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Biochar: A Solution to Oakland's Green Waste?

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Abstract

Lawrence Berkeley National Laboratory (LBNL) has been working in conjunction with the Department of Energy on finding new and innovative ways of sequestering atmospheric carbon, and lessening the population's carbon footprint. LBNL is committed to finding interdisciplinary and creative ways to ensure a carbon-neutral future. In the spirit of this commitment, this research project examined the economics of converting Oakland's residential green waste stream to biochar as an alternative waste management solution. Biochar is a charcoal created from biomass by pyrolysis. Carbon in biochar has been found to stay stable for thousands of years, unlike carbon in compost and thus may be a better alternative than compost in reaching a city's carbon sequestration goal. In addition, some biochar's have been found to act as a valuable soil amendment, leading to increased crop yields in many cases. Also, pyrolysis produces by-products, syngas and bio-oil, which can be converted into bioenergy. Through calculations and reference research, the preceding potential benefits were examined in order to determine if a biochar production plant would be an appropriate form of green waste diversion in Oakland. The research found that biochar production from Oakland's residential green waste may be profitable. However, this project is laden with assumptions, so further research is recommended to understand how biochar specifically affects local crops, the ability of pyrolysis to handle heterogeneous feedstocks, and how biochar may fit with Oakland's carbon sequestration goals.

Introduction

Lawrence Berkeley Laboratory has been working in conjunction with the Department of Energy to find new and innovative ways to fight global climate change. The lab is committed to finding interdisciplinary and creative ways to ensure a carbon-neutral future for everyone. In the spirit of this commitment, this research project examines the economics of converting Oakland's residential organic, or "green waste," stream into an ancient substance, biochar, as a means of carbon sequestration and alternative green waste management.

For the past 5 years, Alameda County Waste Management's (WM) residential curbside pickup service has collected over 30,000 tons of green waste annually from the city of Oakland. This waste consists of food scraps as well as yard trimmings and is deposited at the Davis Street Transfer Station where it is transported to Grover Landscaping or Zbest and turned into compost. It is then then sold to wholesale outlets and agricultural markets [1], [2]. While net green house

gas emissions for composting has often been found to be less than that for landfills, the diversion of green waste to biochar seems to be an even better alternative.

Compost, slowly leaks the carbon it traps back into the atmosphere. This means that when compost is used for carbon enrichment in soil, over time the carbon level in the soil will drop back to original levels if not continually maintained. Some studies claim that after one year, only about a third of above ground residues such as compost or mulch remain in the soil, and after 2 years only about 10-20 percent of the residue is left [3]. Also, the addition of organic matter to soils can substantially increase emissions of nitrous oxide and methane [3], both known green house gasses.

Like compost, biochar is made from biomass, but is much more stable in its ability to retain carbon than composted material [4]. In fact, biochar in Amazonia has been found to store carbon for thousands of years despite the severe weather conditions of the Amazon [4]. Essentially, carbon dioxide absorbed by plants during photosynthesis is converted into a stable, solid form of carbon during pyrolysis, a process which chemically decomposes organic matter by incineration the absence of oxygen. The carbon from input biomass is thus trapped in solid form in biochar as opposed to converting into a gas, such as carbon dioxide or methane, as it would if the biomass was left to decompose naturally.

Biochar's long term stability also helps it act as a carbon sink. By creating biochar out of organic material instead of letting it rot in the soil, 50% of the input biomass carbon is stabilized in the charcoal structure of the biochar. In this way biochar acts as a carbon sink, trapping carbon from biomass in a solid form instead of expelling it back into the atmosphere as a gas as it would if the biomass was to decompose naturally. The other 50% of input biomass carbon can be used to create bioenergy [5], [6], [7], [8]. This bioenergy is made from the two other byproducts of

pyrolyis, syngas and bio-oil. Additionally, unlike energy created from fossil fuels, the emissions generated from the use of the bioenergy do not contribute to the net CO_2 in the atmosphere. This is because when used for combustion, the carbon released from bioenergy is the recycled carbon from plants as opposed to the buried carbon released into the atmosphere that results from the burning of fossil fuels [3], [7]. For an illustration, see figure 1 below.

