Biochar 101: An Introduction to an Ancient Product Offering Modern Opportunities

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EXECUTIVE SUMMARY

Biochar is a term for charcoal which is used for biological ends, as opposed to heat. It is most commonly used as a soil amendment, but has significant potential as a way to sequester carbon long-term and may be a lower-cost alternative to activated carbon. South American civilizations used biochar for intensive agriculture at least 8000 years ago and recent research shows that some of it is still in the soils. Despite this long history and success in increasing soil carbon, biochar remains little used in modern agriculture. Biochar's chemistry varies depending on the feedstock used and the specific processing conditions used to create it. That variability, combined with the complexity and variability of soils in general, makes biochar as a soil amendment more challenging to use than modern homogeneous fertilizers and other amendments.

There is considerable research ongoing world-wide aimed at exploiting biochar's demonstrated success in the Amazon Basin, but this research is largely focused on narrow applications or specific benefits such as increased water retention or making nutrients more available over time. With the need for global carbon sequestering strategies, further research into the wide-scale uses of biochar as a soil amendment and as a toxin adsorbent are needed, as well as quantification of its carbon sequestration capability.

Biochar is a product with clear benefits, but with many questions yet to be answered. It is a value-added product made from low value feedstocks. The feedstocks for biochar are renewable natural resources but produce varied chemistries. Biochar's history of soil improvement is unmatched in terms of longevity, but the mechanism of its success is difficult to apply broadly. Biochar sequesters carbon; however, the precise balance depends on many variables. Despite the length of time biochar has been used beneficially, it remains a largely unknown product commercially.

Considerable research remains to be done to understand how biochar is produced and how it works. Yet in a period now where every carbon sequestration opportunity is being explored, biochar's time may have come again.

WHAT IS BIOCHAR?

Biochar is a term for charcoal that is used for biological ends, such as a soil amendment, as opposed to heat.[1] Biochar can also be used as a filtration element to bind toxic chemicals and heavy metals. Biochar is made from biomass via pyrolysis, an irreversible thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen. The processing technology can range from small-scale and simple to

[1] Charcoal used as a fuel for heat or energy will eventually be completely combusted, unlike biochar.

industrial and complex. Production systems can be designed to capture by-products like process heat, syngas[2] (synthesis gas), liquid fuels, and wood vinegar.

The first reference to biochar's "discovery" was by a European geologist in 1870, noting areas in South America with curiously productive soils—compared to the typically shallow, acidic soils capable of only short periods of productivity. Archeological studies have identified biochar enriched soils in the Amazon Basin from 8000BC, and anthropological analysis has determined that biochar-enriched soils may have been used to create regions of extremely high productivity to support successive cultures in regions of South America with relatively high populations. In many areas of the Amazon Basin there still remains a carbon rich soil mix referred to as "terra preta." (Mann, 2011.)

Figure 1. Masonry Charcoal Kilns in Idaho ca:1886

Source: National Park Service

The unusual productivity of terra preta sites is due to the organic carbon (biochar) component – as high as 9% carbon – compared to the surrounding areas of 0.5% or less. The organic carbon content in soils has long been known to be a governing factor in soil's ability to hold water, increase nutrient availability, and improve microbial and fungal populations. Soil scientists have been studying terra preta since the 1960s, but, until recently, there has been little interest from conventional agricultural producers. In contrast, there has been considerable interest in biochar for many years among sustainable agriculture advocates and managers of organic production systems. Some practitioners produce biochar for themselves—with excess for sale—and incorporate it into the soil.

Figure 2. Exeter Retort, UK

Source: www.biocharretort.com

Historically, the production of biochar and charcoal was done in covered pits, beehive-style kilns, and large piles, resulting in mostly anaerobic conditions (Figure 1). These production systems were inefficient, polluting and labor intensive. These un-sophisticated systems were also largely uncontrollable. More modern methods, using kilns and retorts with manual or computerized control systems, produce charcoal primarily for heating, and more recently for soil amendments (Figure 2).

Modern units are designed to quickly heat biomass to a temperature where syngas is driven off and returned to the combustion chamber, which then provides an ongoing fuel source for the remainder of the burn.[3] The air/fuel mix is carefully controlled to minimize smoke (particulate pollution) and maximize yield.

