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THE ECONOMICS OF BIOCHAR PRODUCTION: A REVIEW

This University Center for Economic Development technical report explores the economics of biochar production. Consideration is given to its profitability depending on crop production, water retention, transportation cost, pyrolysis efficiency, soil reclamation, carbon sequestration, bio-oil and bio-gas, and regulatory frameworks.

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THE ECONOMICS OF BIOCHAR PRODUCTION: A REVIEW

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Introduction

This University of Nevada Cooperative Extension special publication examines the economic viability of biochar production. Biochar is a material that is carbon-rich, with a chemically and microbially stable molecular structure (Cheng, Lehmann, & Engelhard, 2008) used in soil reclamation, agricultural production, and carbon sequestration efforts. Consideration is also given to the production and application of bio-oil and biogas, as these are additional byproducts of pyrolysis[1]. Biochar is commonly used as a soil amendment, with research suggesting benefits to microbial activity (Warnock, Lehmann, Kuyper, & Rillig, 2007), reduction of heavy metals and other pollutants (Beesley & Marmiroli, 2011; Park, Choppola, Bolan, Chung, & Chuasavathi, 2011; Spokas, Koskinen, Baker, & Reicosky, 2009), increased water retention (Blackwell, Krull, Butler, Herbert, & Solaiman, 2010; Clarke, 2014; Laird, et al., 2010) and increased crop productivity (Chan, van Zwieten, Meszaros, Downie, & Joseph, 2007; Jeffery, Verheijen, van der Velde & Bastos, 2011; Rondon, Lehmann, Ramirez, & Hurtado, 2007; Vaccari, et al, 2011; Yamato, Okimori, Wibowo, Anshori, & Ogawa, 2006), but can also be used to purify water (Liu, et al., 2012; Ogawa, Okimori, & Takahashi, 2006).

Existing research suggests that biochar can be used in climate change mitigation efforts, as its creation reduces biomass being burnt or decaying naturally (Woolf, Amonette, Street-Perrott, Lehmann, & Joseph, 2010) and when amended into soil it may act as a carbon sequestration mechanism (Chen & Yuan, 2011; Lehmann, Gaunt, & Rondon, 2006; Wang, Zhang, Xiong, Liu, & Pan, 2011). As human-induced climate change continues to impact the Western United States[2], an investment in this technology might be a viable and sustainable way to reduce greenhouse gas emissions.

This special publication is designed to describe potential benefits and establish justification for a current biochar field trial in Eureka County, Nevada, as well as future biochar demonstration projects. To our knowledge, few large scale field trials of biochar, such as the one in Eureka County begun in 2013, have yet taken place and the majority of studies on biochar have occurred in laboratory settings only. And while other technologies and techniques exist for achieving the same ends as biochar use, their exploration is beyond the scope of this paper. As of 2010, 90.0 percent of Eureka County's privately owned land was designated as agricultural land, with mining the second largest land use (Eureka County Planning Commission, 2010), two sectors that can benefit from the use of biochar. The current Eureka County biochar field trial and demonstration project is designed to contribute to the financial and scientific literature on the viability of biochar from both a practical and an economic standpoint. Data from field trials are necessary to begin to move toward a more realistic market value based on actual biochar production in the field (e.g. Meyer, Glaser, & Quicker, 2011). Outlined in this special publication are the primary areas where biochar has already demonstrated its economic benefits.

Biochar as a Soil Amendment

There are two main aspects of biochar that make it valuable as a soil amendment. The first is its high stability against decay, meaning that once applied, it remains in the soil for a long period of time allowing its benefits to be

[1] Pyrolysis is a process by which a biomass feedstock is placed in a non-oxygenated environment at high temperatures, resulting in a combination of char, oil, and gas, with the amounts of each dependent on the temperature at which pyrolysis takes place and the feedstock used (Demirbas, 2008; Laird, Brown, Amonette, & Lehmann, 2009; Lee, Hawkins, Day, & Reicosky, 2010; Maraseni, 2010; Sohi, Lopez-Capel, & Bol, 2010).