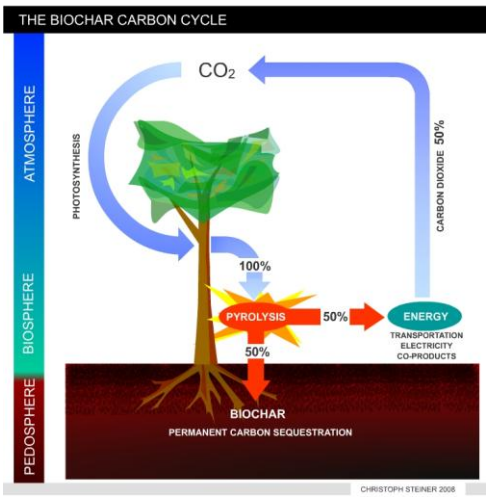

Figure 1 [3]

In addition to its carbon capturing benefits, some biochar's have been found to have amendment properties similar, and in some cases better, than compost. One study reported up to 880% crop yield increase as a result of adding a mixture of biochar and chemical fertilizer to soil [9], but the average increase is claimed to be 38-45% [7]. Studies reporting increased crop yields due to the addition of biochar to soil tend to credit biochars porous structure for its ability to act as a soil amendment. Biochar's porous structure increases water retention capacity in soil and enhances microbiological activity. Biochar also helps balance pH levels in acidic soil, this is commonly referred to as its liming capacity. Furthermore, biochar increases the effectiveness of chemical fertilizer by reducing nitrogen leaching, thus helping the soil retain nutrients from

fertilizer. Farmers using biochar can not only realize savings from reduced fertilizer use, but can also reduce chemical run-off of fertilizer into the natural environment [10], [8], [9].

There are some potential drawbacks to biochar production. One is the risk of hazardous chemicals both in biochar and created as a byproduct of biochar production. The chemical make-up of biochar varies greatly depending on the type of feedstock and the temperature and mode of pyrolysis used. Some of the greatest health threats associated with biochar production are the presence of heavy metals, dioxins, polycyclic aromatic hydrocarbons (PAHs), and "nanoparticles" either in the chemical makeup of the biochar, or in the air as a result of the pyrolysis process. Heavy metals and PAHs can both make their way into the chemical makeup of biochar. Dioxins and "nanoparticles", however often form in the air as a byproduct of biochar production. Dioxin exposure is known to cause cancer, reproductive and development problems, and "nanoparticles," or dust particles associated with biochar production, can cause respiratory problems. However, according to various studies, these potential health risks are dramatically reduced when pyrolysis is performed at lower temperatures as well as with a careful selection of feedstock material [11], [12], [13].

With the benefits of biochar production seeming to outweigh the potential risks, this research focused on examining the possibilities of creating a pyrolysis plant designed to divert Oakland's green waste stream to the production of biochar. There may be potential for the 30,000 tons of green waste a year currently being composted from Oakland's waste stream be converted into biochar. The research examined the costs and benefits associated with converting Oakland's current waste management infrastructure to one that can incorporate biochar production, as well as highlighting directions for future research regarding biochar production from municipal green waste.

Methods

This project performed a cost/benefit analysis for installing a pyrolysis plant infrastructure at Grover Landscaping. It is worth noting that many assumptions were made when considering production of biochar from Oakland's green waste stream. First, it was assumed that Oakland's existing residential green waste collection infrastructure, handled by WM, would be used in collecting feedstock for the pyrolysis plant. Second, Grover Landscaping was chosen as the pilot plant site since it currently handles Oakland's green waste and thus no additional land would need to be purchased for the pyrolysis plant. Thus, both storage and transportation costs of waste for biochar production are large expenses not included in this analysis since they are existing infrastructures for green waste management.

