is further reacted with oxygen and combusted to either carbon dioxide or carbon monoxide and ash. Biomass, especially wood, burns in a two-step sequence of reactions. The first reaction is the conversion of wood to char, and is called carbonization with wood gasification. This is basically the slow pyrolysis conversion discussed above. Once the char is formed, there is a second, hotter reaction, where the char is converted to ash, called char gasification.

Campfires do a nice job of displaying the various gasification reactions. Initially, when the fire is first lit, there is only wood and no char, so the only possible reaction is wood gasification, coupled with combustion of the wood gases. This is the yellow flames that can reach high above the burning wood. Over time, the wood converts to char and the red embers form at the bottom of the fire – this is where char gasification is occurring. If one keeps adding wood to the fire, both reactions are ongoing. At the end, when no additional wood is added, the campfire settles into a bed of embers and just char gasification is occurring. At the end of char gasification, and in the morning, only ash is left.

The key to whether a gasification conditions are occurring during biomass pyrolysis is the presence of the red to white-hot zone of char gasification. The key to the impact of gasifying conditions on the char is to examine the effect of the gasification temperatures on the residual char. Char gasification occurs at much higher temperatures than wood gasification, because there are no volatiles being formed to evaporate and cool the remaining solids. Char gasification is a direct reaction of gaseous oxygen with the char solids, yielding carbon dioxide and carbon monoxide and thermal energy. The energy released heats the char until the reaction is proceeding as fast as there is available oxygen. The rate of char gasification is controlled by controlling the amount of available oxygen. As such, wood gasifies to char as a function of temperature and heat transfer, while char gasifies to ash as a function of the amount of available oxygen.

If there is an excess of oxygen, virtually all the char is consumed and only ash remains. If there is a limited amount of oxygen, then only a portion of the char is consumed and some remains to exit the bottom of the gasifier. However, the char that does avoid complete oxidization has been altered due to the conditions within the gasifier. One effect is the direct loss of some of the organic portion of the remaining char, which increases the relative portion of ash. A second effect is that the residual char has been exposed to high temperatures, so any residual volatiles have been driven off. As such, most gasifier chars have a high portion of fixed carbon and little remaining volatile matter.

In addition, the high gasification temperatures often convert ash carbonates to corresponding oxides by driving off carbon dioxide. The combination of higher relative ash content and higher ash oxides can result in gasifier

chars acting more like lime and raising pH when added to soils. For acidic soils, this is a beneficial impact, but for alkaline soils, elevating soil pH may result in lower crop compatibility and plant growth inhibition.

One final impact of the high temperatures associated with gasifier operations is a portion of the char has been exposed to excessively high temperatures such that adsorption capacity is deteriorated. As discussed earlier, chars typically exhibit an increasing adsorption capacity with increasing heat treatment temperature up to at fairly high temperature, after which the property "collapses" with increasing temperature.

A parting consideration for gasifier chars is most current gasifiers have been designed to fundamentally produce heat or synthesis gas, and any residual char is a byproduct. As such, the properties of the gas tend to dictate the gasifier operating conditions, and the subsequent char quality is "what it is". The end result is that gasifier chars may range from reasonably appropriate biochars for addition to compatible soils to thinly disguised wood ash with sparingly elevated portions of residual fixed carbon.

An additional concern is gasifier chars often represent a diverse mixture of chars, resulting from the sheer size of the gasifier operation and the variability of bottom products exiting the process. Some portions are fully oxidized, some sparingly pyrolysed, and other bits may possess very attractive biochar characteristics. As such, individual samples may not accurately characterize the actual distribution of chars exiting from the entire gasifier process and providing a consistent biochar product may prove problematic with gasifier chars.

If gasifier chars are basically slow pyrolysis char that have been subjected to additional char gasification and the associated effects of additional oxidation and high temperature, then "Fast Pyrolysis" chars are slow pyrolysis chars that are formed *too fast* to allow the conventional slow pyrolysis reactions. The essence of Fast Pyrolysis is that it happens fast enough that new characteristics are imparted in both the vapors and the residual char, characteristics that would not be present if the pyrolysis occurred at a slower rate.

The goal in Fast Pyrolysis is to shift the destination of the fuel value, primarily associated with the carbon atoms in the biomass, from the residual char to the vapor phase, where it can subsequently be isolated by condensing the vapor into a liquid known as "bio-oil". If one examines *Figure 1* and focuses on the yield curve, which tracks the properties of the residual char, and infers the composite properties of the exiting vapors, one realizes that if the residual char carbon content goes up from the starting biomass, then the average carbon content of the exiting vapors must be less than the starting biomass by a corresponding amount.

In Slow Pyrolysis, the solid gets the carbon atoms and the vapors get the higher portion of hydrogen and oxygen, much of it in the form of water vapor. The conventional condensate of the vapor phase of slow pyrolysis is called pyroligneous acid or wood vinegar, and is a fairly well characterized liquid of minimal fuel value, but a historic source of small oxidized organics such as methanol and acetic acid. The goal of Fast Pyrolysis is to modify the pyroligneous acid condensate into something new, called "bio-oil".

Since the goal in Fast Pyrolysis is to increase the carbon content of the bio-oil, then by conservation of mass and chemical species, there will be less carbon available for the residual fast pyrolysis char. In Fast Pyrolysis, the heat transfer rate is increased to an extent that the carbon atoms are swept into the vapor phase, then condensed to capture them as bio-oil. The technique improves the relative percentage of carbon atoms removed from the solid phase, but cannot improve on the initial stoichiometry of the starting biomass – since it is not possible to leave behind a more water-rich solid than the starting biomass.

Most Fast Pyrolysis processes strive to direct as many carbon atoms into the vapor phase as possible and distinguish themselves by creating fractions that isolate excess water in one condensate and other cuts with greater potential fuel value. To the extent this approach yields a bio-oil product of actual market value is up to the consumers of bio-oil to validate. However, the impact on the remaining biochar is predictable.

Fast Pyrolysis char has incrementally lower portion of carbon than slow pyrolysis chars, since the objective was to drive the carbon atoms into the vapor phase. The carbon atoms that remain in the solid phase have not been

allowed to consolidate into typical slow pyrolysis chars, since that would result in additional water vapor being rejected into the vapor phase and deteriorate the bio-oil condensate. As a result, most Fast Pyrolysis chars have been constrained to relatively low temperatures, in order to retain as much hydrogen and oxygen in the char. Additional evidence of the low effective processing temperatures is the high level of volatiles present in many Fast Pyrolysis chars.

As seen in the case of Gasification, Fast Pyrolysis conditions will concentrate the ash constituents in the residual char, as a result of directing the carbon atoms of the biomass into the vapor phase and leaving the ash behind. However, the organic matter left in the char is generally devoid of carbonization char structures, including significant development of graphitic domains necessary for adsorption capacity i.e. not many pore spaces.

A reasonable model of fast pyrolysis chars is a torrefied residual biomass organic fraction with elevated ash level, dictated by the relative partitioning of organics from the starting biomass into the bio-oil phase and the residual char solids. Because the residual char has not been subjected to sufficient temperatures necessary to develop internal surface area, as depicted in *Figure 1*, and because fast pyrolysis char have been depleted of available carbon atoms to enhance the properties of the associated bio-oil, the development of favorable biochar properties in the residual char is severely inhibited. The extent that Fast Pyrolysis chars exhibit favorable biochar properties is generally a measure of the extent within a particular process that some biomass avoids Fast Pyrolysis conditions and/or is inadvertently converted to a better biochar via Slow Pyrolysis conditions present somewhere within the Fast Pyrolysis reactor.

Process-dependent Energy Co-product properties

When choosing between slow pyrolysis, gasification or fast pyrolysis, it really comes down to the value of the products and byproducts. In general terms, all pyrolysis processes produce a combination of char and gaseous products that have relatively low fuel value, compared to traditional fossil fuels, principally due to the low energy density of the starting biomass.

A typical slow pyrolysis, optimized for biochar production, might produce 25 pounds of biochar and 75 pounds of gaseous products from 100 pounds of ash-free dry wood. Assuming the starting wood had an energy content of 8,000 Btu/lb and the char has an energy content of 12,000 Btu/lb, one can see that the char contains 37.5% of the fuel value of the wood. This leaves 62.5% of the biomass energy in the gaseous products, for an energy density of just 6,667 Btu/lb for the 75# of wood gas. By comparison, methane has a lower heating value over 21,400 Btu/lb – or more than 3 times the energy density of wood gas.

For the case of gasification, the goal is to make gaseous products. The theoretical limit of gasification is to gasify all the entire available organic portion of the biomass, which means 100 pounds of ash-free dry wood is converted into 100 pounds of gaseous products. Since energy cannot be created, the gaseous products have an energy density of 8,000 Btu/lb, which is 20% better than slow pyrolysis, but still 2.67 lower than natural gas.

By similar analysis, for fast pyrolysis, the theoretical limit for the bio-oil is 8,000 Btu/lb, which is about 40% of the typical energy density of diesel fuel, which is in the range of 20,000 Btu/lb. Bio-oil has one additional issue, which is that it is not actually an “oil”. Oils can be mixed with other oils, and bio-oil only mixes with water. Oils are predominately hydrocarbons, composed of carbon and hydrogen, whereas bio-oils are almost identically the chemical composition of the original wood. At some level, the label “Bio-oil” may be misleading and a more accurate descriptor, such as “Fast Pyrolysis Condensates” or even “Liquid Wood” may convey a more accurate image of the material properties.

Conclusion

Society has hundreds of devices and industrial processes that use wood and other biomass as fuel, deliver useable heat, and generate ash. A similar integration of options to consume biomass, provide useable heat, and create biochar would simultaneously provide renewable energy, address GHG issues and promote improved agricultural productivity. Distributed biochar production by CHAB devices in affluent and impoverished societies worldwide can make an important contribution to the local and global challenges that face all societies in the future.

Renewable biomass is everywhere, often representing a disposal cost or under-utilized byproduct in fossil fuel-intensive industrial agriculture. Diversion of these "wastes" into sustainable Combined Heat and Biochar devices would complete the recycling of natural resources that Mother Nature practiced before the age of coal, oil and natural gas.

BIOCHAR FOR RECLAMATION IN:
THE ROLE OF BIOCHAR IN THE CARBON DYNAMICS IN DRASTICALLY DISTURBED SOILS

ANDREW HARLEY, PHD
andrewharley@R2INCORPORATED.COM

Shrestha & Lal (2006) defines drastically disturbed soils as those where native vegetation and annual communities have been removed with most of the topsoil lost, altered or buried, and describe three main groups (in order of commonality):

1. Construction related (urban centers, roadways and highways, fills and shoulders)
2. Resource development (mining, oil and gas, aggregate); and
3. Eroded farmland and rangeland.

Historically, drastically disturbed landscapes have been discussed in relation to the alteration of whole ecosystems with respect to nutrient and water cycling (Shrestha and Lal 2006). Soil organic matter decline is seen as a key component in drastically disturbed lands, impacting ecosystem functions such as air and water quality, wildlife habitat condition and agricultural productivity. A landscape-scale approach to managing soil carbon can improve ecological functions of soil and landscapes for the benefit of society (Reed 2007). Recent focus has also been placed on the importance of drastically disturbed lands (especially those of resource development) contributing to the atmospheric CO_2 emissions by soil disturbance and cleared biomass decomposition, and as such, provide an important opportunity to address ecosystem functions, carbon sequestration and general sustainability issues through restoration and reclamation (Shrestha *et al.* 2009). The use of biochar to address these issues in agricultural landscapes also has potential in the restoration of drastically disturbed landscapes. This paper discusses this potential in the restoration of drastically disturbed lands with respect to all three components: ecosystem function, carbon sequestration and general sustainability.

The Potential for Biochar to Improve Ecosystem Function in Drastically Disturbed Landscapes

Akala and Lal (2001) estimate that up to 70% of soil organic carbon is lost during drastic land disturbance. Soil organic matter decline in drastically disturbed land occurs through the following mechanisms (Anderson *et al.* 2008):

- Erosion of soil during stripping, storing, respreading and seeding;
- Water and wind erosion;
- Reduced inputs from vegetation in the form of above-ground and below-ground litter; and

• Dilution as surface soils with higher soil organic carbon concentrations become mixed with soils from deeper in the profile.

The loss of soil organic carbon leads to several physical and nutritional limitations that require addressing during restoration. Additionally, toxicity issues are common in mine soils. A summary of factors limiting mine soil restoration is included in *Table 1*.

Table 1. Role of Biochar in Ameliorating Drastically Disturbed Lands (modified from (Shrestha and Lal (2006)).

LIMITING FACTOR	VARIABLE	PROBLEM	SHORT-TERM TREATMENT	LONG-TERM TREATMENT	ROLE OF BIOCHAR
PHYSICAL	Soil Structure	Soil too compact	Rip or Scarify	Vegetation	Decreased soil bulk density, increased infiltration, and decreased erodibility. Increased water retention due to surface area and charge characteristics.
	Soil Erosion	High erodibility	Mulch	Re-grade, Vegetation	
	Soil Moisture	Too wet	Drain	Wetland construction	
		Too dry	Organic mulch	Tolerant species	
NUTRITIONAL	Macronutrients	Nitrogen deficiency	Fertilizer	N-fixing plants e.g. leguminous trees or shrubs	Yield increases. Slow nutrient release. Soil organic matter stabilization. Retention of released nutrients. Increased microbial activity. Habitat for mychorrhizal fungal hyphae
		Other deficiencies	Fertilizer	Fertilizer, Amendments, Tolerant species	
TOXICITY	pH	Acid soils (<4.5)	Lime	Tolerant species	Designed for alkaline surface charge.
		Alkaline soils (>7.8)	Pyritic waste, Organic matter	Weathering, Tolerant species	High CEC for Na retention.
	Heavy Metals	High concentrations	Organic matter, Tolerant cultivar	Inert covering, Tolerant cultivar	High surface area and cation exchange capacity allows for metal retention.
	Salinity	EC >4.0 dS/m, pH<8.5, SAR<13	Gypsum, irrigation	Weathering, Tolerant species	Mixed with gypsum to reduce soil structural issues. Nutritional values as described. High CEC for Na retention.
	Sodicity	EC <4.0 dS/m, pH>8.5, SAR≥13	Gypsum, irrigation	Weathering, Tolerant species	

Soil amendments are an important component of reclamation programs. These have included coal combustion by-products, biosolids, swine or poultry manure, sewage or paper mill sludge, sawdust, wood residue and limestone slurry by-products. Shrestha and Lal (2006) have summarized the role of organic and inorganic amendments in restoration including:

- Improvements of chemical and physical properties of soil;
- Improved fertility for crop establishment;
- Increased biomass productivity;
- Increased water holding capacity;
- Increased pH, electrical conductivity and cation exchange capacity;
- Increased population of phosphate solubilizing and nitrogen-fixing bacteria;
- Decreased bulk density; and
- Increased percentage of 1-2mm water stable aggregates.

While organic amendments provide a source of nutrients that are readily mineralized, these do not provide a long-term source of soil carbon. Bendfeldt *et al.*(2001) found that the addition of sawdust and sewage sludge to mine soils enhanced soil quality over the short-term (1-5 years) but that there were no lasting improvements. Biochar (long residence times) represents an opportunity to enhance nutrient cycling and other ecosystem services in drastically disturbed lands (amendment, mulch, toxicity reduction).

Biochar is a promising amendment for ameliorating drastically disturbed soils due to its microchemcial (Amonette and Joseph 2009), nutrient (Chan and Xu 2009) and biological (Thies and Rillig 2009) properties as well as its stability in soil (Lehmann *et al.* 2009). Biochar is a carbon-rich product obtained when biomass is heated in a closed container with limited air with the intent of being applied to soil to improve soil productivity, carbon storage or remediation (Lehmann and Joseph 2009). The persistence of organic matter in the order of centuries in weathered tropical soils associated with the application of biochar have been reported by Glaser *et al.* (2001). The persistence is due to the highly aromatic structure of the biochar that is chemically and microbially stable. When compared to other organic amendments (sawdust, manure, Tithonia diversifolia leaves) in a highly degraded agroecosystem Kimetu *et al.* (2008) reported that the application of biochar had the greatest impact on increasing productivity and soil organic carbon concentrations, even though there was no improvement of nutrient availability. Due to the nature of production being dependent on both the feedstock and the process, biochar can be developed for site specific conditions to ameliorate a number of conditions (Table 1).

Ameliorating Physical Limiting Factors

Soil organic carbon plays an important role in soil structural stability (the resistance of soil to structural rearrangement of pores and particles when exposed to different stresses such as cultivation, compaction and irrigation). A minimum of 2% soil organic carbon has been reported to be required to maintain structural stability, with structural stability declining rapidly below 1.5% and there is generally a linear increase of aggregate stability and aggregate size with increasing levels of soil organic carbon (Krull *et al.* 2004). Different types of organic matter perform different functions in aggregate formation, however the labile carbon fraction, consisting mainly of carbohydrates, is instrumental in aggregate formation (Krull *et al.* 2004). Microbially-produced polysaccharides are of importance in the initial production of stable aggregates and that humic substances are essential for ensuring longer aggregate stability (Krull *et al.* 2004). Low rates (100kg/ha; 90lbs/ac) of humic substances with over 70% aromatic carbon improved aggregate stability and reduced disaggregation during wetting and drying cycles (Krull *et al.* 2004). Albaladejo *et al.* (2008) found that a single organic amendment to a degraded semiarid soil was effective in improving soil physical properties. Glaser *et al.* (2002) reported that much lower application rates of coal-derived humic acids (1.5 ton/ha; 50lbs/ac) when compared to undecomposed organic residues (50-200 ton/ha; 45-180 ton/ac) to obtain significantly higher aggregate stability.

The long-term residence time of biochar in soils has been attributed to mineral interactions with attachment occurring as (Hammes and Schmidt 2009):

- Free biochar particles with embedded and associated clay- and silt-size minerals;
- Small biochar particles bound to minerals; and
- Small minerals particles bound to large biochar particles.

These processes leads to improved soil aggregation (Major *et al.* 2009) which are inferred to help maintain long-term soil structural stability. These interactions occur very quickly after application to soil and gain importance over time (Lehmann *et al.* 2009).

This improved soil aggregation and associated pore space distribution with increased organic matter generally increases soil water holding capacity and conductivity (Saxton and Rawls 2006). This relationship has a greater effect in coarse texture than fine textured soils, and even decreasing in heavy soils (Krull *et al.* 2004; Glaser *et al.* 2002). Saving water by reducing runoff and evaporation is critical in enhancing biomass productivity (Izaurralde *et al.* 2001) and can have significant long-term impacts. Albaladejo *et al.* (2008) found higher saturated hydraulic conductivity in plots 16 years after a single application of urban solid refuse to a degraded semiarid soil. Application rates greater 2% soil organic carbon result in significantly higher available water content than lesser application rates, and need to be considered when determining biochar application rates.