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[2] Syngas is the uncombusted volatile gas driven off the biomass by pyrolysis. In the typical biochar retort, 25% of the syngas is used in the combustion process and 75% of the BTUs are "available" for collection or further use. Syngas, or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide. The name comes from its use as intermediates in creating synthetic natural gas (SNG) and for producing ammonia or methanol.

[3] See the Adam retort at http://www.char-grow.com/ and the Exeter mobile retort at www.biocharretort.com/.

Today, there is worldwide research and commercial development aimed at producing biochar from the incomplete combustion of woody biomass with the primary goal of generating renewable energy, including thermal energy and electricity, with a secondary goal of generating biochar as a marketable co-product.[4] Two recent proprietary studies in California and Louisiana have demonstrated that the potential economic value created in generating biochar as an additional marketable product can be the tipping factor in otherwise economically marginal wood to energy projects.

Since charcoal and biochar are produced under the same conditions—with the difference in the end product being particle size—there's an entrepreneurial opportunity for small to moderate sized producers to diversify and maximize their market coverage. Natural charcoal[5] producers can "produce" biochar from their fines and/or convert charcoal to biochar in a size reduction process (grinding) to capitalize on demand and pricing opportunities. However, to the extent that natural charcoal producers have variability in the feedstock they are using, they will have limited control over the characteristics of the resulting biochar. Challenges in biochar production also exist for biomass energy producers who tend to use a consistent feedstock but of relatively small size (e.g., chips or pellets) to insure combustion efficiency, largely ruling out production of a charcoal product.

WHY IS BIOCHAR IMPORTANT?

Biochar can contribute to: soil improvement, increased carbon sequestration, ground water retention, hazardous waste mitigation, land remediation, forest/biomass utilization, and renewable energy generation. Looking at each use individually reveals a multi-faceted product with considerable economic and environmental opportunities.

Soil Improvement

Research has consistently shown biochar to be a valuable soil amendment (Ulyett, 2014). However, research has been less specific on exactly how it is valuable. Biochar has been proven to increase organic soil carbon, increase water retention, make nutrients available over a longer time period, and sequester carbon. However, biochar affects different soils and crops differently and it's not a quick acting amendment. Both of these factors have hampered biochar's marketability for widespread use. Further experience, field trials, and research are expanding knowledge of how to use biochar most effectively. Currently, it appears that in order to be most effective biochar needs to be "site-based" and applied as part of a professionally supervised system.[6]

One of the major drawbacks of biochar—which paradoxically presents one of its greatest market opportunities—is the need to "charge" it prior to use. Biochar is a poorly-activated charcoal so in its natural

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[4] To maximize the economics of boilers, fuel is usually burned completely. In solid fuels the resulting waste is ash. If the process is managed to produce a by-product like biochar, the combustion is necessarily incomplete.

[5] Natural charcoal is in lump form and retains the shape of the parent material as opposed to briquettes, which is ground charcoal held into shape with binders.

[6] *Effective* biochar application is highly dependent on the soil chemistry and experiential analysis of its effects on similar soil chemistry and target crops. What works in Illinois won't necessarily work in Georgia or California, and may not even apply in the next county.

state it tends to absorb nutrients and inhibit fungal and microbial growth. Since activated charcoal is used for absorbing toxins, it is no surprise that biochar performs similarly. Consequently, users have found that biochar is ideally used as an ingredient in a compost or mulch mix. Compost is a vibrant host for nutrients, fungal and microbial activity. Biochar can be charged by mixing it with a compost tea, or by mixing it directly with compost, and letting it incubate for 7 to 21 days (depending on moisture and temperature).[7] Biochar also needs time to become host to its colony in order to ultimately become a useful soil amendment. This can be done in-situ, but will depress the availability of nutrients and micro flora in the soil for some period of time (some have experienced up to a two-year delay in the onset of positive results depending on soil and site conditions).

Although science has yet to determine exactly how biochar works to enhance soil properties, a market is developing among those who have read about the experiences or recommendations of others, and who are willing to try it themselves. Larger scale users, already familiar with and used to dealing with soil science and precise application technologies are more likely to await further evidence, or in some cases to work on development of higher-tech applications to the degree that economics support such efforts.