[2] Drier and hotter weather, reduced snowpack, and earlier snowmelt, leading to more and more intense forest fires (Melillo, et al, 2014) with Nevada experiencing its third year in a state of drought emergency in 2014 (National Drought Mitigation Center, 2014).

persistent (Lehmann, 2007; Sombroek, Lourdes Ruivo, Fearnside, Glaser, & Lehmann, 2003; Pessenda, Gouveia, & Aravena, 2001). The second is its superior ability to retain nutrients compared to other types of organic matter (Sombroek, et al., 2003; Liang, et al., 2006; Lehman, 2007; Lehman & Rondon, 2006; Rondon, et al., 2007; Pietikäinen, Kiikkila, & Fritze, 2000; Saito & Marumoto, 2002). These properties of biochar as a soil amendment allow for climate change mitigation, reduction in environmental pollution, and overall soil improvement (Glaser, Lehmann, & Zech, 2002; Lehmann, 2007; Lehmann & Rondon, 2006) because they allow for a reduction in fertilizer use and other agricultural input requirements resulting in decreased nitrous oxide emissions in fertilized fields (Gaunt & Lehmann, 2008; McCarl, Peacocke, Chrisman, Kung, & Sands, 2009).

However, Shackley and Sohi (2010) caution that the feedstock used should be carefully considered to ensure toxic elements like heavy metals are not in the feedstock prior to pyrolization to avoid the potential contamination of plants. However, Granastein, et al. (2009) found no evidence of dioxins or polyaromatic hydrocarbons, and after conducting their own analyses, discovered only phenanthrene (PAH) in the biochar at a smaller rate than what would be considered an environmental hazard.

Biochar for Soil Reclamation

An important consideration for the Eureka County, Nevada project is the potential of biochar to assist in the reclamation of mine tailings, which could ultimately impact the economic feasibility of biochar use overall. Fellet, Marchoil, Vedove, and Peressotti (2011) conducted an experiment in which they mixed biochar produced from orchard biomass with mine tailings in northeastern Italy. They found that the treated soil's pH, nutrient retention, and water holding capacity increased as biochar content increased, while the bioavailability of Cd, Pb, Tl, and Zn decreased as biochar content increased. The authors concluded that the "changes promoted by the biochar seem to be in favor of its use on mine wastes to help the establishment of a green cover in a phytostabilization process" (Fellet, et al., 2011). This finding could be particularly important in places suffering from severe drought, such as the American West (National Drought Mitigation Center, 2014), as the addition of biochar to previously sterile soils increases the ability of the soil to retain water, which in turn allows for greater crop productivity and helps to prevent erosion. In Nevada, as well as in other states with large mining operations, this finding also suggests that soils already used for one purpose (mineral extraction) can be reused for an agricultural purpose, making it revenue positive.

Water Benefits

Additional research suggests that biochar application improves soil's water permeability levels, providing better water capacity, which can, in turn, lead to improved plant growth (Asai, et al., 2009; Clarke, 2014; Laird, et al., 2010), though some researchers report low confidence in these findings (Shackley & Sohi, 2010). Blackwell, et al. (2010) conducted a field trial during a drought period and found improved crop nutrition in the biochar condition, which they attribute to increased water uptake potential during drought stress periods. They also found that their biochar treatment groups showed significantly less tiller loss compared to the non-biochar group, again suggesting benefits of biochar during drought scenarios.

Crop Productivity

Multiple studies have considered the impact of biochar soil amendments on crop productivity and have found that crop productivity is increased both when biochar alone is added to soil (Baum & Weitner, 2006; Chan, et al., 2008) and when it is added with fertilizer (Steiner, et al., 2007). Asai, et al. (2009) conducted three field experiments to test biochar's ability to increase rice production in Northern Laos. The researchers discovered that in many of the plots, the amendment of biochar to the soil did increase grain yield, although the condition of the soil and whether N fertilizer was included influenced the outcome. In general, however, the researchers concluded that the "Absence of dramatic gains in rice productivity and the significant alternative uses of biochar as an energy source constitute a major economic constraint to the practical application of [biochar] techniques" (p. 84).

This echoes other research that found the economic feasibility of biochar as a soil amendment, regardless of its impact on crop productivity, is highly dependent on the existence of a carbon market and the price of biochar. Specifically, when no carbon market is present, the price of biochar must be approximately $9.19 per metric ton (MT) in order for a farmer to break even, while it must be approximately $4.82 per MT in order for a farmer to turn a profit, excluding the costs of transportation and application (Galinato, Yoder, & Granatstein, 2011). When a carbon market exists at $31.00 per MT of CO_2, the cost of biochar can be as high as $100.73 per MT and a farmer will break even; though if the carbon offset market is as low as $1.00 per MT of CO_2, there is no biochar price scenario in which a farmer does not lose revenue (Galinato, Yoder, & Granatstein, 2011; Granastein, et al., 2009).