While there is currently limited information on costs associated with large-scale pyrolysis plants, this research used the pyrolysis plant described by Lehmann in *Biochar for Environmental Management Science and Technology* in chapter 19, *Economics of Biochar Production, Utilization ang Greenhouse Gas Offsets* [7] as a base for reasonable cost estimates. The plant has an expected life of 20 years and is powered by electricity generated in a diesel engine fuelled by bio-oil and diesel. The plant Lehmann describes has a capacity of 10t/hr of dry feed input of maize stover. Maize stover consists of the leaves and stalks left after corn harvesting, and thus was considered comparable to yard waste collected from the green waste recycling bins. The main difference between Oakland's green waste and maize stover, is the food waste which differs from stover most notably in its moisture content. However, for simplicity, since food waste accounts for only 1/3 of Oakland's green waste [2], possible extra costs associated with drying the green waste were considered negligible. This project also assumed a slow mode of pyrolysis would be used at the plant since slow mode produces the greatest ratio of

input biomass to biochar and reduces some of the health risks associated with biochar production.

While most of the costs were based on Lehmanns estimates, some were calculated using outside source information. For example, Lehmann does not consider a tipping fee that a plant charged for waste collection. However, after speaking with Tom Padia, of stopwaste.org, it was discovered that Grover charges a fee of $30-40/t waste (wet) [1]. This fee was then converted to $/t dry feedstock using a 3:1 ratio of wet tons to dry tons. Also, the 2005 green house gas, (GHG), emission factor of 0.49 lbs. of CO_2e per kWh for average grid electricity delivered by PG&E [14] and Lehmmans estimate of .31 MWh/t feedstock of the electricity produced from bio-oil and syngas [7] were used to determine the amount of CO_2e emission credits that could be obtained by the plant.

In addition to the cost/benefit calculations associated with the pyrolysis plant, several other calculations were made in the following analysis. The 23,000 tons of dry green waste generated by Oakland residents, for example, was calculated considering 10,000 tons of Oakland's 30,000 tons of green waste a year can be considered "wet" food scraps, and using a 3:1 ratio of wet to dry green waste tons.

Results

First, it should be noted that a pyrolysis plant of the size mentioned above, operating 40 hours a week, 52 weeks a year, has a capacity to convert up to 20,800 tons of dry feedstock into biochar. In Oakland alone, however, about 23,000 tons of dry green waste is collected from residential curbside pickups each year. Possible solutions for handling this excess tonnage will be addressed in the discussions section of this paper.

Furthermore, a large initial investment would be needed to build the pyrolysis plant at Grover Landscaping. Lehmann estimates a total initial capital cost of $23.7 million which covers the cost of a pre-treatment plant for biomass preparation (ie reception, drying, and storage), the cost of the pyrolysis plant, and the cost for installing the diesel engine to power the plant. Once the plant has been installed, he estimates the fixed cost of the facility at $21.28/t feedstock accounting for the "amortized one-year value of equipment costs considering purchase price, loan terms, salvage value, etc." (See Table 2, component D). Also, he estimates an operating cost of $31.58/t accounting for feedstock, labour, utilities, maintenance and overhead (See Table 2, Component E) [7]. Although Grover would not need to pay for feedstock, overhead and labor are more expensive in urban areas than national average, thus this operating cost gives a good rough estimate of what can be expected.

As mentioned, both by-products of biochar production, syngas and bio-oil can be converted into bio-energy and used to create electricity. This electricity would help operate the pyrolysis plant. According to Lehmann, amount of electricity produced from bio-oil and syngas obtained from slow mode by pyrolysis is .31 MWh/t feedstock. This, combined with a value of $80/MWh means that a potential of $25/t feedstock could be gained from Oakland's green waste stream (see Component A, Table 2) [7].

Biochar production also has green house gas offset effects. As a result of producing bioenergy, pyrolysis plants can offset fossil fuel and get credit for the displacement of emissions from fossil fuel used to generate elctricity. Estimates for the fossil fuel offsets of slow mode pyrolysis was calculated to be about 0.076 t CO2/t feedstock. In addition, estimates for the sequestration gain from biochar due to its ability to lock photosynthesized carbon in a stable solid form is approximately 0.963 t CO2e/t feedstock [7]. Although the pyrolysis plant

generating biochar can offset some green house gas emissions by using bioenergy, it also produces some emissions from the diesel that is used to power the rest of the plant. These emissions are estimated at about .033t CO2 /t feedstock [7]. This gives a net of -.709 t CO2e/ t feedstock avoided or removed if Oakland's green waste stream was diverted to the production of biochar. These results are summarized in Table 1. Furthermore, The Chicago Exchange sets the value for GHG offsets to $4/t CO2e [7]translating to a net GHG offset value of $2.84/ t feedstock (See Component C, Table 2.)