Ameliorating Nutritional Limiting Factors

Reclaimed lands tend to have highly variable available nutrient contents (Shrestha *et al.* 2009). Soil fertility improvement is an important aspect of soil quality enhancement and C sequestration in soil and biomass. Low rates of fertilizer application are usually recommended for dry areas where rainfall is uncertain (Izaurralde *et al.* 2001). The judicious use of fertilizer, compost and nutrient management has been demonstrated in several long-term experiments (Izaurralde *et al.* 2001). Reduced leaching of applied fertilizer is thus important in the restoration of reclaimed soils. Less water percolation has been reported by Lehmann *et al.* (2003) in soil/biochar mixtures that soil alone. Additionally, biochar porosity and charge characteristics can reduce leaching of nitrogen phosphorus potassium, calcium and magnesium (Major *et al.* 2009).

As a chemical reservoir, soil organic matter is a source of nitrogen, phosphorus , sulfur and other elements (Bauer and Black 1994). Soil organic matter nutrients become plant available during decomposition, and the particulate matter fraction is considered the most important proportion of soil organic matter (Krull *et al.* 2004). Soil organic carbon concentrations <1% are considered a threshold below which effective nitrogen supply is reduced. The importance of soil organic carbon with respect to productivity was shown by Bauer and Black (1994) who estimated that 1 ton of organic matter/hectare (800 lb/acre) increased wheat dry matter productivity between 15.6 and 35.2 kg/hectare (13.8 and 31.0 lb/acre) in the northern Great Plains.

Biochar has a high variability of plant macro- and micro-nutrients due to the different feedstocks and production conditions, however, several trends have been described by Chan and Xu (2009):

- Mineral nitrogen is very low;
- Available phosphorus is highly variable;
- Available potassium is typically high.

Akala and Lal (2001) however noted that over reclamation periods of 15-20 years in Ohio, the carbon:nitrogen ratio increased suggesting the nitrogen deficiency may be a constraint in these landscapes. While biochar itself is a low nitrogen source (Chan and Xu 2009) and is not considered in calculating C:N ratios, it does not appear to immobilize nitrogen (Kimetu *et al.* 2008) and may be an important amendment for nitrogen dynamics in reclamation with the ability to improve the efficiency of mineral nitrogen fertilizer (Steiner *et al.* 2008).

Soil texture also plays a role with fine textured soils retaining greater carbon and nitrogen than coarse textured soils when the same amount of organic matter are added due to the greater protection of organic carbon by clays (Ganjegunte *et al.* 2009). This would suggest that biochar would be more effective for controlling nutrient dynamics in coarse grained soils.

Increased productivity by the application of biochar has been reported by Kimetu *et al.* (2008) on highly degraded sites. Kimetu *et al.* (2008) report a significant increase in seed germination (30%), shoot heights (24%), biomass production (13%) and crop yields (up to 200%). Glaser *et al.* (2002) also cited that crop yields can be enhanced to a greater extent when biochar is applied together with other inorganic or organic fertilizers. In addition to improving fertilizer retention for plant growth (Major *et al.* 2009), biochar may also act as a fertilizer as the cations in ash contained in the biochar are present as dissolved salts and thus readily available (Glaser *et al.* 2002). Cao and Harris (2010) developed a slow release phosphorus fertilizer by using dairy-manure as a biomass feedstock. Additionally, the physical structure of biochar provides a framework for building a slow release NPK fertilizer as proposed by Day *et al.* (2005).

Loss of soil organic matter also reduces cation exchange capacity resulting in lower nutrient retention and supply capacity, as well as water retention capacity (Kimetu *et al.* 2008). Krull *et al.*(2004) found that :

- Cation exchange capacity increases linearly with increased soil organic carbon above a threshold of 2%;
- Soil organic matter contributes to up to 70% of effective cation exchange capacity in highly weathered soils; and
- Charcoal has been shown to be a potentially important contributor to increasing cation exchange capacity.

Oxidation of biochar over time produces carboxylic groups on the edges of the aromatic core, increases cation exchange capacity and the reactivity of black carbon in soil (Glaser *et al.* 2001). As such, metal ions, dissolved organic matter and dissolved organic nutrients are retained through improved cation exchange capacity associated with biochar addition (Glaser, Lehmann *et al.* 2002). Nguyen *et al.* (2008) indicates that this process can occur in the order of months. Increases in cation exchange capacity in the range of 40-50 mmolc/kg were reported by Kimetu, *et al.* (2008) in moderately degraded sites. The oxidation rate of biochar is dependent more on mean annual temperature rather than duration within the soil (Cheng *et al.* 2008). The application of biochar for improved cation capacity in arid and semi-arid environments appears a significant tool for nutrient and moisture retention in drastically disturbed soils.

Biochar has been reported to increase microbial activity in a range of soils that may also improve nutrient availability through a various of mechanisms (DeLuca *et al.* 2009; Kolb *et al.* 2009; Thies and Rillig 2009; Warnock *et al.* 2007). Biochar inoculated with rhizobia and arbuscular mycorrhizal (Thies and Rillig 2009) has been proposed for the reclamation of degraded lands (Blackwell *et al.* 2009) and may play an important role in the availability of water and nutrients in arid environments (Allen 2007) or in drastically disturbed soils where the soil biota has been destroyed.

Increased N_2O emissions have been identified following the application of nitrogen fertilizers, incorporation of crop residue and application of liquid organic wastes and biosolids in reclaimed lands (Palumbo *et al.* 2004) Biochar can be used to offset these N_2O emissions.

Ameliorating Toxicity Limiting Factors

Soil pH in disturbed lands is a function of the quantity, quality and activity of carbonaceous or pyritic overburden material (Akala and Lal 2001) or the nature of site specific management practices where land application occurs (Ganjegunte *et al.* 2008). Generally, disturbed lands lead to a lowering of pH values. Acidic conditions limit root growth and the establishment of plants (Shrestha and Lal 2007).

Soil buffering capacity allows for the reasonable stability in soil pH and determines the amount of other chemicals required to change soil pH. The availability of different functional groups (e.g. carboxylic, phenolic, acidic alcoholic, amine, amide) allows soil organic matter to buffer over a wide range of soil pH values (Krull *et al.* 2004). Soil organic matter maintains fairly stable pH values, despite acidifying factors and more acidic soils are better buffered than less acidic soils. Given the increase in carboxylic groups with time during biochar weathering, the buffering capacity of biochar is expected to be important in acidic soils associated with mine lands.

Smernik (2009) has suggested that biochar amended soils can be used to control the toxicity and movement of organic chemicals. Organic matter can also be used to stabilize toxic metals in soils (Palumbo *et al.* 2004). Soil organic matter has the greatest capacity and strength of bonding with most metals of any soil component (Krull *et al.* 2004) and those metals that bond strongly in organic matter (e.g. lead, copper) are most rapidly adsorbed and most slowly desorbed (McBride 1989). Absorption of metals occurs within amorphous soil organic matter (humic/fulvic substances, lignin), while more condensed components, including charcoal, contribute to the adsorption of metals (Krull *et al.* 2004). Tejada *et al.* (2007) showed that the addition of organic wastes with high humic acid concentrations is the most beneficial for remediation of lead impacted soils. Municipal biosolids combined with limestone or other high calcium carbonate equivalent residuals are being used to restore metal contaminated sites (Brown *et al.* 2009).

High lead sorption (93-100%) observed by Cao and Harris (2010) on a low specific surface area biochar from dairy-manure was attributed to precipitation with phosphate rather than direct adsorption. Modeling by Cao *et al.* (2009) confirmed this by showing that approximately 85% of the lead retention was due to phosphate precipitation while the remaining 15% was due to sorption. This work shows the importance of determining the biochar characteristics to address a specific issue.

Arid and semi-arid regions with low rainfall and high evapotranspiration rates are particularly prone to salinization (Uliana 2005). The development of oil and gas as well as coal-bed natural gas (also called coal-bed methane) produces large volumes of groundwater (referred to as produced water) required to recover either the oil or natural gas (Whittemore 1995; Zhao *et al.* 2009). Major concerns associated with these waters include salinity, sodicity and high carbonate/bicarbonate, and where applied to soils, result in significant increases in soluble salt accumulations over time (Ganjegunte *et al.* 2008) resulting in adverse soil physical and chemical conditions that restrict soil water movement (Vance *et al.* 2008).

Enhancing soil organic carbon is an important component in the reclamation of salt-affected soils. Organic amendments including manure, compost and farm byproducts have been added in conjunction with gypsum to increase biomass yield (Ansari 2008; Ghosh *et al.* 2009; Izaurralde, *et al.* 2001). To date biochar has not been investigated with this application. However, the properties of biochar described above would suggest that this is a promising application where produced water is used in land application programs, especially when combined with intensive fertilized irrigation programs where the biochar can be used to reduce fertilizer requirements and potentially offset other greenhouse gases.

The Role of Biochar in Sustainability during Disturbed Land Restoration

Sohi *et al.* (2009) has developed a spatial context for the use of biochar in an agricultural landscape that has similar implications for the resource industry. The resource sectors have adopted both industry-wide and company-specific sustainability practices, for which biochar may provide opportunities. While additional costs may be incurred with the use of biochar as a more intensive reclamation strategy, these may be offset with other sustainability targets, including carbon sequestration.

Factors to be considered include feedstock sources, manufacturing facility location, land use and application considerations.

Feedstock Sources

Mining land is commonly associated with either agricultural and forestry activities that can produce wastes that can act as a feedstock for a sustainable biochar production system (Lehmann *et al.* 2006). For example, Cao *et al.* (2009) have proposed that high-phosphorus animal waste has the potential as a feedstock for a phosphorus-rich fertilizer as well as for the mitigation of lead contaminated soil. Other biochar feedstocks that can be incorporated into the mining cycle include:

- Biomass cleared for operation and infrastructure at the mine site;
- Woody biomass weeds;
- Fuel mitigation in forests;
- Biomass production from the land application of produced or mine water; and
- Waste products from the mining operations e.g. wood pallets.

Facility Locations

The proximity of a pyrolysis facility to the feedstock is important in determining logistical and cost impacts (Sohi *et al.* 2009). The optimal position is to have a 'closed loop' scenario, i.e. the application of biochar in the same location that produces the feedstock. However, where mining operations are located in remote areas, transport costs may be prohibitive. Where possible to meet sustainability guidelines, the development of the closed loop approach is optimal. These may also provide opportunities for income generation within the local community, meeting social sustainability guidelines. Economic analyses are required to determine the most cost effective location for the facility when considering the transportation of feedstock and the finished product, especially if carbon sequestration standards are to be met.

While the focus of this paper has been on the application of biochar to soil, the other side of the pyrolysis process is the formation of an energy source. In remote locations, provided a sufficient and on-going feedstock is present, this is may also provide an opportunity to provide energy and/or heat to buildings at the mine site.

Application Considerations

Rates of biochar application over the landscape scale generally involved in disturbed land reclamation may be prohibitive. Glaser *et al.* (2001) estimated 250 ton/ha (100 ton/acre) to a depth of 1 meter (3.1 feet) where characteristic in the 'Terra Preta' soils. However, lower rates of 1-3 ton/ha (0.9-2.7 ton/ac) are predicted by Glaser *et al.* (2002) to be sufficient for significantly increasing production.

While the application of biochar over large areas can be cost-prohibitive (Blackwell *et al.* 2009), reclamation generally involves the re-application of topsoil and opportunities exist to incorporate biochar during the application phase or for the mixing of biochar with topsoil during the stripping and storing stage. If suitable biomass is removed during the mine clearing stage, this provides another opportunity for the generation of biochar and incorporation during topsoil removal. As heavy equipment is already utilized in various phases of the mine establishment and reclamation phases the incorporation of biochar into these processes would add value and not burden.

Shrestha and Lal (2007) found that the most of the soil organic carbon in reclaimed soils in Ohio was found in the upper 5 cm, however land use (hay, pasture, forest, agriculture) had a significant influence on deeper soil organic carbon concentrations. While current restoration techniques involve either surface spreading or the shallow incorporation of carbon amendments, deeper incorporation (up to 60 cm) will provide access to a much larger soil volume for rooting and provide a moisture reservoir in arid and semi-arid climates (Palumbo *et al.* 2004).

Additionally, the burial of biochar has also been considered as an option (Sohi *et al.* 2009). Where carbon sequestration is a priority, this option may be effective prior to mine pit backfilling and reclamation.

Grazing is a common post-reclamation land-use (Anderson *et al.* 2008; Bengson 1999). A potential integration of biochar is using the cattle to incorporate biochar into the soil simply as they graze. Additionally, the incorporated biochar may be used as an offset to the nitrates produced by the cattle. Bengson (1999) estimates that cattle excrete 30-65 lbs of green manure each day producing approximately 190 lbs of nitrogen and 60 lbs of phosphorus per acre. Urine patches in grazed pastures can be a dominant source of N_2O. Biochar has been proposed as a means to reduce the soil inorganic-N pool available for N_2O-producing mechanisms (Clough *et al.* 2010; Rondon *et al.* 2005; Van Zwieten *et al.* 2009) as well as methane sources (Van Zwieten *et al.* 2009). The influence of biochar on these non-CO_2 greenhouse gases is uncertain at this time. While Rondon *et al.* (2005) and Van Zwieten *et*

al. (2009) reported a reduction in emissions, no significant reduction of the inorganic –N pool was been reported by Clough *et al.* (2010). Van Zwieten *et al.* (2009) attributes the specific characteristics of the biochar as influencing the activity of the microorganisms responsible for N transformations.

Carbon Sequestration

Carbon sequestration is essentially the process of transforming atmospheric CO_2 into biomass through photosynthesis and incorporation of biomass into soil as humus. Globally, soils have the capacity to draw substantial amounts of CO_2 from the atmosphere by photosynthesis in cropland, managed forest and grassland soils (Izaurralde *et al.* 2001). At a local and regional scale, increased adoption of land use management that incorporates multiple ecosystem services could deliver significant benefits.

The potential for soil to sequester carbon has been well documented (Izaurralde *et al.* 2001) and the storage of carbon in soils is hypothesized to depend on four main factors (Knops and Bradley 2009):

1. Organic matter inputs;
2. Organic matter decomposability;
3. The level of physical protection of organic matter in aggregates; and
4. The depth at which the organic matter is deposited.

The carbon content of spoil material is typically very low compared to undisturbed surface soils, therefore the potential for carbon sequestration is significant (Shrestha and Lal 2006), predominately through the development of soil horizons over long (decades) time periods. The low soil organic carbon in drastically disturbed soils can be enhanced by:

- Proper reclamation;
- Adoption of Best Management Practices;
- Improvement in soil fertility using integrated soil management technologies;
- Nutrient cycling by returning biomass to the soil; and
- Growing leguminous annuals or tree plants with potential for biological N2-fixation.

Soil organic carbon sequestration is focused on enhancing natural capacity of ecosystems to increase rates of organic matter input into soil in a form with long residence time (Post *et al.* 2004). Drastically disturbed soils are the ones with the high potential to sequester soil organic carbon at rates of 0.5 to 1.0 ton C/ha/yr and as high as 4 ton C/ha/yr (Shrestha and Lal 2006). Additionally, the most degraded sites have been shown to have the greatest response to any form of organic matter, including biochar (Kimetu *et al.* 2008).

Traditional reviews of the potential for terrestrial carbon sequestration have focused on agricultural, forestry and grassland. Negative externalities of such an approach include the competition for agricultural lands, decreased food and fiber production, increased consumer prices and the increased use of pesticides and herbicides in reduced tillage agriculture (Izaurralde *et al.* 2001). Palumbo *et al.* (2004) estimates that disturbed lands in the United States (1.4×10^8 ha) can account for a modest, yet significant carbon sequestration potential (11 PgC over 50 years). An evaluation by Sperow (2006) of carbon sequestration potential in East-Central mine lands of the United States indicated that current carbon sequestration potential represented between 0.3 -1% of the CO_2 emissions of the same region. Biochar may be able to increase the amount of offset emissions via the following mechanisms (Gaunt and Cowie 2009):

- Avoided emissions from conventional use of feedstock biomass;
- Stabilization of biomass carbon;
- Avoided emissions of N_2O and CH_4 from soil;
- Displaced fertilizer and agricultural inputs;
- Enhancement of agronomic efficiency and yield; and
- Fossil fuel displacement.

While the actual numbers for increased carbon sequestration from the use of biochar in the restoration of drastically disturbed lands are unknown at this time, it is anticipated that it will increase the numbers quoted above. While there is still no formal approach (approved methodology) for sequestering carbon through biochar, these techniques can be implemented immediately and provide a transition towards larger efforts moving forward.

Conclusions

Izaurralde *et al.* (2001) have noted that soil carbon sequestration is able to play a strategic role in GHG emission control. Compared with other proposals for the immediate removal of atmospheric CO_2, terrestrial sequestration techniques are well established, immediately deployable and known to have beneficial effects on the environment. The strategic use of biochar in disturbed lands is an important piece of this strategy. As has been shown above, biochar has the potential to increase productivity and mitigate several detrimental properties associated with disturbed land reclamation, it is not an unreasonable assumption that the addition of soil organic carbon in the form of biochar can be done without net cost to reclamation projects. Techniques for the reclamation of disturbed land are well established, and the incorporation of biochar in soils as another amendment can be easily adopted.

The evidence from both the study fog biochar application itself and the body of reclamation and restoration work would suggest that the application of biochar would be most effective in the reclamation of highly degraded sandy to clayey sandy soil types. Additionally 2% organic carbon appears to be the threshold at which significant changes to physical properties (e.g. soil structure, available water content) occur. Application rates if biochar with this criterion may have the most promising opportunities for the restoration of drastically disturbed landscapes.

However, no general application rate can be determined from the data available and requires testing for specific soil and plant conditions (Glaser *et al.* 2002). Palumbo et al (2004) recommended a program of systematic research to understand how interacting processes are expressed in various mineralogical, geochemical and hydrologic settings for the optimal application of biochar in disturbed land reclamation. This is especially true for the arid and semi-arid regions where mining is common and, to date, little biochar research has been undertaken (Blackwell *et al.* 2009). Additionally, appropriate carbon trading protocols are required for generating another income stream (or at minimum a process for entities to calculate a carbon impact number in order) for mining companies and land owners (Shrestha *et al.* 2009).

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BIOCHAR SUSTAINABILITY IN:
BIOCHAR AND SUSTAINABLE PRACTICES

GLORIA FLORA
gflora@s-o-solutions.org

Background

Biofuels and biomass-based energy have the potential to become major contributors to the global primary energy supply over the next century, expanding significantly in both developed and developing nations.[1] However, unchecked, overzealous establishment of plantations for biomass production and excessive removal of biomass from agricultural systems and natural ecosystems can cause of plethora of social, cultural, environmental and economic ills. Genetic modification of plant species for expediting biomass growth can likewise lead to a range of problems, from perceptions of danger to actual environmental chaos from unintended consequences. Given these potential pitfalls and the intensifying interest in all forms of bio-energy and biomass utilization, agencies and conservation organizations are scrambling to develop sustainability standards.

Sustainability standards and guidelines are therefore not only timely but also essential. Fortunately, the call to action has been heeded by a broad spectrum of government and non-governmental organizations at international, national and regional levels. This section of the report will outline the current thinking on biomass sustainability as it relates to biochar production from industries to small community operations, through partnerships and collaborations to single providers. Primarily, this section provides a brief bibliographic review of the current leading reports on biomass sustainability and certification.