The cost of feedstock itself impacts the economic viability of biochar projects (Roberts, Gloy, Joseph, Scott, & Lehmann, 2010; Shackley, Hammond, Gaunt & Ibarrola, 2011). Shackley, Hammond, Gaunt, and Ibarrola (2011) found that this cost can cause the overall cost of a project to vary greatly. Roberts, Gloy, Joseph, Scott, and Lehmann (2010) note that the various available feedstocks must be carefully considered for each individual project in order to accurately predict the economic viability of biochar, bio-oil, and biogas production and application. They observe that this consideration is also important if a project is to avoid net greenhouse gas emissions and more energy consumption than generation if it is to remain economically and environmentally sustainable.

Economics Considering Carbon Sequestration Potential

One factor that could make the production and use of biochar economically feasible is its impact on greenhouse gas emissions assuming the existence of a viable carbon market (Field, Keske, Birch, Defoort, & Cotrufo, 2013; Galinato, Yoder, and Granatstein, 2011; Pratt & Moran, 2010; Roberts, Gloy, Joseph, Scott & Lehmann, 2010). Pratt and Moran (2010) use Marginal Abatement Cost Curves (MACCs) to consider this and conclude that a range of factors, including the price of carbon in the market as well as benefits to crop productivity, all influence the economic feasibility of biochar projects.

Galinato, Yoder, and Granatstein (2011) conclude that there are two overarching scenarios in which the use of biochar as a soil amendment can be economically feasible. The first occurs when there is a carbon market that recognizes the avoided emissions and carbon sequestration due to the application of biochar in agricultural soils. The second occurs when the market price of biochar itself is low enough to allow farmers to earn a profit after applying biochar to crop fields. Additionally, Field, Keske, Birch, Defoort, and Cotrufo (2012), using life cycle analysis (LCA), find that the breakeven point for biochar production and use when a carbon market exists lies at approximately $50.00 per Mg CO_2eg, meaning that biochar projects can be profitable when they are able to capitalize on the impacts on carbon emissions.

Brown, Wright, and Brown (2011) were slightly more conservative with their calculations, which again relied on some benefit from carbon offsetting[3]. The authors found

[3] The authors discuss the American Clean Energy and Security Act, which would have created a cap and trade

profitability to be related to using all three of the byproducts of the pyrolysis technique (biogas, bio-oil, and biochar), presuming the existence of some type of carbon-offsetting value to biochar. Additionally, profitability varied due to pyrolysis technique, with fast pyrolysis (FP) lending itself to better profitability than slow pyrolysis (SP). Using corn stover as a feedstock with a cost per metric ton between $0.00 and $83.00 (estimates using $83.00) and hypothesizing 2,000 dry metric tons per day of the stover, Brown et al. (2013a, 2013b) found 124,000 metric tons of bio-char can be generated per year using FP, and 262,000 metric tons using SP. The authors concluded that the internal rate of return (IRR) would be insufficient to make biochar profitable at the $83.00/MT cost level, and even if the feedstock were free, it would only generate profits between 8.00 percent and 17.00 percent. Fast pyrolysis would be profitable even at $83.00/MT but only because of the higher generation of bio-oil, which could be used for transport fuels, suggesting an IRR of 15.0 percent to 26.0 percent and between 29.0 percent and 37.0 percent in the free feedstock scenario. Using these estimates, fast pyrolysis would be the most economical choice to generate biochar. Depending on the end-use of the biochar, this could be perfectly acceptable however research has demonstrated that pyrolysis temperature can alter the stability and benefits of biochar, especially as a soil amendment (e.g. Chen & Yuan, 2011; Demirbas, 2004; Ippolito, et al., 2012; Novak, et al., 2009; Rutherford, Wershaw, & Cox, 2004).