Table 1 **Estimated Green House Gas offsets for Slow Pyrolysis in CO2e/t feedstock**

Operate pyrolysis	.033
Credit for displacement of electricity	-.076
Sequestration gain from biochar	-.963
Net GHG Offset	-.709

In summary, considering the above mentioned costs and benefits, production of biochar at Grover would result in a net gain of about $35/t feedstock without accounting for possible added monetary benefit from selling biochar to local farmers, or environmental benefits seen by decreased fertilizer run-off. A summary of the cost/benefit analysis is shown in Table 2.

Table 2 **Summary of Cost/Benefit Analysis**

Component	**Value in US$/ton dry feedstock**
A. Electricity value from produced bio-oil and syngas	25.00
B.Tipping Fee	60.00
C. Value of offset GHG emissions	2.84
D. Fixed Cost of Facility	-21.28
E. Operating Cost of Facility	-31.58
F. Net	34.98

Conclusions

Overall, the move to production of biochar from Oakland's residential green waste stream looks promising. Granted this analysis is laden with assumptions, there seems to be

evidence to support that biochar production may be a good future investment in the development of CO_2 emissions reduction and green waste diversion.

One concern with this project, however, is the capacity of the plant. The hypothetical plant in the example above has a maximum capacity lower than the expected inflow of green waste from Oakland. In addition, Grover Landscaping composts green waste from all over Alameda County, not just Oakland. One possible solution to this problem is to do both composting and pyrolysis at Grover Landscaping. This way the pyrolysis plant could operate at full capacity while waste that is not converted into biochar is still handled in an environmentally friendly manner. In addition, handling both waste management methods at one plant could be an effective way to pilot biochar program. One should keep in mind however, that an extra cost is likely to be added for the separation of waste between the pyrolyis plant and the composting facility. This extra cost may be worth the investment, though, if it translates to the creation of more jobs. Since more man power may be needed to handle both operations at the facility, job creation could be a great benefit to adding a pyrolyis plant to Grover. The cost for additional labor and a change in infrastructure can be absorbed, however, by the net gains from biochar production and additional gains from selling biochar to local farmers.

Additionally, savings may be realized with economies of scale, where average cost per output decreases with increased production or plant growth, if Grover starts off with a small pyrolysis plant, then later expands its operations economies of scale can be realized as employees and managers adjust to the new infrastructure of biochar production. Also, increasing returns to scale, where outputs are more than doubled with doubled inputs, may be expected in the future as technologies for pyrolysis in the use of biochar production improve.

With all of the potential benefits of biochar in mind, one may wonder why this project is not already underway. Sometimes, underproduction of a potentially beneficial product is due to unaccounted for positive externalities. In this case, one major externality would be environmental benefits due to decreased fertilizer run-off with the use of biochar in agriculture. The problem is that such an externality is hard to asses monetarily and thus often goes unaccounted for, as seems to be the case with biochar production. Also, it is difficult to get cities to invest in an unproven technology. Biochar production it is a relatively new technology when considered on a large scale and even the conclusions considered in this paper are based on many assumptions.

Looking ahead, there are a few areas which further research would help in the adoption of biochar production for waste management. It is recommended that further research be conducted to assess the potential of biochar to increase major crop yields in California in order to determine more accurate profit margins expected for local farmers. In addition, further research is needed to determine the ability of pyrolyis to handle heterogeneous inputs such as municipal green waste. Another feedstock worth researching is heterogeneous wood waste. Currently Oakland's wood stock is diverted to Covanta where it is processed into a type of renewable energy, but Covanta can only handle "cleaner" wood waste, i.e. wood with little lead paint or glue and non pressure treated lumber [1]. If pyrolysis and biochar production could be shown to handle such feedstocks, then it may be more likely to be adopted as a means of processing wood waste. As a final recommendation, research should be conducted on the alignment of carbon sequestration through biochar production with Oakland's climate action plans and sequestration goals. If it can be shown that the production of biochar from green waste aligns with current city goals, then Oakland may be more likely to consider investment in a pyrolysis plant.

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