Carbon Sequestration and Renewable Energy Production

Biochar's use as a carbon sequestration tool is gaining in importance and could dominate its historic benefit as a soil amendment. While there remains considerable debate over the carbon neutrality of using biomass for electrical energy generation, biomass remains a potent source of high-temperature heat—which neither solar nor wind can easily generate.[8] Also not in dispute is the fact that plants are a renewable resource and can be used as fuel. Whether biomass fuels are universally carbon neutral or not, biomass fuels are cleaner than coal and come from renewable resources. Biochar can be an end product of a heat generation process, and can then be used to improve soils, mitigate pollution, and provide long-term carbon sequestration benefits. These advantages weigh in biomass utilization's economic and environmental favor.

There is the opportunity to address carbon sequestration goals and renewable energy targets through the use of biochar. Biomass can be combusted in a well-designed and -operated boiler[9], or pyrolized in a retort to generate syngas, while producing biochar, with the end result that a significant component of the carbon from the original plant is sequestered. In recent trials with a biochar retort in New Mexico, the process consumed only 25% of the energy in the feedstock. Seventy-five percent of the energy was recovered as syngas and used for downstream processes needing heat. In addition, 60% of the incoming feedstock was left as biochar (i.e., carbon), which was destined as a compost amendment and hazardous waste adsorbent. According to Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) if incentives for carbon sequestration become stronger, the justification for using biochar could shift further in its favor. If the cost of biochar drops as expected, the value of economic or regulatory incentives for its use would become drivers not currently part of biochar's "benefit portfolio" (Sohi, 2009).

[7] The process can be compared to making sourdough: you first mix yeast (a fungi) with sugar to "activate" the colony; then add flour and incubate to create a culture for making bread dough.

[8] High-temperature heat is a requirement for a wide variety of industrial processes, including the generation of base-load electricity.

[9] When biomass is completely combusted, as is typical in a boiler whether the output is process heat or heat to generate electricity, the residue is ash—with little-to-no carbon content. If the process is managed to produce biochar, the combustion is incomplete and the residue is biochar, which is 99+% carbon.

Water Retention

The carbon content in soils has long been known to be a governing factor in soil's ability to hold water. A USDA meta study (Jeffery, 2011) showed that increasing the carbon content of soils can increase water retention, but that the degree to which it is affected depends on the type of soil and the amount of carbon. Another study concluded that increasing organic carbon in sandy soils (technically, "coarse-textured" soils) has the greatest effect on water retention (Rawls, 2003). The dependent factor in this study was the initial carbon content, and the effect of adding biochar on the final soil carbon content was found to vary considerably depending on the specific soil type, crops planted, and nutrient balance. Yet another study concluded that soils enhanced with biochar could mitigate climate change effects by adding resilience to crops by increased soil water availability (Koide, 2015).

Hazardous Waste Mitigation and Land Remediation

Activated charcoal, also called activated carbon, is used to adsorb chemicals and toxins. The efficacy of activated charcoal is largely dependent on its particle size because the removal rate and amount is directly related to its surface area. "Activation" is the result of additional chemical and/or mechanical processes. Tests using un-activated biochar are being planned to temper liquid mine waste in Arizona, New Mexico, Colorado, and Montana to determine if the cost-benefit ratio is acceptable for wide-scale remediation and mitigation efforts.[10] By taking advantage of the various characteristics of biochar there is considerable potential for remediation of "waste" lands or brownfield sites. Especially in concert with herbaceous plantings, areas such as strip mines, severely eroded or desertified areas and toxic waste sites can be successfully remediated (Jinchun, 2013). Using biochar in bioremediation (i.e., hazardous waste treatment) and for filtration (as in water treatment facilities,) could offer significant opportunities but further research and cost-benefit analysis are needed. Biochar is not as effective as activated carbon (it has only 20 to 60% of the surface area), but it is cheaper to produce. Early trials to use un-activated biochar, and to activate biochar, have shown modestly positive results, but more and larger pilot projects are needed.