Blackwell, et al. (2010) also identify carbon offsetting as a way to make biochar economically feasible. However, the researchers also provide other potential sources that could make it profitable, especially with fluctuating costs of fertilizer. The researchers provided four other ways that would help make biochar economically feasible. These included the most efficient application of biochar (which they identified as using the banded method where biochar is placed where plant roots will develop), the lowest biochar application rate for the highest return, the longest duration of effect, and minimizing the cost of soil application and biochar creation. In order to test whether biochar could be economically feasible, the researchers conducted four field trials, growing wheat with various rates of biochar or P fertilizer in different combinations. Additionally, twelve years of economic data from six regions in the wheat belt were analyzed to aid in generating economic models. Results from the field trial found the optimal rate of biochar application to be approximately 3 t/ha banded biochar at a 50kg/ha fertilizer application rate. On average, the grain yield would increase by about 10.0 percent, with fertilizer savings at about 50.0 percent. Anticipating these savings yearly, over twelve years this would yield an estimated price point of up to AU$70.00/ha in fertilizer savings; AU$170.00/ha over twelve years for a 10.0% crop yield increase; and if both conditions were met, biochar costs of up to AU$240.00/ha. If there were diminishing marginal returns of the fertilizer, crop yield, or to both, the biochar cost would fall to AU $40.00/ha, $100.00/ha, and $140.00/ha respectively (Blackwell, et al., 2010).

It should be noted that while no national carbon market exists in the United States, cap and trade carbon markets do exist in four regions: the Southeast (including Alabama, Florida, Louisiana, Mississippi, and Texas); the Northeast (including Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, and Maryland); the Midwest (including Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin) (Union of Concerned Scientists, 2014); and the West (including Arizona, California, Montana, New Mexico, Oregon, Utah, and Washington) (Center for Climate and Energy Solutions 2014).

Not all states are encompassed within the four regions where a cap and trade carbon market

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on greenhouse gases and provided a market for offsetting carbon dioxide. The bill was defeated in the Senate in 2009 (H.R. 2454).

exists. Consequently, the potential profitability of any biochar project will be directly impacted by the state in which it takes place. If a project takes place in a state with no carbon market, there is no potential to sell carbon offsets for a profit.

Profitability of Bio-oil and Biogas Production

Existing research suggests that the only way to make the production and use biochar profitable is to also capture and sell the byproducts of its production including bio-oil and biogas. Yoder, Galinato, Granaststein, and Garcia-Perez (2011) examine the economic tradeoffs associated with biochar and bio-oil production. After performing two analyses, the first that took into account the variation in bio-oil and biochar price caused by quality variation and the second that excluded these considerations, they concluded that the final price of both were highly dependent on their quality, which they found to be related to the temperature at which pyrolysis occurs. However, while the pyrolysis condition may be an economically important consideration, even reaching an optimal combination of bio-oil and biochar production may not result in an enterprise that is profitable overall.

Abdullah and Wu (2011) find potential of biochar to be incorporated along with bio-oil to create a bio-slurry that can be used as a high-energy-density fuel. Extending their research further, the researchers examined whether the bio-oil could be separated out into two distinct elements, one that was more suited towards being combined with biofuel for use as a transport fuel, and a lower quality one that could be used to generate bio-slurry. They found that the bio-oil of lower quality was still successful when combined with biochar to be used as a bio-slurry in terms of its atomization quality, pumpability, and stability. Brown, Thilakaratne, Brown, and Hu (2013b) also assess the economic viability of biofuel, noting that the Renewable Fuel Standard in the United States mandates the production of 16,000 million gallons per year of cellulosic biofuel by 2022. Using a fast pyrolysis technique followed by hydroprocessing, with corn stover as the biomass input, the minimum fuel selling price for bio-oil would be $2.57 per gallon, with the biogas and biochar being used to heat and power the facility (or sold back to the energy grid). Again, the results can vary based on the biomass used, the reactor used, and the bio-oil fraction, with the most important variable in economic viability being the fuel yield stemming from the yield from pyrolysis and then the hydroprocessing step.

Accounting for Transportation

One major factor that influences the economics of biochar production and use is transportation. Palma, et al. (2011) considers how costs change when biochar is produced in one place and then moved to another. They considered the economic feasibility of mobile pyrolysis facilities through an exploration of two types of biochar in three states that move a varying number of times. Using a Monte Carlo financial simulation model that included transportation logistics analysis based on geographic information systems (GIS) data, they concluded that the net present value of biochar improves as the number of times the mobile pyrolysis facility is moved decreases. Similarly, Coleman, et al. (2010) determined that while a portable pyrolysis machine had the benefit of reducing the transportation costs of large, bulky biomass by converting it on-site, operating efficiency was more optimal if positioned in one place near the biomass rather than moving it frequently. Coleman, et al. (2010) also found that the transportation of biochar itself is too bulky and too low-density for transportation and therefore not economically viable, a position with which Adullah and Wu (2011) would disagree. Adullah and Wu argue that pyrolysis of biomass will provide transportation benefits since the biochar itself will be much smaller but is a high density energy material compared to transporting the larger, less granulated biomass.