This review will look at biomass sustainability through the lens of biochar production. Even though biochar production and use have many advantages, people still have solid concerns that, similar to the head-long rush into biofuels from corn, certain critical aspects may be being overlooked. Central to their concerns is ensuring procurement of biomass in ways and amounts that do not significantly affect human food supply, wildlife habitats, biodiversity, hydrologic functions and forest ecosystems. Likewise, people do not want materials that could be up-cycled[2] to be irretrievably altered in a biomass-consuming system.

Secondarily, but critical to certain sectors, are concerns that new and expanded use of biomass will reduce availability and increase prices for current biomass uses such as animal feed, the production of paper, cardboard, durable wood products, pellets for wood stoves and in other energy industries such as methane production.

1 Berndes, Göran, et.al.. "The Contribution of Biomass in the Future Global Energy Supply: a Review of 17 Studies". Biomass and Bioenergy, Vol. 25, Issue 1, July 2003, pages 1-28. http://www.chem.uu.nl/nws/www/publica/Publicaties2003/E2003-40.pdf
2 Recycled to an equally as valuable or better product

Sustainability Overview

The most common definition of sustainability is when society and systems use, consume or employ resources at a rate and in a way which ensures that future generations (of all species) will be able to benefit equally from those same resources. The Bruntland Commission is credited with coining a definition of sustainable development as "meeting present needs without compromising the ability of future generations to meet their needs". [3] Sustainability concerns cover the carrying capacity and resilience of environmental, social and economic systems and to the interrelationships within the whole.

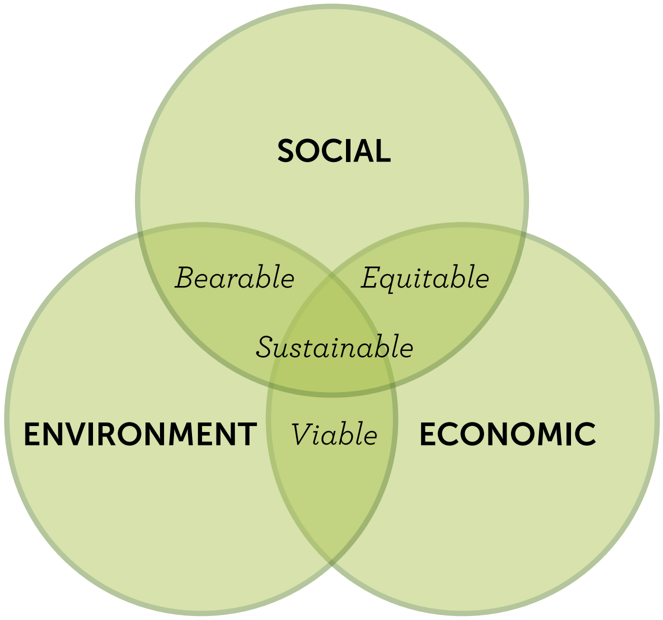

Figure 1. Environment, Social and Economic needs converge into a sustainable center

This simple schematic depicts the relationships between the environmental, social and economic sectors and their demands and interdependence upon each other.[4] Sustainability is achieved when pressures and demands are balanced to ensure no system is unduly impacted beyond its ability to stabilize, reproduce and remain not only viable, but healthy.

Other popular, more specific definitions include: "Sustainable means using methods, systems and materials that won't deplete resources or harm natural cycles." [5]; sustainability "identifies a concept and attitude in development that looks at a site's natural land, water, and energy resources as integral aspects of the development" [6] ; and "sustainability integrates natural systems with human patterns and celebrates continuity, uniqueness and placemaking.".[7]

In the case of biochar production and use, the greatest concern is placed on the sustainability of environmental systems since that is the source of biomass and the end location of biochar. However, as indicated by the schematic above, the environment is inextricably linked to social and economic systems. The deep-seated fear about

3 United Nations - World Commission on Environment and Development. "Report of the World Commission on Environment and Development: Our Common Future". Geneva, Switzerland. 1987 http://www.un-documents.net/wced-ocf.htm
4 UCN. 2006. The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. Report of the IUCN Renowned Thinkers Meeting, 29–31 January 2006 http://cmsdata.iucn.org/downloads/iucn_future_of_sustanability.pdf
5 Rosenbaum, Marc. "Sustainable Design Strategies," *Solar Today*, March/April, 1993
6 Vieria, Edwin. "A Checklist for Sustainable Developments" in a resource guide for "Building Connections: Livable, Sustainable Communities," American Institute of Architects, Washington, DC.. 1993
7 Early, D. "What is Sustainable Design," *The Urban Ecologist,* Society of Urban Ecology, Berkeley, CA. Spring 1993.

the sustainability of biochar production reflect concerns that pressures from the other spheres, particularly the economic sphere, will exert too much influence over choices and practices related to biochar. Thus, the environment and certain elements of society, particularly the rural poor, will be unduly impacted, i.e. be rendered unsustainable.

Biomass Overview

Biomass, ecologically speaking, is the aggregation of all living organisms, from microbes to plants to animals, present in an ecosystem and part of the active carbon cycle. Fossil fuels, although derived from biomass, are no longer characterized as such due to extensive mineralization and their long absence from the active carbon cycle.

At the most fundamental level, biomass is created by the conversion of the sun's energy to matter by cells capable of photosynthesis, i.e. plants. Plants, by performing this critical function, become purveyors of energy to animals higher up the food chain. The levels of the food chain, called trophic levels, concentrate energy into less and less biomass. For example, a plant-eating mammal, like a cow, may need 16 pounds of grain to create one pound of meat. Simply, the most abundant form of biomass is found at the first or primary producer level. One measure of the first level of biomass production is net primary production (NPP).

For convenience of discussion and in considering sustainability guidelines for biomass-to-energy and biochar production, biomass can be divided into three sources. Plants - living or recently living – and their by-products are the primary source of abundant biomass. Secondary sources are found after humans have processed plants, in whole or part, into other materials and uses (lumber, paper, palm oil, food stuffs, animal bedding, etc.). The biomass available for conversion to energy may be either production waste or materials that have been used and are ready for disposal, thus both are commonly found in the waste stream.

Tertiary biomass sources come from higher trophic levels: animals and their by-products. Although possible, these are seldom used for biomass-to-energy, because of the scarcity of supply, high content of non-energy producing matter especially water, and social concerns over practices like incineration of carcasses and human waste. (Note that this discussion does not extend to by-products of biomass byproducts such as methane gas from manure and landfills.)

Because biomass removal and utilization are viewed mainly as economic activities, biomass sources are identified by recognizable economic sectors within the context of the environments in which the biomass is produced. The sectors are agricultural, forest and municipal solid waste. Examples of biomass sources in each sector are:

Agriculture – Primary

- biomass crops (planted to create harvestable biomass),
- dual purpose crops (grown for food/feed and biomass),
- biomass removal from land in the Conservation Reserve Program (CRP),
- material from fallow fields, buffer strips and riparian areas adjacent to cultivated fields,
  - Secondary
    - crop residuals (utilizing materials that are currently burned off, composted, tilled-in or hauled off-site),
    - animal bedding (e.g. chicken litter)
    - food processing residuals
    - Tertiary
      - manure
      - offal

Forest – Primary

- trees harvested for biomass (dead and live),
- low value logs cut as part of stand management (usually sold for pulp)

• thinnings (both understory and overstory),
  – Secondary
    » slash (residual waste from stand management activities, typically piled and burned),
    » residuals from wood processing (slabwood, mill ends, bark , chips, sawdust)
    » urban forestry trimmings and waste
      – Tertiary
        › pulp slurry

Municipal Solid Waste

  – Secondary
    » combustible solid waste
    » compostable solid waste
    » residuals from energy production (such as expressed algae)
    » yard waste
    » bio-based materials from natural disasters
      –Tertiary
        › carcasses
        › human waste

The Scope of Sustainability Guidelines

Sustainability guidelines need to cover the biomass sectors noted above, particularly the primary sources, but also must consider a plethora of related issues. Some are overarching, others sector-specific, still others only regionally significant.

Sustainability like most challenges must look upstream and downstream, addressing supply and demand, as well the factors that influence them. Clearly, sustainability guidelines must address at a least two levels above the point of utilization. For instance, use of biomass at a biochar production facility must not only be fully aware of the conditions of the local supply of biomass, but also the regional impacts and the ecoregions impacts of its removal and use. Regional and national policies will directly affect that plant's operations. Likewise, regional and national opinion and perceptions on biomass use will also play into informing those policies.

In turn, national policies need to take into consideration international policies and ensure compatibility with agreements, trade regulations and socially and environmentally acceptable practices as defined in instruments such as those developed by the International Union for Conservation of Nature, the United Nations World Commission on Sustainable Development and the Forestry Stewardship Council. Specific guidelines and recommendations from reports by collaborative efforts of these organizations and others are discussed below.

Regulatory Framework – Sustainability guidelines are strongest and more readily adhered to and enforced if they are mandatory. In lieu of a framework for codifying mandatory practices, voluntary compliance to guidelines can be successful if peer-pressure, watch-dog groups and market advantages combine to create incentives for sustainable practices.

Compliance – Guidelines, whether mandatory or voluntary, need to be concrete and measurable. Conceptual guidelines may be of help in creating greater understanding of system interrelationships but knowledge does not necessarily lead to positive and sustainable practices when economic imperatives are deemed of greater importance. Thus, there exists a preference for a more rigorous regulatory and compliance structure for biomass in general and biochar in particular.

Metrics – Performance or lack thereof, needs to have metrics for confirming that practices are within acceptable tolerances for ensuring the sustainability of biomass feedstocks. This becomes increasingly difficult in situa-

tions where the baseline measurements can only be estimated. Agreement on data configuration, data sources and assumptions in quantification are necessary.

Scope – Sustainability guidelines/regulations need to be valid for a wide range of biomass types, particularly primary sources. Assessments cannot stop at simply the above-ground supplies but also consider the impacts to soil and hydrologic systems from repeated short-cycle harvesting of surface biomass.

Life Cycle Assessment – The entire life-cycle of individual types of biomass feedstocks must be taken into consideration. Indigenous, local biomass typically will have a smaller carbon footprint than biomass imported from hundreds of miles away. But the entire supply chain must be examined to ensure that the pitfalls of previous efforts such as biofuels using corn-to-ethanol, do not reoccur. (In the case of corn-to-ethanol, only after substantial investments were made in infrastructure and increased corn production, was it realized that the energy return on energy invested (EROEI) fell far short of positive, besides causing serious price disruption in corn-based food systems). The goal in biomass to energy production is to reduce the overall input of fossil fuel energy and in turn the level of greenhouse gas emissions. Renewable energy systems requiring greater fossil fuel inputs than are offset defeat their purpose.

Hydrologic Systems – Given that only 3% of water on the surface of the earth is potable and that 6 billion people and all terrestrial ecosystems are dependent on it for survival and that climate change is disrupting hydrologic cycles on a massive scale, water must be a key consideration in biomass production and use schemes. Similar to the concept of EROEI, an analysis of 'energy return on water invested' must be part of the life-cycle assessment.

Biomass physically serves important functions for the hydrologic cycle on a micro-scale as it protects the soil from erosion and creates protected microclimates for plant reproduction by providing shade and water retention. (See nutrient cycling below)

Social Equity – Land use issues are critical to the sustainability of biomass and sustainability of human cultures and practices. Conversion of productive farmland from food crops to biomass production is an anathema to social justice and battling hunger. Likewise conversion of native forest ecosystems and their many resources, upon which most cultures depend, cannot be converted to biomass plantations without causing significant social impacts, including severe health and psychological damage.

In developed countries, many people are fortunate to live in woodland or agricultural settings that are highly prized for their scenic views and naturalness. There is growing resistance to biomass removal, as it is perceived to remove key elements that make living in such setting so desirable psychologically and valuable from an economic standpoint.

Biodiversity – As noted under social equity, substitution of plantations for native forest and grasslands causes severe consequences for humans. From an ecological perspective, the impacts to wildlife, biodiversity and complex ecosystems from land development are equal or greater, however they may be less visible to humans in the short-term. Essentially, land conversion from native ecosystems removes primary production capacity, often irreversibly in the context of human life spans.

Biomass also serves as habitat for important microbes, insects and small amphibians and mammals. Biomass in waterways provides critical fish habitat.

Nutrient Cycling – Biomass, particularly decaying materials, recycles nutrients back into soil while providing habitat, shelter, water retention and erosion protection.

Land Use – Biofuels can be substituted for fossil energy only if the large-scale production of biofuels is biophysically feasible, meaning the production is not constrained by the availability of land and fresh water sources for energy crop production.[8] Humans are already developing the earth's surface at an alarming rate. In America, two acres of farmland per minute per day are being converted to development. In a five-year period in the mid-

8 Giampietro, M., Ulgiati, S., and Pimentel, D., "Feasibility of Large-Scale Biofuel Production," BioScience, 47(9), 587-600. 1997

nineties, more than six million acres of agricultural land—an area the size of Maryland—were converted to developed uses.[9] It will be key moving forward to assess the land and water needs relative to the proposed biomass and biochar targets to ensure sustainable choices.

To once again look at the example of unintended consequences, massive subsidies to promote American corn production for ethanol have shifted soy production to Brazil where large areas of native grasslands are being converted to soybean farms. The expansion of soy in the region is contributing to deforestation in the Amazon.[10] Deforestation reduces the capacity of natural systems to absorb carbon among other ills.

Natural Capital – Natural capital represents the goods and services that nature provides typically "free of charge" and not readily replicable by human endeavors without great cost, even if possible. Disruption of native ecosystems and even small natural areas can deplete that natural capital, which globally is valued at $16 to $54 trillion (USD 1997) annually. [11] This is an average of $33 trillion a year. For perspective, the annual gross national product globally from all human endeavors equals $18 trillion a year. [12]

Economics – Simple economics suggest that production and retrieval of biomass need to be economically feasible within sustainability guidelines. To exceed sustainable capacities to increase short-term gain has dire consequences for environments and societies that are already compromised, particularly those that have reached the point of limited to no resilience. The loss of natural capital combined with the cost of repairing and restoring compromised ecosystems typically exceeds the value of the material extracted.

Biochar, in the face of this economic/sustainability dual challenge, is advantaged by the creation of a series of sustainable products simultaneously extracted from a flow of biomass. For example a forestry company may have a post and pole operation that sends the residual ends and tops to a chipper that converts that biomass into biochar. The conversion into biochar will release thermal energy that can be used to dry the timber products to increase the value of those products. The biochar can then be put back into forest soils to increase timber yields and sequester carbon. An integrated sustainable approach will likely require multiple products that support each other and the environment that produces them.

Pest Management and Invasive Species – Planting monocultures and/or removing natural controls (predators -- including insects--and their habitats) bodes danger because as has been illustrated repeatedly historically, once pests and/or invasive species are introduced, it is nearly impossible to eradicate them. Pests and invasive species convert habitat, limit ecosystem resilience, out-compete beneficial plants and animals and reduce food supplies for people and animals. Biochar in production creates extremely high temperatures, cost-effectively killing insects and weed seeds, thus allowing the safe use of insect- or disease-infested biomass.

Primary Reports

Extensive research and collaborative efforts have been invested into understanding the relationship of biomass to natural systems and its potential use in the human system, particularly for the creation of renewable energy. More recently, as the benefits of biochar become even clearer, interest in the conversion of biomass to biochar is growing rapidly. Along with that is the concern for the sustainable use of biomass, particularly in light of the increasing interest in biomass use for a variety of other purposes and products.

Pyrolysis (the technology used for biochar production), while it can produce the same benefits of standard biomass-to-energy (heat and power) systems, also produces biochar. Almost all emissions are captured for addi-

9 American Farmland Trust, "Farming on the Edge: Sprawling Development Threatens America's Best Farmland". http://www.farmland.org/resources/fote/default.asp
10 Butler, R. (2008), "U.S. biofuels policy drives deforestation in Indonesia, the Amazon," news.mongabay.com. Retrieved 16 December 2009 from http://news.mongabay.com/2008/0117-biofuels.html
11 Costanza, Robert, et.al., "The value of the world's ecosystem services and natural capital". Nature, Vol. 87, May 1997. http://www.uvm.edu/giee/publications/Nature_Paper.pdf
12 Ibid.

tional energy so greenhouse gas (GHG) emissions are dramatically reduced during the conversion of biomass to biochar. This soil-enhancing product also sequesters carbon long-term when returned to the soil, which can thereby increase the production of biomass. Thus, biochar offers greater energy capture (efficiency), a carbon-negative life-cycle assessment[13] and a marked reduction in GHG emissions.

The biochar community is seeking strong sustainability guidelines to ensure that this very promising process does not get derailed by concerns (legitimate or perceived) over biomass sustainability. Fortunately, biomass use supporters, conservationists and social equity groups, working together to develop standards and guidelines, have accomplished significant work to date. Biochar practitioners and promoters can adopt some of the excellent protocols that have already been developed on biomass sustainability generically. Of important note are sustainability standards drafted by the Pacific Northwest Biochar Initiative.

To this end, the rest of this section of this report will summarize the approach and results achieved by several groups and organizations in the quest to develop sustainability guidelines for biomass use or for certification programs for ensuring sustainable use that will be most suitable for the biochar community.

International Sustainability Certification & Guidelines

Roundtable on Sustainable Biofuels (RSB): The RSB is a project of the National Polytechnic School of Lausanne, France, with a mission to ensure that biofuels deliver on their promise of sustainability.[14] The following, in italics, is directly quoted from the report.

Objectives of the RSB Certification Systems

The RSB certification systems provide a comprehensive process for verification of compliance with the RSB standards for responsibly produced, processed and traded biomass/biofuels. The RSB certification systems facilitate the comprehensive, consistent, credible, transparent, effective and efficient implementation of RSB's principles and criteria and RSB standards for production, processing, conversion, trade and use of biomass/biofuels.

It is designed to provide:

- *flexible, effective and efficient approaches to implementation of RSB principles and criteria;*
- *a performance, stability and risk management-based compliance management system;*
- *consistent, credible and transparent verification of the implementation of the RSB principles & criteria;*
- *comprehensive, consistent, credible and transparent compliance with international norms;*
- *tangible benefits for using certified biofuels,*
- *incentives for participants to perform in a responsible way, and to*
- *facilitate market access, where market regulations call for sustainability criteria for biofuels*

The RSB relies on the European Union's (EU) sustainability criteria for the use of biomass (for biofuels and bioliquids specifically but apply broadly to all biomass use) as defined in the Renewable Energy Directive (RED), published in the Official Journal of the EU, June 2009.[15] It covers six areas of sustainability in detail along with reporting requirements and methodologies for quantifying GHG reductions. Very broadly, those are:

1. Meet a 35% reduction goal for GHG emissions due to biomass replacing business-as-usual fossil fuel use.
2. Biomass shall not come from lands of high biodiversity value (in certain forests, grasslands and unique areas).