Woody Biomass Utilization

The forest sector is looking for additional ways to use woody biomass as an economic tool to bring more acres into active management and address challenges such as wildfire risks, excess fuel loading, habitat restoration, and forest health concerns. Small diameter trees as well as dead or dying trees have little or no value in most traditional forest product markets. These materials may provide benefits as feedstocks for renewable energy production; however, the costs of removing the materials often exceed the value provided in these markets. The addition of markets for co-products such as biochar may make these operations more economically viable. Economic opportunities may be further enhanced as the carbon sequestration benefits of biochar gain increased market value. Biochar has proven to be effective in sequestering carbon from a renewable raw material. How that raw material is processed and what other benefits can be derived from it without negating its positive carbon footprint is for another discussion; however, the potential for biochar to provide a tool to use low-to-no value woody biomass and inspire better forest management globally is notable.

[10] The "spent" biochar still has an energy value and can be smelted to recover metals, and/or to break-down some of the toxins adsorbed, as opposed to simply landfilling as hazardous waste.

EMERGING USE OF BIOCHAR, RESEARCH FINDINGS AND PRODUCTION METHODS

Table 1. Estimated Relative Cost of Biochar Production

30g drum retort	*$4.25/#*
500g TLUD-style retort	*$1.75/#*
Mobile 500G closed retort	*$2.00/#*
3MW Boiler	*$0.75/#*

Source: H.Groot

Interest in biochar has increased steadily over the last 20 years. The search for carbon sequestration strategies is a major driver in its increasing popularity. Additionally, research and experimentation are beginning to clarify the mechanisms that generated the benefits the Amazonian people discovered and exploited millennia ago. Modern agriculture depends dominantly on inputs of non-renewable resources, and there has always been a positive correlation between high organic content and soil health and productivity. In looking for low-carbon footprint or carbon sequestering techniques that have a positive effect on agricultural production, biochar stands out.

Through the end of the twentieth century, research on biochar was sparse. Results were generally positive, but not to the degree seen with chemicals used widely in production agriculture, and further investigation of biochar for use in large-scale agriculture has therefore been a relatively low priority. However, based on the activity on the supply, technology development, and demand sides, it appears that biochar's star is rising. For example, throughout the US, Australia, and Europe, vineyards are including biochar in their annual application of compost/amendment blends. In Louisiana a large industrial-scale biochar producer is serving cotton producers and other large-scale commodity agriculture enterprises as word-of-mouth and research results confirm the claims of long-term yield increases.[11]

Two meta-analyses of the historical research (Jeffery, 2011; Sohi, 2009) found that biochar is indeed a carbon source, but that effects on soil biochemistry vary depending upon a number of factors. For example, research shows biochar's effects vary with soil types, moisture, weather conditions, and the health and vitality of the soil into which it goes. Consistent findings are that biochar breaks down slowly, so its benefits are long-term, and it can enhance soil performance at the same time it sequesters carbon. Generally, studies have found that biochar does little to boost already nutrient-rich soils, but that biochar appears to make nutrients more available over a longer period of time.

There has been limited research on use of biochar to clean up toxic/hazardous chemical sites. Biochar has long been a potential feedstock for activated carbon—which is a widely used adsorbent for toxins and heavy metals. However, the supply of biochar has been limited, and cost prohibitive for bulk applications, since the market has been dominated by small producers with production costs has high as $4.25 per pound (Table 1). Recent (2015) retail prices for biochar were $15 to $25 per pound. Larger scale production technologies and opportunities to generate biochar as a secondary product to biofuel or energy production appear to be able to drive production prices as low as 10¢ per pound (Rasmussen, 2015).

[11] See http://www.coolplanet.com/biocharviticulture and http://www.ithaka-institut.org/en/home for more.

Figure 3. Exeter Retort

Source: http://www.biocharretort.com

Over time, with practice and tinkering, biochar production methods have improved from an environmental-impact standpoint. Currently there are commercially available units, capable of modest production volumes, for a reasonable investment and which require minimal labor to operate. More modern retorts are illustrated in Figures 3 and 4. The Exeter Retort (Figure 3) is a closed, mobile unit capable of pyrolizing chunky non-homogenious feedstock (wood slabs, firewood, small logs, etc.). Another style of farm-scale retort in development is the TLUD (top-lit, up-draft) retort, here made from a 500 gallon propane tank (Figure 4). It's most suited for stationary operations and tests have been run using pecan shells and softwood chips from forest restoration projects. At the larger end of the scale are industrial operations capable of generating liquid biofuel, syngas, and energy, as well as biochar.