Similarly, a portable pyrolysis facility has been found to be beneficial in a forest scenario. Biomass can be taken from the area and can help in preventing fuel accumulation which could lead to forest fires, and would also reduce the need to pile-burn biomass thereby reducing greenhouse gas emissions. The biomass could be pyrolysized on site, and then the biochar could be amended directly into the soil from the areas the biomass was removed from in order to support nutrient development and provide carbon (Coleman, et al., 2010), a similar method to that being attempted in the Eureka County field trial.

Finally, in order to create a high volume production of biochar, it may be necessary to establish a transportation infrastructure that can handle high-density biomass. It may be the case that there is not enough biomass close to a pyrolysis facility, or that the byproducts of pyrolysis will need to be transported further away. Rail is one of the primary systems of transportation in the United States. Research into rail transportation in the United States suggests costs are highly dependent on the amount of competition in an area, the part of the United States being transported through, the owner of the railcar, and overall distance traveled (Gonzales, 2012). The ability to transport biomass, biochar, biogas, or bio-oil may require some reasonably large alterations to the existing infrastructure, leading to further cost considerations.

Regulation of Biochar

Another consideration in terms of the cost of biochar is whether or not there would be regulations on biomass and whether biochar would be deemed a waste material and how that influences its use as a soil amendment (Shackley & Sohi, 2010). Such a consideration is likely to be country-dependent and may require further research to construct appropriate public policy designed to regulate biochar production and management. At this time, no such regulations exist in the United States. The European Union (EU) has issued a brief on the topic of biochar regulation, noting that Switzerland is the first country in Europe to approve biochar for agricultural purposes, while Japan approved biochar for soil conditioning back in 1984. In the EU, all chemical products must meet regulations set by REACH (Registration, Evaluation, and Authorization of Chemicals), including biochar if produced in the EU (VBS-Technical University of Ostrava, Energy Research Center, 2013). After meeting these regulations, the biochar would need a European Biochar Certificate in order to be used in agricultural production (European Biochar Certificate Foundation, 2014). These sorts of regulations mean further costs to demonstrate that the regulatory standards and requirements are being met, influencing the overall economic feasibility of any biochar project.

Although regulations may result in increased costs, McGreevy and Shibata (2010) hope for regulation on biochar production and its addition to soil as a way to be able to market produce as “COOL VEGE™”, branding it in a way to stand out from its competition and to be able to markup cost. Already in Japan as part of a larger Carbon Minus project, produce such as cabbage, grown in a biochar amended soil, is marketed for up to 3.0 percent to 5.0 percent more to retailers due to its eco-branding.

Conclusion

Many factors must ultimately be taken into account when assessing the economic variability of any biochar project. Research suggests that biochar projects are most profitable when a carbon market exists. If the amount of carbon emissions offset or avoided through a given project can be calculated, this can be sold, ultimately making a project economically viable. The existence of a market for the byproducts of biochar production, biogas, and bio-oil can also impact a project’s overall economic viability if the benefits of these byproducts can be effectively and efficiently captured. Economic viability is also dependent on the impact of biochar on crop productivity. If overall crop yields can be increased through the amendment of biochar to soil, the additional product can also be sold at a profit in the market.

Of course, these are not the only factors that must be considered when determining the economic feasibility of biochar production. The cost of biochar feedstock, the costs of transporting biochar from the production facility to the application site, other costs associated with production itself such as those imposed by the pyrolysis facility, and the costs associated with abiding by various regulations, must all also be considered. There are also potential effects of biochar use that may not be easily incorporated into an economic analysis, such as its prospective impact on eroded soils. In states with significant mining operations, such as Nevada, the potential of biochar to reclaim mine tailing piles may also impact fiscal viability. Finally, there may be unknown costs to creating and using biochar due to the limited amount of field trials that have occurred. This makes the current biochar field trial and demonstration project in Eureka County all the more important in contributing to the literature, not only with regard to the economic viability of creating and amending biochar to soils, but also in order to further the understanding of how biochar expresses itself and interacts in a real world environment.

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