13 Roberts, Kelli, et.al., "Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic and Climate Change Potential" , Environmental Science and Technology, Vol. 44, No. 2, 2010. http://www.css.cornell.edu/faculty/lehmann/publ/ES&T%2044,%20827-833,%202010%20Roberts.pdf

14 Roundtable on Sustainable Biofuels, "Introduction to the RSB Certification Systems". Technical Draft, RSB reference code: RSB-DOC-00-001. March 2010 http://cgse.epfl.ch/page85866.html

15 Official Journal of the European Union, "Directive 2009/28/ED of the European Parliament and of the Council of 23 April 2009" http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

3. Biomass shall not come from lands of high carbon stocks (wetlands, contiguous forest, old growth).
4. Biomass shall not come from peatlands.
5. Agricultural biomass must come from farms implementing best management practices.
6. Requires sustainability practices and/or certifications associated with biomass/biofuels products be characterized and available.

Forest Stewardship Council (FSC)

FSC is an independent, non-governmental, not-for-profit organization established to promote the responsible management of the world's forests.[16] They have developed a set of principles and criteria for responsible forest management that includes the removal and use of biomass. They focus on certification of products and services derived from the world's forests. Again, direct quotations are in italics.

The ***FSC Principles and Criteria*** *describe how the forests have to be managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations. They include managerial aspects as well as environmental and social requirements. In fact, FSC rules are the strictest and FSC's social and environmental requirements are the highest.*

These 10 principles and 56 criteria form the basis for all FSC forest management standards. Based on these 10 principles, the FSC has developed further rules (called policies or standards) that further define and explain certain requirements stipulated in the 10 principles.

Here is a summary of some of the points the FSC Principles and Criteria require. Many of the points listed below will appear almost basic – but in many places even these basic requirements are not fulfilled. This is where FSC can have the biggest positive impact.

- *Prohibit conversion of forests or any other natural habitat*
- *Respect of international workers rights*
- *Respect of Human Rights with particular attention to indigenous peoples*
- *Prohibit the use of hazardous chemicals*
- *No corruption – follow all applicable laws*
- *Identification and appropriate management of areas that need special protection (e.g. cultural or sacred sites, habitat of endangered animals or plants)*

Overview of the FSC Principles and Criteria[17]

Principle 1. Compliance with all applicable laws and international treaties

Principle 2. Demonstrated and uncontested, clearly defined, long–term land tenure and use rights

Principle 3. Recognition and respect of indigenous peoples' rights

Principle 4. Maintenance or enhancement of long-term social and economic well-being of forest workers and local communities and respect of worker's rights in compliance with International Labour Organisation (ILO) conventions

Principle 5. Equitable use and sharing of benefits derived from the forest

Principle 6. Reduction of environmental impact of logging activities and maintenance of the ecological functions and integrity of the forest

16 Forest Stewardship Council. 2010 http://www.fsc.org/pc.html
17 Ibid.

Principle 7. Appropriate and continuously updated management plan

Principle 8. Appropriate monitoring and assessment activities to assess the condition of the forest, management activities and their social and environmental impacts

Principle 9. Maintenance of High Conservation Value Forests (HCVFs) defined as environmental and social values that are considered to be of outstanding significance or critical importance

Principle 10. In addition to compliance with all of the above, plantations must contribute to reduce the pressures on and promote the restoration and conservation of natural forests.

National Sustainability Guidelines

General

In the Energy Independence and Security Act of 2007, Congress outlines some general sustainability requirements for biomass, specifically which lands could qualify as sustainable sources. This was particularly germane for its references and restrictions on biomass from public lands.

The concern over public land use comes from historic examples. When a mandate, real or perceived, is absorbed by a public land management agency, there is a tendency to move as quickly as technologically possible to fulfill that mandate. In the case of resource extraction, such as timber harvest, especially when there have been strong economic motivations for industry, land management agencies have allowed highest immediate economic gain to outweigh other uses and concerns. For this reason, conservation groups have encouraged Congress to provide strict guidelines (such as restrictions on road building to access biomass, age and size class limits, volume limits, etc.) before allowing biomass removal from public lands to become incentivized by legislation.

In May of 2009, Environmental Protection Agency (EPA) released guidelines for biofuels which requires a full life-cycle assessment of GHG emissions. There is no reason to believe that these may not be expanded to include biomass to energy and biomass to biochar production.

Carbon off-sets and cap-and-trade/cap-and-dividend systems increase emphasis on terrestrial carbon sequestration. This invites conflicts between leaving biomass in place for active carbon sequestration and removing it for fossil-fuel replacing energy -- a challenging conundrum.

Pacific Northwest Biochar Initiative Sustainability Protocols (written for national application):

Pacific Northwest Biochar Initiative (PNBI) organization is an informal network of biochar enthusiasts, businesses, practitioners, promoters and educators. At a regional conference in Washington State in spring of 2009, PNBI organizers and others volunteered to take a leadership role in establishing sustainability guidelines for the biochar community in the United States. This was in response to a strongly stated need to advance sustainability hand-in-hand with biochar practices.

PNBI's recommended sustainability guidelines referred to other existing guidelines (paying particular attention to the comprehensive work done by Sustainable Biofuel Alliance) as well as developing their own innovations. Arguably, these guidelines offer the most comprehensive framework applicable to biochar production than any others identified to date. The intent is to have these protocols further developed and adopted by the emerging United States Biochar Initiative (USBI).

Sustainability Protocol Purpose[18]

1. *To set forth a shared vision and direction for the future of this technology among Biochar proponents to prevent unintended consequences.*
2. *To make clear to a broader stakeholder group that the pioneering efforts in biochar production are directed toward helping people, helping the planet, and creating value.*

Three areas are covered in specific protocols for:

- *Creation of Biochar Energy*
- *Sequestration of Carbon from Biochar Production*
- *Production of Biochar soil amendments*

The Sustainability Protocol lays out principles, which set goals for all participants in the lifecycle of biochar. Similar to SBA's format, these principles are followed by baseline practices. The baseline practices are intended to set the threshold for where sustainability begins. As more information from actual practices is gathered, it is expected that the biochar community will go on to develop metrics for sustainability standards and indicators. These standards could ultimately serve as the criteria for third party certification.[19]

Principles

Principles have been developed that cover political, economic, social and environmental sustainability and integrity aspects of biomass/biochar production and use. Environmental justice, food security, community action, fair labor and democratic operating principles are included in the political, social and economic sector.

The environmental aspects addressed are comprehensive: from greenhouse gas emissions, genetically modified organisms, and conservation of biodiversity to basic air, soil and water. Uses of chemicals and next-generation feedstocks are also covered in relationship to human and ecosystem health. Life-cycle assessments are recommended to ensure covering all aspects when assessing sustainability.

The physical aspects of biochar production and use are addressed, with specific recommendations from the sectors above, under:

- Feedstocks
- Transportation
- Production
- Distribution
- End Use

PNBI recommends that the next step would entail the formation of sub-committees to address nine target areas taken from the above as well as including committee recommendations for a reference library, regulatory interface as well as policy, technology, funding and the human dimension.

This work-in-progress shows tremendous potential for expansion and development into fully functional guidelines and protocols for practical sustainable practices and policies options.

Sustainable Biodiesel Alliance

Although their mission is sustainable biodiesel, this non-profit organization[20] has taken a very comprehensive look at sustainability of biomass and their example is worth examining closely, specifically their publication,

18 See http://sites.google.com/site/pnwbiochar/sustainability-protocol
19 Ibid.
20 Sustainable Biodiesel Alliance. http://www.sustainablebiodieselalliance.com/dev/

Principles and Baseline Practices for Sustainability. [21]

The Principles cover environmental, social and economic issues and set the stage for their Sustainability Guidelines.[22]

Their Sustainable Feedstock Baseline Practices, with the exception of Item 6 --Waste Oils, below, all of the Baseline Practices apply to biomass sustainability, the word biodiesel can be interchangeable with biomass energy. A new addition to the concepts outlined in the other examples is the Localization Principle (Item 8). This is gaining increasing popularity as people come to understand that local production can enhance community well-being, increase local economic strength, complement community resilience and well-being, and reduce the overall carbon footprint of activities.

Sustainable Feedstock Baseline Practices

1. **Soil Quality and Conservation** – contributes to long-term maintenance and enhancement of soil quality
2. **Water Resources Quality and Consumption** – protect water quality and conserve water resources.
3. **Ecosystem Protection** – Biodiversity - does not lead to the destruction, degradation or declassification of high conservation value areas; areas of high biodiversity; habitats of rare, threatened or endangered species; or rare, threatened or endangered ecosystems. Protected areas, including forested areas, will not be declassified or appropriated for sustainable [biodiesel] crop production. At the landscape level, sustainable [biodiesel] production systems contribute to the conservation and maintenance of native biological diversity.
4. **Climate** – Emissions & Sequestration Potential - does not Increase GHG emissions and should increase the sequestration potential of current land use when possible.
5. **Energy Use** – improves energy and resource conservation. Wasteful use of fossil fuels should not be replaced with wasteful use of [biodiesel]. Instead, significant reductions in total consumption, together with increased conservation, shall be a priority. The production of sustainable [biodiesel] should utilize alternative and renewable energy to improve energy and resource conservation.
6. **Recycled Fats and Oils**
7. **Fair Wages & Working Conditions** – Farmer, Farm Worker - Fair wages, non-discriminatory and safe working conditions are provided for workers in sustainable biodiesel feedstock production.
8. **Community Benefit** – Localization - Local communities are an integral part of the development of the sustainable [biodiesel] industry. Local strategies for [biodiesel] production with citizen input are created. Local community benefit is prioritized, because the power of local businesses can transform communities for the better by working cooperatively toward a shared vision.
9. **Next Generation Feedstock** – Research and development of sustainable, emerging fuels and technologies is critical for biodiesel industry growth. These technologies shall be developed with the consideration of the aforementioned principles.

Sustainable Production (items 1-9 above) is further evaluated on another sub-set of criteria, some of which also cover Distribution Practices*:

- Air Emissions *
- Water
- Waste Handling & Reduction
- Plant Energy
- Plant/Worker Safety
- Sustainable Purchasing

21 Sustainable Biodiesel Alliance. "Principles and Baseline Practices for Sustainability" http://sustainablebiodieselalliance.com/dev/BPS%20V.1.pdf

22 Ibid.

• Administrative
• Social
• Quality*
• Sourcing and Procurement*

Council on Sustainable Biomass Production (CSBP)

This 22 member independent consortium includes a broad cross-section of major players in bioenergy production, biomass growers, energy producers, germplasm providers, academics, and the agricultural, forestry, and environmental communities.[23] They have developed a statement of intent supporting the development of a national sustainability standard for biomass production and a draft set of sustainability standards. To quote directly:

The CSBP Standard is designed to promote the production and conversion of biomass into bioenergy in a sustainable manner. It will apply to biomass produced from non-food sources, including dedicated fuel crops, crop residues, purpose-grown wood, forestry residues, and native vegetation. The Standard addresses the full complement of sustainability issues, including climate change, biological diversity, water quality and quantity, soil quality, and socio-economic well-being.[24]

The Draft Standard[25] (to be completed in 2010) covers the following nine areas, as well as an overview of Best Management Practices.

1. **Soil** – Biomass production shall maintain or improve soil quality by minimizing erosion, enhancing carbon sequestration, and promoting healthy biological systems and chemical and physical properties.
2. **Biological Diversity** – Biomass production shall contribute to the conservation or enhancement of biological diversity, in particular native plants and wildlife.
3. **Water** – Biomass production shall maintain or improve the quality and quantity of surface water, groundwater, and aquatic ecosystems.
4. **Climate Change** – Biomass production shall reduce GHG emissions as compared to fossil fuels. Emissions shall be estimated via a consistent approach to life cycle assessment.
5. **Socio-Economic Well-Being** – Biomass production shall take place within a framework that sustainably distributes overall socio-economic opportunity for and among all stakeholders (including landowners, farm workers, suppliers, biorefiners, and local community), and ensures compliance with labor laws and human rights.
6. **Legality** – Biomass production shall comply with applicable federal, provincial, state, and local laws, ordinances, and regulations.
7. **Transparency** – Production of certified biomass shall be transparent.
8. **Continuous Improvement** – Biomass production practices and outcomes shall continuously improve based on the best available science.
9. **Integrated Resources Management Plannin**g – Biomass production shall be based on an integrated resource management plan that shall be completed, monitored and updated to address objectives of the CSBP standard, appropriate to the scale and intensity of the operation.

The outcome of the Council's work, along with the SBA's and PNBI emerging standards and guidelines, provide clear and workable sustainability criteria that all practitioners of biomass-to-energy and biochar producers should be encouraged to adopt. These standards and guidelines will also form the basis for future certification programs that will help the producers and consumers ensure that environmental, social and economic issues are all being addressed in a healthy, sustainable manner.

23 Council on Sustainable Biomass Production. http://www.csbp.org/
24 Ibid.
25 http://www.csbp.org/files/survey/CSBP_Draft_Standard.pdf

BIOCHAR GHG REDUCTION ACCOUNTING IN:
POTENTIAL BIOCHAR GREENHOUSE GAS REDUCTIONS

RONAL LARSON, PHD
rongretlarson@comcast.net

The potential for Biochar to significantly contribute to U.S. climate mitigation efforts through atmospheric carbon dioxide reductions (CDR)

5.1 Summary

This section shows how 1 billion tonnes of carbon (1 gigatonne) in Biochar might be added every year to the soil in the United States while removing as much from the atmosphere - to the advantage of both. Biochar's potential benefits for the United States in this Section's topic area of greenhouse gas reductions are large in every sense of the Technology Assessment acronym "EPISTLE"; Economic, Political, Institutional, Societal, Legal, and Environmental. Interestingly, those benefits seem to grow monotonically. The greater the carbon dioxide sequestration, the greater will be the benefits. However, these benefits could be limited by two parameters; the upper bound on the total US land area and the expected annual productivity of that land. All countries face land availability limits. However, the United States certainly has much available land that can be utilized for Biochar production. Many countries have a larger potential for increased biomass productivity – because they have better growth conditions for more months per year and because their soil has a greater potential for productivity improvement. But the US can produce much more biomass per unit land area than at present – and especially as Biochar is applied to this country's considerable available land.

Using the "EPISTLE" framework to expand on the benefits of large scale Biochar:

- **Economic Benefits:** Income will certainly rise in the forestry and agricultural sectors. Adding the energy benefits of Biochar as a new income stream will be hugely important in rural America. As Biochar production increases, so will this benefit.
- **Political Benefits:** At the local producer level, Biochar could be even better received than wind or solar on visual impact grounds. Nationally and internationally, politicians should find great benefit in having addressed Peak Oil, Job Creation, National Security and many other issues besides climate, without significant cost. Providing leadership on Biochar introduction should improve our international image.
- **Institutional Benefits:** Mostly, the impacted institutions will be rural – which are some of the US institutions most in need of help. But all energy, climate, food, and forestry institutions will be impacted positively

by Biochar.

- **Societal Benefits**: Biochar will provide many new jobs, which must stay in America – not overseas. Biochar will provide an increased and more cost effective supply of food and fiber.
- **Technological Benefits**: Because the Biochar production and soils approaches are only beginning to be well understood, exactly what causes the large observed improvements in soil health offers opportunities for many types of engineers and soil scientists to learn and contribute even more.
- **Legal Benefits**: Sorting through the approaches needed to appropriately and fairly recompense Biochar producers will provide a national benefit achieved through the legal profession.
- **Environmental Benefits**: Most of Biochar's benefits will accrue here. Foremost, is the unique capability of Biochar to "permanently" remove carbon dioxide from the atmosphere – with enormous implications if we, along with every other nation, can avoid one or more disastrous carbon-related tipping points. Biochar can't supply all of the nation's needed carbon neutral energy from the released pyrolysis gases and/or thermal energy – nor does it need to. Biochar off-gases, if the Biochar contribution is sufficiently large, can enable an all-renewable energy suite when coupled with the non-dispatchable wind, solar and other RE resources. Biochar can function as the sustainable dance partner for other renewable energy generation. The renewable energy generation with Biochar integration will enable a jump from 20% decarbonized energy generation to 100% renewable energy generation with a carbon negative signature.

These above seven benefit categories should not be viewed as being linearly related to the amount of char. Many of the above benefits will be seen early. Conversely, it may be the last of the annual additions that may prove most valuable – if we can avoid a tipping point. It is too early to make predictions on Biochar's monetary benefits or the need for, or size of, subsidies.

The following pages show that a proposed 1 US "C-wedge" (1 Billion Tonnes or 1 Gigatonne of carbon) size is in rough agreement with several of the existing worldwide bioenergy and Biochar estimates. However, the major bioenergy-related estimates of the US (and by extension, the world) resource base have not included some important biomass resource areas and especially those possible with Biochar. The US biomass resource is available, sufficient, and necessary for Biochar to become the key US renewable energy resource, while also increasing non fossil based food and fiber resources while providing low-cost carbon negative climate values.

5.2 Introduction

This section addresses the possible maximum size of Biochar activities in about 2050 – with some comments on the period from now to 2030. After introducing a few key terms below, succeeding sections cover:

- Projection methodology
- A One Gigatonne Biochar "Vision" Scenario
- Lessons Learned from the Scenario
- Still Untouched Biochar Resource Analysis areas,
- Recommendations for additional resource analysis
- Closing thoughts.

Limits. There will be essentially no discussion in this Section of the three major areas of high current Biochar interest: how to produce char, how to optimize soil productivity and which policies will best enable Biochar. Other sections of this six Section report go into these three critical Biochar topics.

Equation. The many different resource magnitudes which follow (with one exception dealing with manures) follow this simple product relationship:

$$Q = P \times A \times F \qquad (5.1)$$

Where:

Q = annual weight of carbon that can be sequestered (we will only use the metric units that are standard in Biochar literature: GtC/yr =giga tonnes carbon per year, where giga = billion = 1.0 E9)

P = productivity expressed as dry biomass annual growth per unit area (t biomass/area-yr; t = tones)

A = area from which the biomass is annually harvested (area as ha = hectare, gha = gigahectares, Mha = megahectares, and m2 = square meters)

F = fraction of carbon in char derivable from the annual biomass growth (typically ¼ =0.25 by weight)

In the US, it is most common to talk about the resource base in annual biomass (our primary units), not carbon terms, this may be referred to as feedstock. The former is close to twice the latter. Caution is also urged in making sure the data comparison is for dry and not green tonnes. Here we use only dry tonnes, whose percentage of both biomass and carbon is about twice that of green tonnes.

5.3 More detailed projection methodology

A US goal.

There have been only a few attempts to project the upper limits of Biochar's possibannual contribution to carbon dioxide (CO_2) removal [Read[26], Lehmann[27], Lenton[28]]. In particular, this following analysis has been heavily influenced by recently deceased Professor Peter Read, who seems to have been the first to urge large Biochar numbers. His proposed global goal total was around 10 gigatonnes Carbon per year (10 GtC/yr). However, we are unaware of any study that allocates a share of the global atmospheric carbon excess to the US. That share would seem to be high. Although less than 5% of the global population, until recently with the growth of energy consumption (and new expanded fossil carbon) in China and India, the US has been consuming about 25 % of the global total.[29] But we have nowhere near 25% of the global land area, which is about 13 Gigahectares (Gha). The United States has only about 1 Gha or less than 8% of the global total, and much of the US land area is cold, arid, and/or mountainous. On the other hand, we are the most prosperous nation, and there are substantial benefits to doing as much as we can, even while paying other countries to help remove the rest of our large legacy share.