WHAT IS BIOCHAR'S PRODUCTION AND APPLICATION POTENTIAL?

Figure 4. TLUD Retort

Source: H. Groot

The potential for biochar production is enormous given the biomass supplies that could be utilized. Pyrolysis reduces the volume of feedstock about 50%, so 100 cubic feet (1 CCF) would yield about 50 cubic feet (0.5 CCF) of biochar. In one USFS Ecological Restoration project in southeast Arizona, 21,200 CCF of woody biomass to be removed would produce 10,600 CCF of biochar. If the biochar were used in the surrounding agriculture fields to increase soil carbon by 1%, it would enrich 620 acres while sequestering 5,830 tons of carbon.[12]

In addition to utilizing biomass from forest restoration projects, the raw material for biochar production could come from other sources, including urban wood or wood waste.

As indicated in Dovetail's 2010 report on urban wood: "*The number of trees, and hence the volume of wood, removed annually from our nation's urban forests is significant. Estimates of removal (due to pests, wind storms, construction, hazard trees, etc.) range from 16 to 38 million green tons per year. Even the lower value of these estimates is comparable to total annual harvests from America's National Forests.*"[13] If the lower amount were converted to biochar, it would sequester approximately 800,000 tons of carbon while raising the soil carbon by 1% on 850,000 acres.[14]

[12] 1,060,000 cubic feet of biochar at a bulk density of 11 pounds per cubic foot is 11.67 million pounds or 5830 tons; at an application rate of 9.4 tons per acre that would treat 620 acres.
[13] http://www.dovetailinc.org/reports/Urban+Wood+Utilization+and+Industrial+Clusters_n284?prefix=%2Freports
[14] (16 million Tons x 2000 pounds/short ton)/11 pounds per cubic foot = 2.9 billion cubic feet of feedstock. At a 50% yield, we have 1.45 billion cubic feet of biochar. At 11 pounds per cubic foot, we end up with 800,000 short tons, and applied at 9.4 tons per acre we can treat 848,000 acres.

Another Dovetail report (2014) on wood waste reported that: *The softwood and hardwood forests of the United States provide wood products that are used in many applications including: lumber and other building materials; furniture; pallets and other forms of containers and crating; posts and poles; and a wide-range of consumer goods. This wide array of products generates waste wood when these products are disposed at the end of their useful lives. This waste wood is typically included in the categories of Municipal Solid Waste (MSW) and Construction & Demolition (C&D) wood, with the total amount generated in 2010 estimated at 70.62 million short*[15] *tons; this amount is difficult to track and may be understated.*[16] This amount of woody biomass (70.62 million tons) converted to biochar would sequester 35.3 million tons of carbon while treating 3.8 million acres of farmland to a 1% increase in soil carbon. To put this in more relatable terms, we can consider how much U.S. cropland needs improvement. The USDA's National Agricultural Statistical Service reported there were 318 million planted cropland acres in 2010. It takes 9.4 tons of carbon per acre to increase soil carbon content by 1%; therefore, almost 3 billion tons (6.1 million railcars) of biochar would be needed to enhance all U.S. cropland. However, not all U.S. cropland needs soil enhancement. The Natural Resource Conservation Service (NRCS) estimates cropland soils in the US range from less than 2% to a high of 20% carbon. In some of the Amazonian terra preta sites the soil carbon content is 8% --as compared to less than 2%, and as low as 0.5% in adjacent non-terra preta sites (Mann, 2011). With this reference in mind, in the near term the biochar application in the U.S could prioritize raising the productivity of sites where soil carbon content is less than 8%.[17]

USDA's National Agricultural Statistical Service reported there were 318 Million planted cropland acres in 2010. It takes 9.4 Tons of carbon per acre to increase the soil carbon content by 1%. Thus, almost 3 billion tons (or 6.1 million rail cars) of biochar would be needed to enhance all cropland today.

WHAT ARE THE BARRIERS TO REALIZING BIOCHAR'S FULL POTENTIAL?

The basic need for more biochar production is a key constraint in its more widespread use along with the need to produce a consistent, commercially reliable product. While the benefits of biochar as a carbon soil amendment are fairly consistent, research has shown there is often variability in the finished product due to the pyrolysis conditions and the feedstock. Peak temperatures in the kiln and feedstock are the primary variables; however, many producers do not measure temperature, nor can they control it accurately. Some feedstocks (like poultry litter or bones) produce higher levels of potassium or calcium than purely woody or ag-waste biomass. This underscores the need for testing the biochar along with the soils to optimize applications.