So, the logical question is: Given the US carbon legacy, what should our percent of the total be and how does that square with the figures from the questions above? This is the subject of the next subsection – in which we show one way to achieve 1 GtC/yr, which is 10% of Prof. Read's recommended annual total.

Biochar units.

Biochar units are not yet standardized. Although the US remains on the "English" system (including all of our agriculture and forestry data), most of the technical Biochar data is expressed in metric terms. We shall stick with metric units but the following conversions may be helpful:

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25 Victoria University of Wellington Institute of Policy Studies Working Paper 07/01; Holistic greenhouse gas management: mitigating the threat of abrupt climate change in the next few decades. *With reviewers comments and author rejoinders; P. Read* and A. Parshotam*** Also see a 2008 video of Peter mentioning Biochar is at http://vimeo.com/5666985 (This makes strong connection to the work of Prof. William Ruddiman on early anthropogenic causation of CO_2 rise.

27 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. DOI: 10.1007/s11027-005-9006-5. [Found at http://www.css.cornell.edu/faculty/lehmann/publ/MitAdaptStratGlobChange%2011,%20403-427,%20Lehmann,%202006.pdf] There are a large number of Professor Lehmann's Biochar publications at http://www.css.cornell.edu/faculty/lehmann/publications/index.html

28 Lenton, T.M. and Vaughan, N.E. (2009) The radiative forcing potential of different geoengineering options. Atmospheric Chemistry and Physics 9, 5539-5561. url: http://www.atmos-chem-phys.net/9/5539/2009/.

29 http://pdf.wri.org/navigating_numbers_chapter6.pdf (Fig. 6.1) http://www.docstoc.com/docs/976444/CARBON-DIOXIDE-AND-OUR-OCEAN-LEGACY/

1 hectare (ha) = 2.47 acres; 100 hectares = 1 square kilometer. 1 square mile = 2.59 sq. km;
1 kg = 2.205 pounds; 1000 grams = 1 kilogram; 1000 kg = 1 tonne (t); 1 tonne=1.102 tons

Carbon weight and what to call it

The world of carbon avoidance and carbon removal is mostly (not universally) using carbon, and not carbon dioxide, as the standard unit. We have about 800 GtC in the atmosphere now and many climate experts would like to remove about 200 GtC. However, the US' Energy Information Administration (EIA) has just switched to reporting CO_2.[30] The relationship between the two is by atomic weight ratio 44/12 = 3.67. Despite EIA, we shall stick with C, not CO_2, as the more basic unit for Biochar. If we have 1 t C, that carbon is equivalent to 3.67 t of CO_2.

The term "wedge" was coined by two Princeton Professors[31] to mean the avoidance of 25 GtC over a 50 year period of linear growth (a triangle shape) assuming the linear growth ends with 1 GtC/yr of avoidance. This assumes carbon-neutral capabilities from energy technology areas like energy efficiency, solar, wind, biomass, nuclear, etc. They have never mentioned Biochar.

However, "wedge" has also come to mean the end annual rate (of 1GtC /year) value as well. The concept fits well with Biochar, with the same annual rate units (weight/time). However, for Biochar, we have the added complexity of needing to talk about three variables: biomass rate units, Biochar rate units, and carbon rate units. In order to take advantage of the shorthand that the term "wedge" offers, but limit ourselves to the end-value meaning, we will introduce two new terms:"B-wedges" and "C-wedges".

- B-wedge is the unit of annual biomass harvested supply- measured in annual tonnes of biomass GtB/yr.
- C-wedge is the amount of carbon (not char) annually placed in the ground, measured as GtC/yr.

One needs to produce more than 1 tonne of char to obtain one tonne of carbon in the char. Those paying for sequestration will be paying for tonnes of carbon sequestered, not tonnes of char.

Productivity units

This is the term P in Equation 5-1. Because it is hard for most of us to visualize tonnes and hectares, we only show biomass productivity in a more easily visualized form: kg/m2-yr. This unit is one tenth the numerical value given in Eq. 5-1. That is, 1 kg/m2-yr is the same as 10t/ha-yr.

Carbon-neutral aspects of Biochar.

There are a range of possible carbon-neutral impacts for Biochar - about which more is said in subsection 5.5.3.

The time required.

The proposed 1 C-wedge goal for the US Biochar industry is a long-term peak goal. However, it is perceived as being possible before 2050. The year 2030 is probably (but not completely) out of the question, as that would require immediate action and a worldwide commitment that is not yet evident.

5.4 Our Projection – A Biochar Billion Tonne Vision (BBTV) Scenario

5.4.1 Summary Figure and Table.

Using the above framework, the required numbers described above for weights and areas for our 1 C-Wedge sce-

30 http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html
31 http://carbonsequestration.us/Papers-presentations/htm/Pacala-Socolow-ScienceMag-Aug2004.pdf

nario are based on a 2005 bioenergy-based combined DoE – USDA study called the "Billion Ton Vision" (BTV).[32] The BTV provides a detailed breakout – with some components providing only tens of Megatons and tens of Mega-acres. All of the BTV is expressed in English units, requiring conversion for our use. . Biochar is not a topic in the BTV report but everything in the BTV is relevant to a Biochar study. The details of the BTV itself are given in supplementary material. Here we only concentrate on the possibilities of expanding the BTV – which was intended to meet 30% of the US biofuel industry needs. To emphasize both the similarities and the differences, we shall call this new expanded scenario the Biochar Billion Tonne Vision or BBTV for short. The term "Billion" in BTV refers to dry biomass (not carbon) tons (not tonnes) of biomass. In the BBTV, "billion" refers to the tonnes (not tons) of carbon (not biomass) in the produced char. For simplicity, they are taken to be in the ratio of 4:1 units of biomass to one unit of carbon in Biochar.

Figure 5.1 shows the BBTV graphically. The same information is in *Table 5.1*. The main central large "exploded" Pie-chart shows the nine elements of the BBTV. These nine B-wedge flows are themselves fed from eight outer supply rectangular stock "boxes".

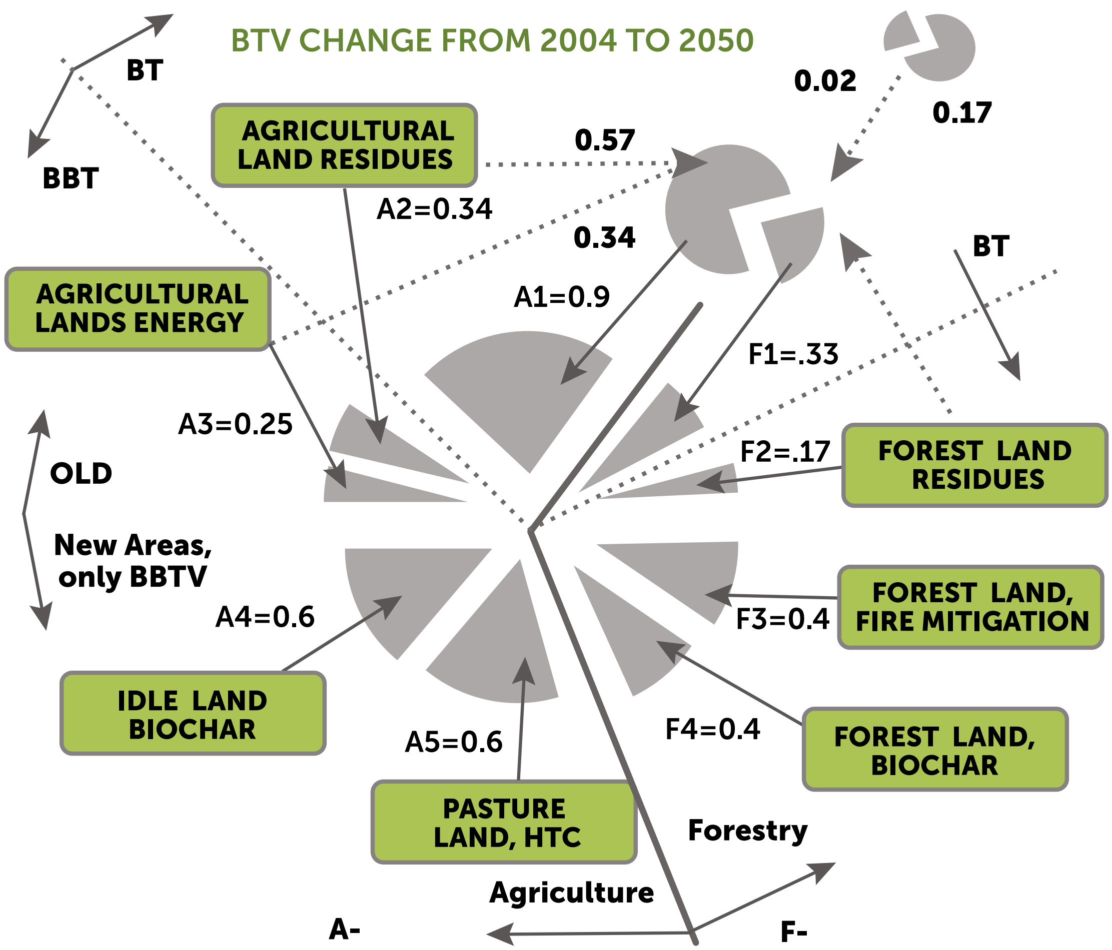

Figure 5.1. Schematic Relationship Between the BTV and the BBTV

The diagonal lines from the origin separate three main region. The heavy solid lines separate the five agriculture B-wedges from the four forestry B-wedges. The horizontal line separates the four new categories of sequestration in the BBTV from the five older types. These four now provide a total of 2 new B-wedges – half of the postulated 4 in total. The two dashed lines in the upper right quadrant separate the two BTV B-wedge segments from

32 http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

the seven in the BBTV.

Continuing along the upper solid line we see that the 1.24 BTV B-wedge is about 30% the size of the 4 BBTV B-wedges in the central "pie". The BTV is "fed" by only three sources: two from the Agricultural side (waste and energy components) and one from Forestry wastes.

Continuing even further to the upper right, one sees that the situation in 2004 was dramatically smaller and of a different character. The sources in 2004 for biofuels were predominantly from Forestry. And all sources were from waste. The BBTV changes the ratio slightly back towards forestry. Even more of a shift is possible, given the larger portion of US land in forestry.

The more detailed descriptions of these nine B-wedges follow the explanation of the tabular form included in *Table 5.1* of *Figure 5.1*.

Table 5.1 Details to reach a total of 4 B-wedges

Type of B-wedge	B-Wedges (GtB/yr)	Area (mega ha)	Productivity (kg C/m2-yr)	Comments
Part 1 – BTV Categories				
A1a Ag Residues	0.41	129	0.16	
A1b Other Residues	0.16	28	0.28	
A1c Perennials	0.34	24	0.71	Agri forestry
A1 – BTV- Agriculture	0.91	182	0.25	Assumed fi rm -
F1a Fuel wood	0.05	129	0.02	
F1b Processing Res'ds	0.13	na	na	
F1c Urban Residues	0.04	na	na	
F1d Logging	0.06	204	0.01	Extremely low productivity
F1e Fire fuel reduction	0.05	24	0.11	
F1. BTV – Forestry	0.33	357	0.05	Assumed fi rm
BTV total	1.24	539	0.12	Part 1 Subtotal
Part 2 – Three Small Mods to BTV				
A2 – Residues expanded	0.25	129	0.25	44% increase in A1a and A1b
A3. More Agri-forestry	0.34	24	0.71	equals A1c , new land
F2 - residues expanded	0.17	na	na	75% more of F1 Residues
Expansion of vision areas	0.76	153	0.65	Part 2 Subtotal
Part 3 – Four New or Larger Mods to BTV				
A4.New land Agri-forestry	0.6	40	0.75	New - use idle and pasture lands
A5. HTC emphasis	0.6	40	0.75	Much expanded "wet" part of A1b
F3. Fire emphasis	0.4	na	na	8 x F1e (Fire)
F4. Energy emphasis	0.4	20	1.00	8 x F1a
New areas	2	140	0.71	Part 3 Subtotal
BBTV Total B-Wedges	4	619	0.32	Can sequester 1 GtC/yr Biochar
Agricultural subtotal	1.5	182	0.41	37% of total; 1.65 x A1
Forest subtotal	1.3	357	0.18	33% of total; most gain in F3+F4
New Biochar land subtotal	1.2	80	0.75	30% of new total; 1.32 x A1

5.4.2 Description of Columns

Type of B-wedge The first column lists the nine main B-wedge types. The two that are at the top (A1 and F1) are designated Part 1 – here with additional detail over that in *Figure 5.1*. These are directly from the BTV – but combining some of their smallest BTV items. The Part 2 terms A2, A3, and F2 are expansions of resource areas

that are in the BTV (Part 1), The final four new BBTV items A4, A5, F3 and F4 are in Part 3 of the table. These major expansion terms, none specifically considered in the BTV, are now half of the new BBTV total – the bottom half of *Figure 5.1*

Below the three parts is the total BBTV. The final three lines separate out the total in a different way not shown explicitly in the figure. These emphasize the new inclusion of idle land (A4) and converted pasture (A5), as new additions to the agricultural land category.

B-wedge Magnitudes The second table column shows the key variable of this Section: total supply of annual biomass. The different magnitudes for the nine B-wedges range from 0.17 to 0.91.

Land Requirements and Productivities. The third column gives one possible land requirement in mega hectare units. The fourth column (biomass productivity in kg of carbon per m2-yr) is presented to help affirm the reasonableness of the B-wedge values and land areas of the two columns to the left. Three conversion factors are in this fourth column. A factor of 1000 converts from "megas" to "gigas"; a factor of two to convert from biomass to carbon, and a factor of ten changes from tonnes per hectare to kg/m2.

5.4.3 Assumptions.

The quadrupling growth factor in the forestry sector was made a little larger than the approximate tripling in agriculture. (In 2004 the forest sector supplied almost 8 times the bioenergy resource as that from agriculture) Second, the Table shows that the three extensions of Part 2 totaled much less than the Part 3 total (a 61% increase vs 161%). The four new areas now are half the total (2 B-wedges out of 4). Third, the land requirements have gone up but much less and are probably on the high side, as explained further below. Fourth, no large changes were made in the BTV's specified productivities.

5.4.4 The BTV numbers – Part 1 - Portions A1 and F1 totaling 1.24 B-wedges.

Part 1 of Table 1 gives the entries making up the 0.91 + .33 = 1.24 B-wedges of the BTV's A1 and F1 categories. Additional detail is provided in the supplementary material, but much of Part 1 can be understood as we discuss the remaining seven B-wedge categories.

5.4.5 The BBTV extensions of the BTV: Part 2 - Portions A2, A3 and F2 totaling .76 B-wedges.

These are all relatively small extensions of specific items found in the BTV.

A2 (Expanded Ag residues; 0.25 B-wedge) assumes that a larger portion of Ag residues can be obtained than is assumed in the BTV. In part, this is justified by the monetary value that will accompany their use in Biochar – a technology not included at all in the BTV. This also assumes an expanded pro-Biochar policy framework – whereas the BTV (appropriately) assumed no new policies. It is key to understand that if Biochar production and utilization are done effectively more carbon will be placed on agricultural land over longer periods of time then if the residues are left in place.

A3 (Expanded agri-forestry; 0.34 B-wedge) asserts that agriforestry has a larger future (by a factor of 2) than given in the BTV. The principal BTV author, Dr. Robert Perlack,[33]has indicated that their 2010 update will also increase in this category – presumably justified by a change in national policy since 2005. The obvious reason for wanting this change is the large B-wedge increase that is possible with little change in land area. Here the land is assumed to be agricultural land – available as food productivity increases (due in part to Biochar) allowing conversion from food crops to energy crops. This land area assumption also could occur as more food is grown by consumers, less is lost after harvesting, land is freed up as we move away from corn ethanol, and possibly a move towards a vegetarian diet.

33 Private communication

F2 (Expanded forestry residues; 0.17 B-wedge) is like A2 – a larger collection of existing residues. In part this is an assumption that Biochar facilities will be smaller and more widespread than bioenergy facilities. Then transportation costs will be less of a constraint. It also assumes that the monetary value for char-making will be high – that Biochar producers will be more willing to pay more for Biochar B-wedges than bioenergy B-wedges (in part because of increased incentive payments that recognize the greater difficulty in supplying carbon-negative benefits).

Land changes: None.

Productivity Changes – minimal changes for the residue portion; the agri-forestry is similar to that in the BTV.

Subtotal: These total 0.76 B-wedges – a 61% increase over the BTV values.

5.4.6 Major Extensions of the BTV – Part 3 Portions A4, A5, F3, F4 - totaling 2 B-wedges.

These four large categories are lumped together to emphasize that all were minimally considered in the BTV. These categories are different, but not drastically different, from the preceding five areas.

A4 (Land conversion; 0.6 B-wedges) assumes that Biochar policy will encourage more land for agriforestry than can be taken out of agriculture. Therefore, land will be converted from both idle and pasture land – perhaps roughly half from each. The BTV has minimum mention of land conversion – with Agricultural land relatively constant. Of course Biochar users might view this land as the "lowest-hanging-fruit." The energy crops are presumed in this category to be short rotation crops (SRC), such as switchgrass, miscanthus, willow, etc. The land area could be less (perhaps much less) than indicated with future improvement in productivity through bio-technology (Bt)[34]. However, no Bt assumption is being made here.

A5 (High moisture content feedstocks; 0.6 B-wedges) is a major expansion of the conversion of manures and other moist biomass waste streams that are mentioned in the BTV. A5 includes the presumed success of the Biochar technology called hydrothermal carbonization (HTC). This is a form that is capable of converting B-wedges to C-wedges at a ratio near 2:1 rather than 4:1. There is an assumed conversion of about 40 Mha of pasture land as shown in the "land" column of Table 5.1. Perhaps one-third of all US manure and moist non-urban waste is captured. This category also includes a large use of HTC to convert most forms or urban waste – a very small category in A1, which (in 2004) could not have predicted this promising new form of Biochar – much better known in Europe than the US.

F3 (Forest fire mitigation emphasis; 0.4 B-wedges) assumes about a 650% expansion of a small part of F1. This would make a new Biochar asset, by its regular removal, out of much of the biomass that annually is consumed in US forest fires. More than a third of all US forestland is owned by national, state and local governments, but the BTV shows only a small B-wedge contribution from this vast resource. This F3 area is also intended to cover the possible intentional use of BLM and USFS land for intentional new tree-planting sequestration purposes – a use that could enhance their recreational and other uses. Such lands are now eligible for wind and solar. Biochar could be an addition to the recent availability of these lands for wind and solar.