The International Biochar Initiative (IBI) has established a standard for biochar certification which requires testing of a given feedstock for an array of properties. To maintain IBI certification, biochar that varies by more than 10% from the original certified product's analysis requires additional testing -- so changing feedstock to

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[15] A short ton is the US measurement equivalent to 2000 pounds. A long ton is British at 2200 pounds, and the metric ton (tonne) is 1000kg or 2204 pounds.

[16] http://www.dovetailinc.org/reports/MSW+and+C%26D+Wood+Waste+Generation+and+Recovery+in+the+U.S._n628?prefix=%2Freports

[17] The reference of 8% soil carbon is included for discussion purposes, while recognizing that goals for soil carbon and soil productivity thresholds are highly regional and likely extremely variable.

accommodate new sources, or blending biochar to create custom mixes could require recertification of each variation, adding expense. Since launching the program in 2013, few producers have sought or maintained IBI certification, choosing instead to rely on their own marketing and branding to provide customer satisfaction.[18] Some producers provide broad chemical and/or physical data, but most just sell biochar on its “merits”.

For larger, industrial scale producers variability in supply is less of a problem, assuming most of their feedstock comes from consistent sources. However, in a natural resource dependent system with very low profit margins and relatively high raw material costs, consistency is difficult to manage. Feedstocks from woody or ag-waste sources tend to come with high acquisition costs (labor and transportation) which limit their profitability. Since price is heavily dependent on distance-to-buyer/processor, low prices are the norm since, in most areas, there is either a glut of supply or a dearth of processing capacity.

One approach, currently under discussion by non-industrial scale producers, is to form an aggregation and marketing enterprise to produce a blend of local/regional biochars which maintain a relatively consistent chemical profile. However, there is a need to determine how broad an array of providers could participate, what criteria they would need to consider in their individual process controls, and how product or blends might be matched to specific consumer needs. For instance, softwoods from forests of the southern United States have a lower yield and tend to pyrolize at lower temperatures than hardwoods. Softwood biochar is also generally more acidic than hardwoods or agricultural residue. Since southern soils are often more sandy and more acidic, softwood-derived biochar is not ideal without additional treatment and cost. Conversely, while hardwood biochar is better suited to those southern soils from a purely chemical profile standpoint, shipping costs from a predominantly hardwood growing region may be prohibitive. Having a distributor with the ability to create blends of locally produced biochar with particular profiles could help to address these issues.

Further analysis is needed to address the variables inherent in a geographically wider-scale system. *From a business perspective:* what are the price points at which biochar can be profitably produced and shipped? At what scale? Can a distributed production system work, or will a stationary multi-product processing operation (biofuel/syngas/heat/electricity) be the only way to succeed economically? *From a process standpoint:* How much variability is acceptable in feedstocks? How tightly does the temperature need to be controlled? Are there other process control factors which need to be considered? And finally, *from an environmental standpoint:* How much is the sequestered carbon worth and can the other environmental benefits of biochar be monetized (e.g., water filtration, wildfire risk reduction, and carbon storage)?

ECONOMICS OF BIOCHAR

The market for biochar is currently fragmented and will probably continue to be so until production capacity increases sufficiently for consolidation and commoditization to occur, as typically happens in the maturation of a sector within a free market. Historically that process can take decades, so there appears to be an opportunity for small- to medium-scale producers to tap into the expanding numbers of certified organic, natural, and

[18] As of Dec 29, 2015, the IBI lists two currently certified biochar manufacturers and three manufacturers with expired IBI certification, see: http://www.biochar-international.org/certification/manufacturer_directory

environmentally conscious growers, many of whom are targeting local markets. The strongest opportunity would seem to be in collaborative efforts to serve both the smaller, local buyers, and larger transitional organic/natural growers through an aggregation enterprise. With interest from end users growing—and as more of those end users are larger and larger agricultural producers—a consistent and growing supply is needed. With greater demand, the supply should respond with biochar which has the needed consistency and accurately known properties.