F4 (Conversion of existing commercial forests to energy emphasis; 0.4 B-wedges) is similar to A4 in supplying an additional dedicated (not a residues-based) biomass resource. The BTV assumed this type of resource only for agriculture, not for forestry. F4 assumes that a portion (not very large) of existing forests is converted from pulp and paper to Biochar (for reasons of profit maximization following Biochar-friendly policy). The contribution here includes coppicing and/or harvesting on a multi-year (perhaps 5-10 year) basis (rather than the short rotation crops (SRCs) of category A4. This F4 category might surround existing older native

34 http://www.isaaa.org/resources/publications/pocketk/24/default.asp; http://www.pgeconomics.co.uk/pdf/GM_crop_yield_arial.pdf

forests - to improve biodiversity.

5.5 Lessons from the BBTV Scenario

5.5.1 Land Area

The middle numerical column of *Table 1* shows a moderate (roughly 16%) addition to the roughly half of the US total (just under 1 gigahectare) land being used by agriculture and forestry. On the agriculture side (no change in forest land area), there is about the same percentage decrease in idle and pasture land.

Pasture land conversion. Although the category A5 for manures shows 40 new megahectares in use within the BBTV – the assumption is that the considerable US pasture land use will not be greatly changed. This lack of real land use change is due to the use of manures from dairies, feedlots, poultry operations and urban sewage, These operations could not have been considered in the BTV, because the HTC process is so new, even within the Biochar community. There are at least three companies in Germany engaged in this alternative approach - that does not require drying of the feedstocks.[35]

Other-than-land options Given that land area is a serious constraint in achieving even larger Biochar potential, we note that neither the BTV nor this BBTV have considered two other large water-based, potential biofuel resource areas: land-based algae and ocean algae. The annual per unit land area yield from algae installations is perhaps 4 or 5 times larger than identified above and can utilize the US plentiful desert lands. Biochar, in the event of phasing out fossil fuels, could be the best way of providing the CO_2 that the algae need for fastest growth. Algae was not considered in either the BTV or BBTV because of its developmental status.

The oceans (and perhaps some freshwater inland lakes) are another possible means of handling land use scarcity. Again, this needs much development. Some Paleogeologists believe that a small floating water plant (azolla) and water-based "sequestration" was the main reason for huge CO_2 reductions during past climate cycles[36]

In summary, land constraints for Biochar technologies do not appear serious.

5.5.2 Productivity.

Most of the BBTV productivity numbers were taken to be similar to those in the BTV. The productivity figures are nowhere near the large values found in some of the bioenergy literature discussed below. Only two of the productivity estimates in *Table 5.1* are at all large – but those two are well below values given in the literature.[37]

NPP. The 4 B-wedge values in the BBTV can be related to Net Primary Productivity (NPP – a measure of global photosynthesis). The world total NPP is often listed as about 60 GtC/yr[38] – of which 10% (more than the US 8% share of global land area) or six B-wedges are assumed in the USA. As four B-wedges would contain about 2 GtC/yr, this implies a commercial utilization of 1/3 the US share of NPP – a number that may seem surprisingly high. On the other hand, dividing 60 GtC/yr by 13 Gha gives 4.6 t/ha-yr or .46 kg/m2-yr, which is very close to the world average NPP (0.43 kg/m2-yr) given by Wikipedia.[39]

The maximum value in *Table 5.1* is only 2.5 times as large. The average yield in both the BTV and BBTV is on the order of the average NPP. American foresters and farmers can certainly do better than the average. An exhaustive study of NPP was conducted by Dr. Edward Smeets of Utrecht University in the Netherlands.[40] Dr. Smeets

35 http://www.hydrocarb.de; http://www.cs-carbonsolutions.de/ ; http://www.suncoal.de/en
36 Knies, J., U. Mann, B. N. Popp, R. Stein, and H.-J. Brumsack (2008), Surface water productivity and paleoceanographic implications in the Cenozoic Arctic Ocean, Paleoceanography, 23, PA1S16, doi:10.1029/2007PA001455.
37 http://www.treepower.org/pictures/biomassenergyintegration.pdf, http://www.treepower.org/globalwarming/oakridge.pdf
38 http://daac.ornl.gov/NPP/npp_home.html; http://www.fao.org/nr/climpag/globgrids/NPP_en.asp
39 http://en.wikipedia.org/wiki/Primary_production
40 http://www.chem.uu.nl/nws/www/publica/Publicaties%202008/NWS-E-2008-13.pdf

projects (p 81 of his thesis) doubled NPP by 2050. This would place the BBTV as consuming something closer to 1/6 of the US NPP. He states that today's NPP average conversion of incoming solar energy is about 0.3% (using 180 W/m2 average). He says that a future conversion of 2% is possible. This is about half the theoretical limit for C-4 plants, thereby justifying a factor of 7 improvement as being possible.

On p 56, Dr. Smeets also gave another reason for not using today's NPP values:

"The difference in yield is caused by the fact that in stable natural ecosystems, plants have passed their rapid growth phase. Food and energy crops are usually harvested during or soon after the rapid growth phase and have thus higher average yields."

In some Asian countries the human appropriation of NPP is much higher than the above postulated US factor of about 1/3.[41] See also additional comments on NPP in Subsection 5.5.4.

5.5.3 Additional Clarifications.

Additional carbon negativity. There are additional contributions to carbon negativity (carbon neutrality discussed below) beyond Biochar's initial placement in soil, including:

Intentional growth of biomass (mostly trees) where none previously existed sometimes going by the name REDD.[42]

Increased above-ground growth following placement of the Biochar in the soil (and the same below ground in added Biochar-caused roots, bacteria and fungus).

- Reduced need for fertilizer
- Retention of Nitrogen Oxide
- Lowered release of Methane
- Lowered release of particulates from open biomass combustion
- Augmented sequestered carbon both above ground and in the soil.- after the char has been placed in the ground with augmented productivity
- Reduced water pumping (the use of biopower to replace fossil sources is in the carbon-neutral category discussed below)
- Possible capture of CO_2 following use of the pyrolysis gases in a process known as Biomass Emissions Capture and Sequestration (BECS).[43]

We estimate 20-25% sequestration additional to the postulated 1 C-wedge that should be considered in valuing Biochar. This important aspect of Biochar has just begun to get research attention and is outside the scope of this Section.

Varying carbon content of Biochar Char is often said to be about 85% carbon when produced at typical slow pyrolysis temperatures. How to achieve the exact assumed 4:1 ratio of 4 B-wedges to1 C-wedge must be the subject of a much longer study. Slow pyrolysis biochar production gives about this ratio, whereas fast pyrolysis biochar production would require about a 6:1 ratio.

The important fast pyrolysis yield reduction is counterbalanced, however, with the possible use of the HTC approach mentioned above. In HTC, about 97% of the carbon in the biomass can stay in the resultant product.[44]

So much is uncertain in this analysis that coming within 10% on the C-wedge number would be surprising, even if perfect on the B-wedge values. In any case, the extra equivalent carbon reductions listed in the first paragraph of this subsection should make up the difference in Sequestration potential. We assume the 4:1 ratio for simplicity.

41 http://www.worldwildlife.org/science/pubs/imhoff_nature.pdf
42 http://www.cifor.cgiar.org/publications/pdf_files/cop/REDD_paper071207.pdf
43 http://en.wikipedia.org/wiki/Bio-energy_with_carbon_capture_and_storage
44 http://www.biochar.org/joomla/images/stories/Pechoelbrennen/MaxPlankCharcoal.pdf

Timing A transition to 1 Biochar C-Wedge could be well underway by 2020, and of course testing is already in progress. Commercial scale operations have been rumored in Australia.[45] This study has not attempted to address introduction timing issues – except for a brief probability example in Subsection 5.7.

Carbon neutral benefits The pyrolysis gases and exothermic energy release obtained with all Biochar production can be used to displace fossil fuels. There seems likely to be a reduction in needed nitrogen and phosphorous fertilizers, with a carbon neutral offset on the production of the fertilizer. Water use reduction could be important. Maybe more important is the indirect impact of enabling other renewable energy resources by providing backup. This is possibly in total half as large as the carbon negative total.

Magnitude of 1 C-wedge We must recognize that four B-wedges leading to about 1.5 C-wedges (combining the carbon negative and carbon neutral potentials) in the US are huge carbon totals. In CO_2 terms, this would be 5.5 gigatonnes CO_2 – .4 gigatonnes CO_2 less than 2006 US carbon dioxide emission equivalence from the US consumption of petroleum, natural gas and coal.[46]

Working with other Countries Some countries today have much larger annual productivities. The US will have to participate outside the US if we assume responsibility for the rest of our (roughly25%) "legacy" CO_2.

Dollar Size of a 1 C-Wedge Biochar Industry A commonly-stated future wholesale value for Biochar is $200/tonne. The Biochar 1 C-wedge total then would be at least $200 Billion USD per year. At the ratio of 4 units of biomass for one of char, this implies a biomass tonne (after conversion) being worth $50 per tonne (but costing less). But since one-quarter the initial carbon could end up as useful energy, the total Biochar industry value is perhaps closer to $300 Billion per year. The 2009 US GNP was about $14 trillion,[47] so this would be above 2% of the US economy.

Fossil Fuel Displacement. Since biomass has an energy value of about 17 GJ/tonne, the annual input energy for four B-wedges will be about 70 Billion GJ or 70 Exajoules per year. The US total energy consumption (105 EJ/yr) is only 50% larger – again showing that 1.5 C-wedges of char and energy is a very large number. But roughly half of the B-wedge total (or 35 EJ/yr) is serving a new carbon-negative sequestering function and would not show up in the national accounts as consumed energy. More work could show that this example of 4 B-wedges is sufficient to meet all the needs that cannot be met by combined energy efficiency and renewable energy (EE/RE). It now appears that 1 C-wedge of Biochar, when used as the primary RE backup source, could allow the US to be completely fossil-fuel free.

5.5.4 Relationships between the US and World Biomass Resource Totals

The IBI Biochar projection The most detailed Biochar data we have seen was prepared for International Biochar Initiative by Dr. Jim Amonette.[48] He assumed Biomass limits ranging from 1.2% to 3.2% of an NPP of 61.5 GtC/yr. The 3.2% scenario, by coincidence, assumed about 2Gt carbon of input biomass – essentially the same as the 4 B-wedges of the BBTV. So, although Dr. Amonette was thinking of a world total, his analysis can apply well to our US-only 1 C-wedge situation. The main difference between the assumptions is that the BBTV assumes a 50% conversion of carbon in biomass to char, while Dr. Amonette assumes a 40% conversion. One justification for the more optimistic number in the BBTV could be the partial use of the HTC means of conversion; Dr. Amonette's value is certainly reasonable as well. Dr. Amonette's upper limit of 3.2% of a worldwide 61.5 GtC/yr as the NPP basis for his choice of supply is also realistic given the IBI emphasis on residues. To get to really large values requires all 9 of the components given above. So there is really no disagreement between the two analyses, except this Section's assumption of highly favorable Biochar policies and thereby, the availability of Biochar-dedicated as well as waste resources.

45 http://www.carbonedge.com.au/docs/CarbonEdge-CE2_Special_Report-biochar.pdf; http://www.biochar-international.org/sites/default/files/Quirk.pdf
46 http://tonto.eia.doe.gov/energy_in_brief/greenhouse_gas.cfm
47 http://en.wikipedia.org/wiki/Economy_of_the_United_States#Energy
48 http://www.biochar-international.org/images/final_carbon_wpver2.0.pdf.

Other Global NPP. projections To better understand the differences in NPP between the US and other parts of the world, a good starting point is an article by Field.[49] The greater productivity of the Southeastern part of the US stands out in these world maps, while also demonstrating that the tropics are superior even to Florida. The NPP in Field's study was slightly less than 60 GtC/yr.

A comparative study by Berndes is perhaps the most often quoted.[50] However he does not look at the US and his range of estimates is so broad as to not be helpful for this work. Several of those he compared, but especially one by the USEPA,[51] well exceed the estimates in the BTV. The differences are primarily in the different assumptions of future technological progress. The BTV and the BBTV conservatively assumed only minor technological improvements.

By far the most optimistic view of Biomass in the future we have seen was a Swedish study[52] which justified (in their Figure 9), 1300 EJ of available Biomass energy. Almost 1000 EJ of the total came from "Biomass production on surplus agricultural land." Converting to carbon units by dividing by 17 GJ/tonne biomass gives about 80 B-wedges and therefore about 20 C-wedges. Using the assumed 10% ratio between the US and world totals again, we see that the BBTV's 4 B-wedge assumption would be about twice easier to achieve

5.6 Unaddressed Scenario Issues.

5.6.1 Economics - Influence on the BBTV Projections

B-wedge costs. Ideally, the cost of Biochar should have been a central part of the BBTV Scenario of Section 5.4. The lowest price we have heard is in Brazil at $75 per tonne, for relatively small bags of char (not Biochar) being sold retail along a highway. Biochar is being sold commercially in large quantities at a reported $500/ton on the US East coast. Small quantity sales at $1 per pound ($2200/tonne) are known to occur. All these from resources that might have a negative cost (can receive a "tipping fee") or might cost $100/tonne or more. The further elaboration of costs is outside the technical limits of this Section.

Hardware costs No aspect of the hardware economics should disfavor Biochar – as Chemical Engineers today work routinely with biomass inputs. The magnitude of hardware costs for modern charcoal sales for the home barbecue market is kept confidential, but there are many companies involved. The equipment to produce char is not particularly complicated. Like all manufactured products, equipment should become less expensive as experience and manufacturing output accumulates.

Life-cycle Assessments (LCAs). A recent life-cycle assessment for Biochar is important[53] Dr. Kelli Roberts has shown that today, Biochar can be economically competitive in some situations with small travel distances. More such Biochar LCAs are needed.

5.6.2. Other Influences on the Future of Biochar

Improved plant species Previous subsections identified future technological progress as the main driver for a larger future NPP (and therefore more available B-wedges). That in turn, if true for food crops, will open up more farm land for energy crops. This optimism is based on a growing improved understanding of genomes. It was not found necessary in the BBTV to invoke Genetic Engineering (GE) or Genetic Modification of Organisms (GMO),

49 http://www.sciencemag.org/feature/data/982246.dtl
50 Berndes, G., Hoogwijk, M. and van den Broeck, R.: 2003, 'The contribution of biomass in the future global energy supply: A review of 17 studies', Biomass and Bioenergy 25, 1–28.
51 Lashof, D.A. and D.A. Tirpak, eds. Policy options for stabilizing global climate. 1990, Hemisphere Publishing Corporation: New York, Washington, Philadelphia, London.
52 http://www.worldbioenergy.org/system/files/file/Report%20091130_final.pdf
53 http://www.css.cornell.edu/faculty/lehmann/publ/ES&T%2044,%20827-833,%202010%20Roberts.pdf

but certainly advances here will impact the future of biomass in general.[54,55]

Soil science progress. We have much to learn on why Biochar improves soil productivity. We should see significant yield improvement as soil scientists (and practitioners/amateurs) are able to perform more experiments with well understood "boutique" chars.[56]

Present large use of biomass for energy. Biomass energy production is today worldwide a larger contributor to global energy need than either nuclear or hydro energy, much less wind and solar. Starting from a large base allows rapid growth worldwide that will have a US influence as well. Existing expertise. A large portion of the US workforce is already trained in agricultural and forestry. Organizations like 25 x 25 have endorsed Biochar. The agricultural sector is a powerful lobby.

The US is not alone. The views of other countries, especially developing countries, generally favor Biochar. The action of the UNCCD in UNFCCC deliberations was a helpful sign.[57] Australia, the United Kingdom, Germany (and possibly Japan and Canada) have larger Biochar programs than the US.

Reasons for pessimism: There is a dwindling supply of key nutrients. Biochar can help, but possibly not enough on some, such as phosphorous. There will be increasing competition for a limited supply of water. Population pressures will take over more land for housing. More mouths to feed will keep some land from being used for Biochar. Drastic climate change could occur, with increasing temperatures and sea levels also reducing land availability and yields. Biochar will always be in competition for residues and land. Some still-unidentified carbon dioxide removal (CDR) technology could prove superior in some way. Bioenergy/biofuels could win the biomass resource competition if CDR is not taken on as a national goal.

5.6.3 Policy Issues that Relate to a BBTV

Carbon credits. By far the most important policy driver will be the presence of carbon credits – the subject of a separate section. The biomass availabilities of this section assume these credits.

National major policy topics. The BBTV exercise, unlike the predecessor BTV, was performed with the specific assumption of new favorable policies. But there are many aspects of Biochar that will benefit from policies for other current national "crisis" areas. Jobs, peak oil/gas, oil spills, coal requiring CCS; national security, recognition of the capability for any biomass operation to support solar and wind; rising concerns about sustainable development, etc. We have identified no major current policy discussion that seems likely to slow down Biochar.

Carbon negativity. One very important policy gap is the lack of any national goal related to carbon negativity. The existing carbon-neutral policy approaches are absolutely critical, but they will not achieve the early goal of 350 ppm espoused by Bill McKibben[58] and Jim Hansen.[59] The recently concluded Cochabamba conference called for 300 ppm. Unfortunately, that conference also rejected Biochar for reasons discussed in the next subsection.[60]

Certification. Emphasis on standards and certification for biofuels will advance Biochar. Many standards have been developed with Federal funding support.

Geoengineering Geoengineering discussions are taking on increasing importance for Biochar and vice-versa. The recently concluded "Asilomar Conference" considered Biochar quite seriously.[61] Most of geoengineering's controversy has been about Solar Radiation Management (SRM), not the less well-studied CDR into which Biochar fits. A better umbrella might be the term "Biosequestration" or "Biomimicry-driven carbon reduction." The

54 http://www.arborgen.us/
55 http://www.isaaa.org/
56 http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0965336
57 http://www.biochar-international.org/policy/international
58 http://www.biochar-international.org/biochar/carbon; http://www.orionmagazine.org/index.php/articles/article/4418/
59 http://www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf; http://www.re-char.com/2009/06/25/dr-james-hansen-on-biochar-and-soil-based-sequestration/
60 http://pwccc.wordpress.com/
61 http://www.climateresponsefund.org/

former term, as well as "Biochar", appeared in the recently released American Power Act (APA), developed by Senator John Kerry.[62]

5.6.4 Objections of Anti-Biochar Groups

There has only been one main group vocal in their opposition to Biochar. Their (quite effective) opposition has three parts:

Objections with no or minimum validity: Limited char lifetime and added soil productivity. These and others are fully rebutted in a Q&A format at the IBI website.[63]

Issues which will benefit from certification: Biodiversity and indigenous populations issues. These objections seem resolvable if the certification procedures (already in process for Biochar) require that local populations have a meaningful input.

Topics which require more research: The issue of toxicity clearly requires a government-funded R&D effort. However, toxicity may not be a serious problem – given the long history of mankind's living with char. Charcoal is even used to clean up toxic waste areas and is prescribed for oral ingestion.

5.7 Needed Research and Activities to Accelerate Biochar Growth

Continued research and development is obviously needed to prove the preliminary favorable conclusions of this section. Many in-field experiments are critical. Research is needed especially on more photo synthetically productive plant species. This Section may have significantly underestimated the B-wedges available as genetic specialists achieve the same improvements for energy crops as they have for food crops.