THE BOTTOM LINE

Biochar is a product with clear benefits but many questions have yet to be answered. It is a value added product made from low-to-no value feedstocks; all the feedstocks come from renewable natural resources and can produce heat at a minimum, with the potential for a number of additional energy products. Biochar's history of soil improvement is unmatched in terms of longevity, but the mechanism of its success remains largely unknown. Biochar sequesters carbon; however, the precise balance depends on many variables, which further depend on the manufacturer's process and feedstocks. From a market perspective, biochar's economics are murky as both the supply and demand sides are still developing.

Considerable research is needed to understand how biochar works best in large-scale applications as well as on further development of biochar production technology. Despite the length of time biochar has been used beneficially, it remains a largely unknown product commercially. In a period where every carbon sequestration opportunity is being explored, biochar's time may have come again.

REFERENCES

Brantley, K.E., Brye, K.R., Savin, M.C. and Longer, D.E. 2015. *Biochar Source and Application Rate Effects on Soil Water Retention Determined Using Wetting Curves.* Open Journal of Soil Science, 5, 1-10; 2015.

Bratkovich, S. and Fernholz, K. 2010. *Urban Wood Utilization and Industrial Clusters: A Twin Cities Case Study.* Dovetail Partners. http://www.dovetailinc.org/report_pdfs/2010/werc63010finalreportsm.pdf

Bratkovich, S., Howe, J., Bowyer, J., Pepke, E, Frank M, and Fernholz, K. 2014. *Municipal Solid Waste and Construction and Demolition Wood Waste Generation and Recovery in the U.S.* Dovetail Partners. Available at: http://www.dovetailinc.org/report_pdfs/2014/dovetailwoodrecovery0914.pdf

EPA 832-F-00-017 September 2000. *United States Environmental Protection Agency; Wastewater Technology Fact Sheet Granular Activated Carbon Adsorption and Regeneration*

International Biochar Initiative. *Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil.* IBI-STD-2.0; http://www.biochar-international.org/characterizationstandard; October 2014

Jeffery S., Verheijena F, van der Veldea M., Bastos A. 2011. *A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis.* Agriculture, Ecosystems & Environment; November 2011

Jingchun T., Wenying Z., Rai Kookana, Arata Katayama. 2013. *Characteristics of biochar and its application in remediation of contaminated soil; Journal of Bioscience and Bioengineering.* Volume 116, Issue 6, December 2013

Koide, R. T., Nguyen, B. T., Skinner, R. H., Dell, C. J., Peoples, M. S., Adler, P. R. and Drohan, P. J. 2015. *Biochar amendment of soil improves resilience to climate change.* GCB Bioenergy, 7: 1084–1091. doi:10.1111/gcbb.12191

Lewandowski, A. 2002. *Organic Matter Management*. Soil Quality Institute, Natural Resources Conservation Service, United States Department of Agriculture.

Mann, Charles C. 2011. *1491*, second edition, Random House, NY; 2011

Perry A. 2011. USDA Agricultural Research Service; *"Carefully Unraveling the Intricacies of Biochar";* November/December 2011 issue of Agricultural Research magazine

Rasmussen E., Miles T. 2015. *Port of Tacoma: Using Biochar as a Component for Stormwater Filtration in a Log Yard*. IBI Journal, March 2015

Rawls W., Pachepsky Y., Ritchie J.C.,Sobecki T.M., Bloodworth H. 2003. *Effect of soil organic carbon on soil water retention*. Geoderma 116, 61– 76; 2003

Sohi S., Lopez-Capel E., Krull E., and Bol R. 2009. *Biochar, climate change and soil: A review to guide future research*. Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land and Water Science Report 05/09 February 2009

Soil Carbon Coalition; For application rates: http://soilcarboncoalition.org/

Spokas K., Cantrell K., Novak M., Archer D., Ippolito J., Collins H., Boateng A., Lima I., Lamb M., McAloon A., Lentz R., and Nichols K. 2012. USDA Agricultural Research Service. *Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration*. Journal of Environmental Quality

Ulyett J., Sakrabani R., Kibblewhite M., and Hann M. 2014. *Impact of biochar addition on water retention, nitrification and carbon dioxide evolution from two sandy loam soils.* Volume 65, Issue 1, pages 96–104, January 2014

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