It seems that a relatively small incentive will be needed in many locations to justify Biochar's use. Added soil productivity may not be enough. Without policy, R&D and some early voluntary credits, the needed experience to determine the values and economics of Biochar may be too-long delayed. Policy work should also include more on the need and importance of conversion of land use, with analysis especially of impacts on biodiversity. The best forms of Biochar production will also depend on R&D advances in the transportation sector. More research on electric and hybrid vehicles may remove much of the competing biofuels demand for B-wedges.

Lastly, it appears that new improved forms of certification are especially needed – to overcome the valid concerns of Biochar-skeptics about biodiversity, indigenous populations, and other social and sustainability issues.

The B-wedge estimates of this Section are only intended to be approximate. Emphasis should be placed on the realism of the nine proposed areas and postulated productivities associated with the nine different possible B-wedge types. The uncertainties are very high, much as in the projection of future fossil fuel supplies. *Figure 5.3* is an attempt to display this uncertainty – which is now predominantly due to uncertainty in future US and world policy on carbon negativity.

This Section's often repeated value of 4 B-wedges is meant to be a most likely upper limit value; the odds are even as to being higher or lower. But this graph is also meant to say that under those same optimum policies, the chance of getting at least 3 B-wedge is near certain – by 2050. Under these some optimum policy conditions, one might get to a mean of 3 B-wedges by 2040 and 2 B-wedges by 2030. Less-than-optimum policy would limit the 2050 total to only the middle (orange) curve or even the blue lowest curve.

62 http://kerry.senate.gov/americanpoweract/pdf/APAbill.pdf
63 http://www.biochar-international.org/sites/default/files/Biochar%20Misconceptions%20and%20the%20Science.pdf

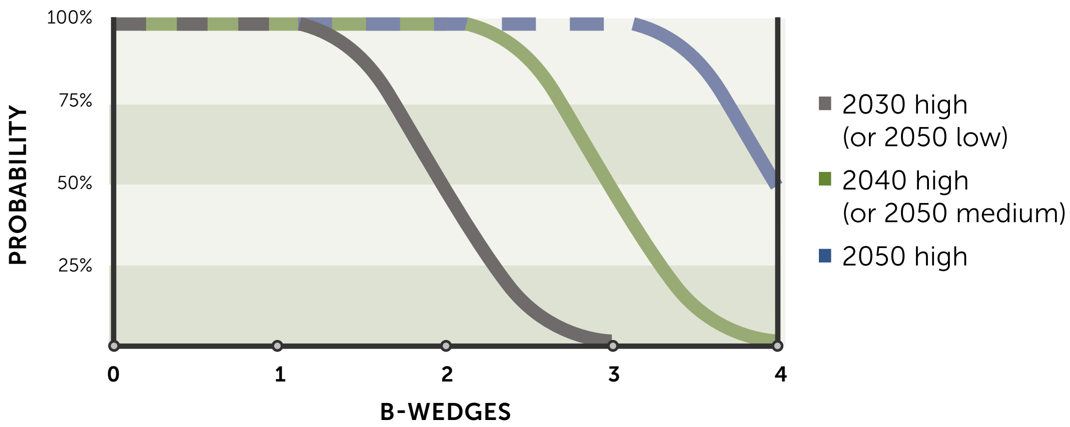

Figure 5.3. Three B-Wedge Scenarios

5.8 Closing Remarks

Biochar analysis remains a very complicated topic. Despite enormously rapid progress over the last few years, important unanswered questions abound. There is ignorance about Biochar's existence by most policy analysts – even those active in energy, climate and soil areas. This should not be surprising, given almost no governmental funding.

Nevertheless, we conclude that Biochar could become THE major carbon-negative technology in both the United States and the world. It also seems likely to become one of the top three carbon-neutral supply sources as well (supporting solar and wind to be even larger than without Biochar). No major impediments for large scale introduction for Biochar have surfaced – save that of adequate incentives. Although there are upper land limits to its introduction, those limits do not now look insurmountable. The necessary biomass resource (about 4 B-wedges in the US and 40 B-wedges globally) seem to be available, if the political will is there.

Thanks are especially offered to Mr. Jonah Levine who suggested the topic and provided editorial guidance. Also thanks to many Biochar friends, especially those at the Yahoo "Biochar-policy" list, and those met at several Biochar conferences over the past three years. who have helped hone the ideas expressed here.

BIOCHAR RELEVANCE IN GHG MARKETS IN: CARBON MARKET IMPLICATIONS FOR BIOCHAR

ADAM REED, JD
Adam.Reed@Colorado.edu

Carbon Market Basics: The What And The Why

A carbon market is a trading system where entities – individuals, corporations, or governments – trade entitlements to emit climate-forcing greenhouse gases such as carbon dioxide. A carbon market develops because a group of entities agrees to collectively limit, or "cap," their total emissions of greenhouse gases (GHG) in order to mitigate global climate change. Realizing that reducing emissions may be lower cost for some entities than for others, the agreement permits trading of emissions entitlements – also known as "carbon allowances" or "carbon credits" – so that entities with high emissions reduction costs may purchase entitlements from those with lower costs. In this way, "cap & trade" carbon markets are thought to drive down the costs of reducing emissions, because entities with aging, expensive-to-retrofit equipment may purchase emissions reductions from entities with more liquid capital that invest in cleaner technology. Carbon markets also act as a means of transferring wealth from entities using "dirtier" equipment and practices to entities using "cleaner" equipment and practices, both through the trading itself and through the initial auctioning of allowances, which generates revenue that governments may then redistribute to other activities. (CBO 2009, IEDC 2009).

Carbon markets may be mandatory or voluntary. A carbon market created by a government or group of governments, and which requires all emitters within particular sectors to play in the market, is known as a "compliance market." Examples include the Kyoto Protocol to the United Nations Framework Convention on Climate Change (hereinafter "Kyoto"), the European Union Emissions Trading System (EU ETS), and the Regional Greenhouse Gas Initiative (RGGI) in the Northeastern United States. (Lokey 2009, IEDC 2009, CBO 2009). Markets created by other entities that do not require economy-wide participation are known as "voluntary markets." Examples of these include the Chicago Climate Exchange (CCX), the Voluntary Carbon Standard (VCS), and the Climate Action Registry in California. (CBO 2009). Compliance markets command significantly higher prices for emissions entitlements than do voluntary markets, because failure to meet one's obligations in a compliance market often comes with regulator-imposed penalties. (Lokey 2009).

Carbon markets are often "nested" within each other. Compliance markets in particular tend to align themselves according to a series of coordinating authority levels. States will "nest" domestic compliance markets within an international market in order to simplify compliance for covered entities and in order to allow its entities to sell emissions entitlements on a global carbon market. Thus the EU ETS is an EU-wide market that is designed to allow the member states to meet their goals under the Kyoto Protocol. (Lokey 2009). In the event that the United States Congress were to pass the American Clean Energy & Security Act (ACESA), which would

create a US-wide compliance carbon market, the US would almost certainly seek to align the targets and goals of ACESA to an international agreement, likely the successor to the Kyoto Protocol, which expires in 2012. Voluntary markets may also nest themselves within compliance markets. The CDM Gold Standard, for example, is a voluntary carbon offset market that enforces higher sustainable development criteria than the general CDM compliance market, and demands a higher price for its offsets, which are sold to discriminating buyers. (Gold Standard 2009). A party could purchase a CDM Gold Standard credit and use it for compliance purposes, with the added ability to publicly state that its purchases are supporting sustainable development as well as emissions reductions. Other voluntary markets, such as the CCX and VCS, exist independently of compliance markets, and specialize in the trading of credits that are not yet recognized or available through compliance markets. (Lokey 2009).

Nuts And Bolts: What Gets Traded In A Carbon Market, By Whom, And When?

Nearly all emissions entitlements share the same fundamental identity:[64]

1 emissions entitlement = 1 metric tonne of carbon dioxide equivalent (tCO_2e)

Different markets have different terms for an entitlement. Kyoto uses Assigned Amount Units (AAUs) for developed country allowances, and Certified Emission Reductions (CERs) for offsets generated in developing countries through the Clean Development Mechanism (CDM). The EU ETS trades EU emission Allowances (EUAs), which are quantitatively equivalent to AAUs. CERs may count as EUAs as well, provided the country in question hasn't exceeded the number of CERs allowed for use under its "supplementary clause" in its EU ETS agreement. Other regional markets have similar arrangements. (Katoomba Group 2010).

Like any other market, a carbon market consists of buyers and sellers. Buyers "bid" (suggesting prices at which they would purchase a right to emit) and sellers "ask" (suggesting prices at which they would sell a right to emit). If a bid matches an ask and both parties agree to move forward, a price is set and a transaction is made, either for the entitlement itself or for the right to transact at a future date at a set price (an "option"). The price that the parties agree to and subsequently transact using at a given point in time is known as a "spot price." In general, buyers are either parties that need to purchase emissions entitlements to satisfy their carbon obligations or traders attempting to profit from a future rise in the price of entitlements. Sellers are either traders, parties with excess emissions that they do not need to meet compliance obligations, or developers (funders, operators, aggregators, or a host of other sub-parties) of carbon offset projects. Many exchanges on a carbon market are facilitated by carbon brokers, who are analogous to stock market brokers, but have specific expertise in carbon commodities. (e.g., Brokers Carbon 2008).

Emissions entitlements may be traded at any time, but all capped entities must hold a sufficient number of emissions entitlements to account for actual emissions at the end of a compliance period. This varies by market. Parties to Kyoto, for example, must hold the correct number of allowances at the end of 2012. The EU ETS has two compliance periods, one from 2005-2007, and another from 2008-2012. The CCX's latest compliance period ends in 2010. RGGI has a compliance period that ends in 2014, and annual compliance periods for 2015-2018. (Katoomba Group 2010). The end of a compliance period can result in dramatic spikes or falls in the price of entitlements, as entities must make last minute purchases or sales in accordance with their actual emissions. (Lokey 2009).

Carbon Offsets, An Important Subspecies Of Emission Entitlement

Carbon offsets are tradable emission entitlements created by entities that are not subject to GHG emissions limitations. Offsets exist for two reasons. First, it is prohibitively expensive for regulators to directly track and limit emissions from certain kinds of distributed sources: farmland, forests, livestock operations, vehicles, and many others which, despite their small size individually, contribute mightily to overall GHG emissions.

62 Some carbon markets use multiples of this identity. The CCX, for example, uses the Carbon Financial Instrument (CFI), which equals 100 tCO_2e rather than 1 tCO_2e.

It is far easier to measure emissions from large emitters, such as power plants, where a gauge can be installed in an emissions pipe. Second, despite the difficulties of measuring emissions from distributed sources, many of them can achieve emissions reductions more cheaply than large emitters. Offset methodologies allow such non-capped, distributed entities to quantify and verify actions taken to reduce their emissions, and then sell the verified reductions to capped entities in need of extra emissions entitlements. In the absence of offsets, capped emitters above their own emissions thresholds must purchase allowances from other capped emitters. Offsets offer the covered over-emitter a cheaper alternative: purchase offset credits.

The US Congressional Budget Office estimates that the use of offsets within the national cap & trade system contemplated under ACESA would reduce the net costs of compliance in 2030 from $248 billion to $101 billion (estimates are in 2007 dollars), a reduction of about 60 percent. Under such a scheme, **CBO estimates that 52 percent of required emission reductions from ACESA could be met by a combination of domestic and international offsets by 2030.** (CBO 2009). The Clean Development Mechanism (CDM) is Kyoto's offset system, wherein offsets generated in non-capped developing countries are referred to as Certified Emission Reductions (CERs), and may be used by capped developed countries for compliance. CERs may also be used to satisfy EU ETS obligations for capped emitters. (Lokey 2009).

Carbon offsets may be generated through land management practices in both the agricultural and forestry sectors, as well as through a range of other methods, but a number of monitoring and verification challenges must be addressed through an offset verification or certification scheme. Land management practices such as low- or no-till agriculture can remove carbon dioxide from the atmosphere and store it in plants or soils. Offsets of any kind require substantial care in the design of verification schemes, and land management offsets require even more care. This is because a capped entity is already monitoring its emissions, and so long as its emissions are below the entity's allocation and the monitoring equipment is functioning properly, it is not the regulator's concern how the emissions were reduced. A non-capped entity claiming emissions reductions for offset certification presents a different set of challenges to the regulator. When the emissions reductions are attributable to land use practices, additional challenges such as permanence concerns and increased leakage risk arise. (CBO 2009, Olander & Galik ##). These challenges are discussed below.

- Did the entity really do anything differently, that they would not have done anyway? This is the additionality question. A true offset must come from an activity that would not have occurred under a business-as-usual scenario. Additionality can be proven in any number of ways, and the allowable methods depend on the carbon market into which the offset is to be sold. Some additionality arguments (any *one* of which might be used to prove additionality, depending on the offset certification scheme) include:
  - » Activity not mandated by other laws;
  - » Activity reduces GHGs after a particular date;
  - » Activity is not common in the industry;
  - » Activity is not profitable (or is less profitable than another regular activity) without carbon credit revenue;
  - » Activity is the first of its kind;
  - » Activity is subject to social, political, institutional, or technical barriers; or
  - » Many others.

- Can we reliably measure the emissions reductions claimed by the offsetting entity? This is the **quantifiability** question. The measure of how many emissions are being abated by the activity in question is a complicated one, and is easily manipulated by a number of factors: selection of the baseline, determination of the life cycle analysis boundary, etc. Emission reductions can be quantified through a calculation that models a reasonably well- understood process, or might be measured directly through sampling. Most offset schemes require a third party to verify emission reductions before credits are awarded, often on an annual basis.

- Are the emissions offsets simply delaying the release of GHGs, or are they permanent? This is the **per-**

manence question. Land management offsets are particularly problematic here, as carbon stored in soils or trees can be released if the soils are reverted to till-intensive agriculture or if the trees are cut down and decompose. Fire, pests, and other environmental changes are of concern as well. Offset programs may address permanence in a number of ways:

- » Requiring legal assurances that the carbon will remain stored, such that if reversal occurs the project developer must sequester more carbon or buy offset credits to cover her position;
- » Assigning expiration dates to each offset;
- » pooling a portion of credits from each project into a reserve, to be used in the event that any one project's offsets are reversed; or
- » requiring project developers to deposit money into a regional shared liability fund that will pay out to any project reversed by an act of nature.

- Is the activity that allegedly reduces emissions in fact merely pushing those emissions to another location, or another economic sector? This is the **leakage** question. Again, land management presents special challenges: practices that wholly displace emissions generating activities to other areas are not providing any net savings in GHG emissions. Leakage is extremely difficult to control, and is often beyond the abilities of the offset generator to manage. Offset programs may choose to "discount" carbon credits to account for unavoidable leakage. This process involves awarding the developer only a portion of the emissions reductions achieved, on the assumption that a percentage of them are probabilistically likely to be reversed. (CBO 2009).

Offset verification schemes (for voluntary markets) and certification schemes (for compliance markets) allow offset generators to prove the legitimacy of an emissions-reducing activity through the designation of "methodologies" or "protocols" specific to that activity type. A typical methodology will require an offset generator to prove the additionality, quantifiability, permanence, and non-leakage of a particular project or set of similar projects before carbon credits are awarded. This process can be long, arduous, complicated, risky, and extremely expensive. Lokey estimates that certifying a CDM project can cost between USD 58,000 and 500,000 per year, depending on the complexity of the project. (Lokey 2009). Even after all the money and time has been spent on offset certification, there is still a risk that the project may not be awarded credits. Cost and risk are even higher in the absence of an established methodology, because the developer must propose a new methodology that the CDM Executive Board might accept, reject, or modify significantly before acceptance. (Lokey 2009). A schematic of the CDM process is included below for illustrative purposes. In the event that ACESA becomes law, and a U.S. carbon market is created, the US Environmental Protection Agency and US Department of Agriculture will have joint responsibility for establishing offset verification procedures for the market. (CBO 2009).

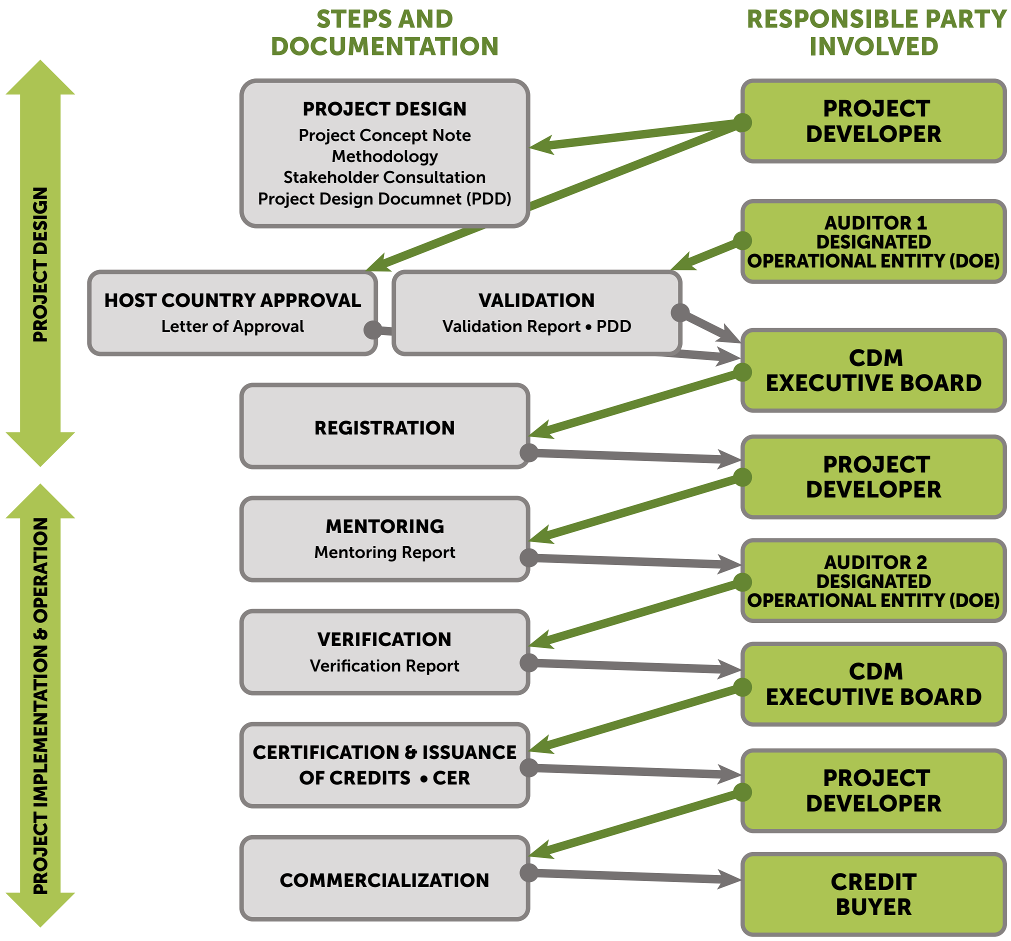

Figure 1. CDM Project Cycle (Credit to: Carbon Association Australasia Ltd.[65])

Soil carbon-based offsets often provide too few emissions reductions to be significant on a per-farm basis. Purchasers of carbon offsets generally seek packages of 50,000-100,000 tonnes of emissions per transaction, while the typical farm may only generate 1000 to 2000 tonnes of emission reductions. Moreover, transactions costs would quickly overwhelm the carbon revenue from such a farm, even if buyers were interested in such packages. Thus it is likely that carbon aggregators – firms that collect carbon emissions from multiple projects and package them together for sale on the market – will be critical parties in the marketing of soil carbon-based offsets. (Haugen-Kozyra 2007).

The Clean Development Mechanism offers several flexible certification and bundling mechanisms for smaller scale or distributed activities. CDM's Small Scale (SS) and Programme of Activities (PoA) processes provide simplified (though still quite complex) procedures and reduced transaction costs by grouping projects under a single procedural umbrella. Notably, PoA allows offset projects to team up with government or NGO-based grant programs without raising additionality concerns. PoA also allows emission reductions to be calculated and verified through sampling and extrapolation techniques, rather than requiring direct measurement or estimation for each individual sub-activity. Neither PoA nor SS are widely used at present. (Lokey 2009).

65 http://www.caaltd.org.

Major Carbon Markets

The Kyoto Protocol to the UNFCCC: Emissions Trading and the CDM Market

Kyoto is a compliance market covering emissions from every developed country in the world, with the notable exception of the United States. Developed countries (called "Annex 1" countries in the cryptic language of the treaty) must cut overall GHG emissions to roughly 5% below 1990 levels. Actual national targets vary. GHGs included in Kyoto are CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Kyoto's compliance period runs from 2008-2012.

Kyoto signatories are allowed to trade emissions allowances for compliance purposes, and may use offsets generated through jointly implemented projects between two Annex 1 countries or through projects implemented in developing countries. The former mechanism is called "Joint Implementation" (JI) and its units of exchange are Emission Reduction Units (ERUs). The latter mechanism is the Clean Development Mechanism (CDM), which generates Certified Emissions Reductions (CERs).

Kyoto allows for the generation of offsets under CDM or JI for afforestation or reforestation of land that was not forested in 1990. So-called Land Use, Land Use Change and Forestry (LULUCF) offsets may only account for a 1% decrease in a capped country's total emissions. To manage permanence concerns, Kyoto allows such projects to earn either temporary CERs (tCERs), which must be reissued every 5 years, or long-term CERs (lCERs), which have 20 year life spans and 5 year re-verification intervals. The UNFCCC has approved 11 LULUCF methodologies, all of them related to reforestation or afforestation.

Parties that have ratified Kyoto must establish their own compliance regulations and domestic or regional trading schemes. The European Union, for example, opted to form a regional compliance market, the EU Emissions Trading System (EU ETS), so that its member states could meet their Kyoto commitments. Such domestic or regional systems place caps on individual companies that have compliance obligations to the State that are analogous to the commitments of the State to the Kyoto Protocol.

Kyoto's offset markets (both CDM and JI) produced 832 $MtCO_2e$ of reductions in 2007, valued at USD 13.4 billion. The quantity of reductions was a 43% increase from the previous year. The CDM market in 2007 accounted for 87% of the volume of the overall project-based offset market. The average price for a project based CER was USD 13.60/tCO_2e in 2007.

Since 2008, considerable efforts have been taken to make projects aiming to avoid deforestation (entitled "Reduced Emissions from Deforestation and Forest Degradation (REDD)") eligible for Kyoto offset credits. These credits currently trade on the voluntary carbon markets. (Katoomba Group 2010).

EU Emissions Trading System

The EU ETS includes the 27 member states of the EU, as well as Iceland, Lichtenstein, and Norway. National governments create National Allocation Plans (NAPs), which set emissions targets for the country and allocate allowances to domestic emitters, including energy companies, ferrous metals, pulp and paper, and building materials. EU ETS's current compliance period runs from 2008-2012. A linking directive allows emitters to utilize CERs and ERUs generated through Kyoto's CDM and JI to meet their domestic compliance obligations, though forestry projects are not allowed. In 2007, 2061 $MtCO_2e$ traded on the ETS, at a total value of USD 50.1 billion. (Katoomba Group 2010).

Chicago Climate Exchange (CCX)

The Chicago Climate Exchange is a legally binding, voluntary market for North America and Brazil. Members join the CCX voluntarily and sign a legally-binding agreement to reduce emissions. The CCX trades Carbon Financial Instruments (CFI), one of which equals 100 tCO_2e, either allowance-based or offset-based. Offsets may

only account for 4.5% of members' emissions. CCX has approved offset methodologies for, agricultural soil carbon, rangeland soil carbon, energy efficiency and fuel switching, forestry carbon (but only for afforestation, long-lived wood, and managed forest projects),renewable energy, among others. CCX had more than 350 members in 2008, including both significant direct emitters, negligible direct emitters such as office-based businesses, and offset developers and aggregators. CCX traded 22.9 million tCO_2e in 2007, at a market value of USD 72.4 million. (Katoomba Group 2010).

Regional Greenhouse Gas Initiative (RGGI)

RGGI consists of Connecticut, Delaware, Maryland, Massachusetts, Maine, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. It establishes a regional carbon market, requiring states to stabilize power sector emissions by 2014, than reduce by 2.5% every year from 2015 to 2018. The first compliance period began in January 2009. Offsets from both within and outside of the member states, including afforestation but not including agricultural soil carbon projects, are conditionally allowed according to a sliding scale percentage that is dependent on the price of allowances. (Katoomba Group 2010).

Oregon Standard

The Oregon Standard requires new power plants in the state of Oregon to reduce CO_2 emissions 17% below the most efficient combined cycle plant. Offsets are allowed. (Katoomba group 2010).

California Global Warming Solutions Act (AB 32)

AB 32's cap & trade system covers about 85% of California's emissions, and provides linkage to the Western Climate Initiative. Offsets from forestry and agriculture are allowed. Implementation of AB 32's many action items began in 2010. (CARB 2010).

Western Climate Initiative (WCI)

WCI consists of the U.S. states of California, New Mexico, Oregon, Washington, Arizona, Utah, and Montana and the Canadian provinces of British Columbia, Manitoba, Quebec, and Ontario. It aims to reduce emissions from members to 15% below 2005 levels by 2020. WCI's first phase will begin in 2012, and its second phase, covering further sectors of the economy, will begin in 2015. Limited use of offsets is permitted. By 2012, WCI will cover approximately 886 $MtCO_2e$ per year. (Katoomba Group 2010).

Midwestern Regional Greenhouse Gas Reduction Program (MRP)

MRP consists of the U.S. states of Iowa, Illinois, Kansas, Minnesota, Wisconsin, and Michigan and the Canadian province of Manitoba. Indiana, Ohio, South Dakota, and Ontario are observers. MRP will begin in 2012 with a regional cap & trade system affecting approximately 1107 $MtCO_2e$ per year. (Katoomba Group 2010).

The Climate Registry

The Climate Registry is a "new governance" multi-state, tribal, and company effort to improve the quality and transparency of emissions data through reporting, accounting, and verification. It includes the District of Columbia and 39 U.S. states, 3 Native American tribes, 6 Mexican states, 8 Canadian provinces, and more than 200 private companies. The Registry is not a carbon market, but its presence is a major facilitating factor for the development of a future carbon market. (Katoomba Group 2010).

UNCERTAINTY IN CARBON MARKETS

At present, carbon markets are rife with macro-scale uncertainties that go well beyond offset project-specific risks. These uncertainties, which can destabilize the price of offset projects that produce emissions reductions well into the future, are detailed in this section. While the uncertainties are substantial, they are not necessary fixtures of a carbon market per se. Rather, they all stem from the political uncertainties surrounding the establishment of carbon markets as permanent fixtures of the global financial system. If politicians succeed in establishing a functioning, mandatory, long-term global carbon market, many of these uncertainties will disappear or be greatly reduced. On the other hand, to the extent that emissions agreements continue to have short life spans and only near-term targets, these uncertainties will persist.

No country has committed to emission reductions beyond 2012. In two years, the driving force behind the establishment of both international and domestic carbon markets will evaporate. (Lokey 2009). Efforts to provide a new climate treaty to contain emissions post-2012 have thus far been unsuccessful. (Doyle & Wynn 2010). Countries will meet again at the end of 2010 to attempt another round of negotiations. In the absence of binding emissions targets, compliance carbon markets will collapse. This has a dramatic effect on the current pricing of offset credits that will be generated post-2012 in multi-year offset projects: post-2012 CERs are worth very little in comparison to pre-2012 CERs. (Lokey 2009).

The United States is the present "elephant in the room" of the global carbon market. As both the largest developed country emitter of GHGs, as well as the only developed country in the world that is not a party to the Kyoto Protocol, its actions have massive impacts on the carbon market. Entry of the United States into a binding international agreement, backed up by a domestic carbon market such as that contemplated in ACESA, would significantly increase global demand for emissions offsets. (Lokey 2009, CBO 2009).

Advanced developing countries (ADCs) will be the "elephants in the room" in the coming decades. As rapidly developing countries such as China, India, and Brazil become developed, they will eventually need to make the switch from producers of global carbon offsets to capped, Annex 1 type countries. No one is certain exactly when or how this will happen. When it does happen, demand for emissions offsets will increase due to the need of ADC-based entities to reduce emissions to comply with new caps. There is a possibility that the successor agreement to the Kyoto Protocol will begin taking steps toward this transition through the utilization of carbon intensity targets, which cap and reduce the GHG emission per unit of GDP ratio rather than overall emissions. Carbon intensity targets would allow ADCs to continue to raise their overall emissions in pursuit of development, but would aim to reduce the rate of emissions per unit of development (Herzog 2007). It is unclear whether ADCs would be able to use carbon offsets to meet carbon intensity targets.

The number of excess allowances is unknown in a carbon market until the near end of a compliance period. Because the internal cost of emissions reductions by covered entities is difficult to predict in the absence of historical data, it is also difficult to predict whether a compliance market will have a lot of excess allowances or very few allowances for purchase as the compliance period draws to a close. As the number of allowances becomes known, the price of offsets can plummet or skyrocket accordingly over a very short time period. (Lokey 2009).

Offset price uncertainty can cause gaming behavior by offset producers. Farmers and foresters expect that GHG prices will rise over time, provided there is a binding emissions treaty, and so are likely to delay mitigation practices until prices rise so as to maximize GHG payments. Thus at relatively low GHG prices (<$5/t$CO_2$e), EPA estimates that soil-based carbon sequestration and forest management will be the dominant mitigation strategies. At mid-level prices (>$15/t CO_2e), afforestation becomes the dominant strategy. In either case, by 2055, EPA estimates that afforestation and sequestration become less feasible due to carbon saturation, harvesting, and practice reversion. At $30 and $50/t$CO_2$e, biofuels dominate the mitigation scene.

Analysis: Biochar And Carbon Markets

This section discusses the implications of carbon markets for biochar revenue models. It does ***not*** discuss the potential impact of biochar on carbon markets, were production of biochar to reach such a massive scale that it began to alter the behavior of carbon markets themselves. Such a development is entirely possible, but analysis of such a development is beyond the scope of this brief and largely qualitative overview.

Biochar feedstock sourcing, production, and application of the product to soils all involve activities that reduce GHG emissions. However, generating a valuable carbon offset from one of these activities is not so simple as demonstrating that emissions have been reduced. Certification of an offset will require proof of the activity's additionality, quantifiability, permanence, and non-leakage. Biochar related activities under consideration as potential candidates for carbon offset generation include: (Gaunt & Cowie 2009)

1. Avoided emissions from conventional management of feedstock biomass – i.e., feedstocks used to produce biochar are not left to decay.
2. Production of electricity, syngas, bio-oils, or on-site thermal energy that reduces electricity consumption or adds renewable energy onto the electricity grid.
3. Carbon captured and stored in biochar through the production process.
4. Agricultural carbon sequestration through application of biochar to soils.
5. Avoided emissions of N_2O and CH_4 from soil through application of biochar.
6. Displaced fertilizer and agricultural inputs (such as water) from improved soil productivity
7. Enhancement of agronomic efficiency and yield.

These candidates can be divided into two fundamental types. Activities 1-3 can be considered pyrolysis facility-level offsets, while activities 4-7 can be considered biochar application-level offsets. This section addresses issues related to each type separately. It is important to remember, however, that claiming a carbon offset at one level in the biochar supply chain may preclude the claiming of an offset at another level. Intelligent structuring of carbon offset generation will maximize offset generation while reducing the often-high transactions costs of certifying the offset. Biochar producers and biochar appliers have different strengths and weaknesses with regard to different offset types. Additionally, the existing structure of carbon offset markets and likely future developments should inform the structuring of biochar carbon offset generation, so as to reduce administrative costs, uncertainties, and bureaucratic delays.

Pyrolysis facility-level offset activities may generate carbon offsets from the activity of sourcing material for and producing biochar itself. While the methodologies for quantifying displaced emissions and captured carbon through biochar feedstock sourcing and production are generally feasible (Gaunt & Cowie 2009), it is not yet clear how these producers will handle issues of additionality, permanence, and leakage.

Generating offsets through the production of renewable electricity, syngas, bio-oils, or on-site thermal energy from biochar production is relatively straightforward, and every carbon market has existing methodologies for renewable energy production that would be close analogues. The same is generally true for avoided landfill emissions or manure emissions from sourcing feedstocks for biochar.

Regarding the generation of offsets for carbon captured in the biochar itself, a producer-captured carbon offset will require approval of an entirely new methodology based on an offset type that certification authorities have never encountered: a carbon-negative production process. The process of introducing and approving a new methodology for a carbon-reduction activity is arduous, expensive, and full of uncertainties. Biochar producers considering such a strategy should carefully consider the risks and high transaction costs of shepherding a proposed methodology through an offset authority before investing significant capital. As explained below, producers may be able to derive similar carbon value from their operations with lower transaction costs by fitting biochar into modifications to existing agricultural and silvicultural soil-carbon methodologies.

For all three pyrolysis facility-level offset types, additionality may be a major barrier to offset methodology validation. This is the case wherever the pyrolysis facility was already operating profitably without carbon revenue. In such a case, even if the pyrolysis facility is engaging in activities that reduce GHG emissions in the ways described above, it may not be allowed to certify offsets under schemes requiring financial additionality because the activities would have happened even without the carbon revenue, and are thus "business as usual." Permanence and leakage may also be difficult to handle if the biochar producer will not be the party applying the product, particularly since some offset certification authorities require actual sampling and on-the-ground monitoring to ensure permanence. But to the extent that biochar appliers may invest in monitoring and verification activities to capture their own carbon offsets, this difficulty will be mitigated.

Should the transactions costs and risks of certifying carbon offsets at the pyrolysis facility level prove too great, biochar producers could choose to deal only indirectly with carbon markets. Most biochar producers would not burn significant enough amounts of fossil fuels to be regulated entities under an emissions cap, thus they would neither purchase nor sell emissions allowances. Nor do biochar producers and biochar equipment manufacturers necessarily need to be generators or sellers of emissions offsets. This is because a) existing methodologies for verifying carbon offsets from soil carbon projects are already focused on the agricultural sector rather than the agricultural inputs manufacturing sector, and b) biochar appliers would already be in a position to ensure the permanence of a soil management project using biochar at the least cost. Of course, this distinction breaks down in the event that a farmer purchases biochar equipment and produces her own biochar for application on her own land. In such a case, the biochar producer might deal directly with the carbon market, but in his capacity as a farmer, not as a biochar producer.

Even in the absence of biochar producers as players in the carbon market, carbon markets can affect the biochar market by creating demand for biochar products or biochar-producing equipment among parties that are generating carbon offsets through agricultural and soil operations, and are using biochar to do so. Biochar producers and biochar equipment manufacturers donot have to generate or sell carbon offset credits themselves in order to derive value from the carbon market. Rather, such entities could experience increased agricultural sector demand for their products. A farmer, for example, might purchase biochar and biochar-producing equipment as part of a scheme of operations to generate carbon offsets that the farmer would then sell to a carbon credit aggregator, who would in turn roll the emissions offsets from hundreds of such farms into a suitable instrument for sale on in the carbon market.

However, even if biochar producers are beneficiaries rather than players in the carbon offset market, this does not abdicate the biochar community's obligation to understand and plan for carbon market opportunities. This is because the ability of an agricultural sector actor to quantify and certify carbon offsets from particular agricultural activities is dependent on the existence of a recognized carbon-reduction pathway or methodology by the offset certification authority. The biochar community should engage with agricultural and soil carbon offset producers and aggregators of carbon offsets in order to provide carbon market mechanisms, pathways, and methodologies to recognize the GHG-reduction aspects of biochar when used by agricultural and soil operations. **In the absence of streamlined, standardized procedures for the creation of biochar-based carbon credits, the transactions costs for such operations may exceed their revenue benefits for the farmer.**

Proving *additionality* for biochar-based land management practices is likely to be unproblematic. Because fossil-fuel based fertilizer is significantly less expensive than biochar, a farmer would likely not use biochar as a soil amendment unless the additional carbon revenue could make biochar cost-equivalent to business-as-usual fertilizer. Such an argument shows *financial* additionality, one of the strongest types of additionality. Simply put, in the absence of carbon revenue, farmers would not use biochar. Thus credits granted for biochar application to soil are producing real emissions reductions that would not have occurred in the absence of the carbon market.

Quantification of reductions for biochar-based land management practices will require new biochar-specific calculation methodologies, that could be incorporated into existing land management offset protocols. Such a strategy would significantly reduce barriers to the acceptance of a new methodology, and reduce the number of procedural hurdles that would need clearing in each carbon offset market. In addition to the sequestration of carbon in soil through biochar applications, a methodology should also account for displacement of nitrogen fertilizers, which release N_2O, a potent GHG, under a business-as-usual scenario. More complex methodologies might attempt to include emissions savings from fuel-switching and process efficiencies in the biochar production process, though this would be challenging to track where the biochar is purchased rather than produced on-site by the farmer or forester. Reduced off gassing from soils; reduced dead zones in ocean deltas; increased biomass production as a result of biochar additions; and other GHG benefits from biochar are all possible but must be quantified to an acceptable level.

Use of biochar in agricultural soils likely provides carbon sequestration with permanence features superior to other kinds of land management offsets. Most land use offsets are at risk of impermanence because a change in land management practices may inadvertently release the stored carbon represented by the offset, through tilling, for example. Because biochar traps carbon chemically, changes in land management practices are unlikely to affect the sequestration properties of the char. The biochar community should place considerable resources into educating offset granting authorities about this aspect of biochar, and proving resistance of biochar/soil mixtures to fire and other natural hazards that might result in a release of stored carbon. Where offset verification and certification authorities utilize credit discounting, expiration dates, carbon credit pooling requirements, or required contribution to a shared liability fund, biochar advocates might take measures to reduce or eliminate the application of such schemes to biochar-based soil carbon offset projects.

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