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The basics of biochar

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Contents

Introduction

Soils have the ability to absorb carbon dioxide and influence its concentration in the atmosphere. Biochar can be used to increase the ability of soils to sequester carbon and simultaneously improve soil health. The goal of this paper is to introduce the concept and origins of biochar, discuss its production process, potential uses, and the benefits and costs of biochar in its key roles in agriculture and climate change mitigation.

What is biochar?

Biochar is just charcoal made from biomass—which is plant material and agricultural waste—hence the name 'biochar'. It is a fine-grained charcoal produced from pyrolysis: the slow burning of organic matter in a low- or no-oxygen environment. What differentiates biochar from charcoal is its purpose; it is produced as an additive to soils, mainly to improve nutrient retention and carbon storage. [1] Although the history of biochar extends thousands of years, its science is still relatively poorly understood.

History of biochar

The term 'biochar' was coined in recent times, but the origins of the concept are ancient.[2] Throughout the Amazon Basin there are regions—up to two metres in depth—of *terra preta*.[3] This is a highly fertile dark-coloured soil that has for centuries supported the agricultural needs of the Amazonians.

Analyses of the dark soils have revealed high concentrations of charcoal and organic matter, such as plant and animal remains (manure, bones and fish). *Terra preta*'s productivity is due to good nutrient retention and a neutral pH, in areas where soils are generally acidic.[4] Interestingly, *terra preta* exists only in inhabited areas, suggesting that humans are responsible for its creation. What has not been confirmed is how *terra preta* was created so many years ago.

Many theories exist. A frontrunner is the suggestion that ancient techniques of slash-and-char are responsible for the dark earth. Similar to slash-and-burn techniques, slash-and-char involves clearing vegetation within a small plot and igniting it, but only allowing the refuse to

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1. J Lehmann and S Joseph, eds, *Biochar for environmental management*, Earthscan publishing, London, 2009.
2. EG Neves, RN Bartone, JB Petersen and MJ Heckenberger, *The timing of Terra Preta formation in the central Amazon: new data from three sites in the central Amazon*, 2004, Springer: Berlin; London.
3. *Terra preta* means 'dark earth' in Portuguese.
4. pH stands for potential of Hydrogen and measures acidity. A neutral pH is neither acidic nor alkaline; J Lehmann and S Joseph, p. 67.

smoulder (rather than burn). [5] Combined with other biomass and buried under a layer of dirt, the smouldering char eventually forms *terra preta*. [6] It is from these hypotheses of early slash-and-char practices that modern scientists have developed methods for producing biochar.

Biochar production

The biochar production process begins with biomass being fed into a pyrolysis kiln—a furnace that burns with little or no oxygen. The biomass could be crop residue, wood and wood waste, certain animal manure, or various other organic materials.

At the end of this, two main products come out of the kiln.[7] The first is biochar, usually representing about 50 per cent of the carbon content of the biomass. The other is biofuel. The biofuel is often syngas, which is a mixture of mainly hydrogen and carbon monoxide, with a little carbon dioxide. The proportions of the three gases vary according to the processes used to create the syngas. However, the important point is that syngas is combustible and so can be used as a fuel source. Depending on the process, the biofuel from the kiln could also be bio-oil, which can be used as a substitute for diesel in some engines.

The pyrolysis occurs at temperatures below 700˚C; but some parameters can be altered, such as the rate of pyrolysis, or the quantity of oxygen. Generally, faster pyrolysis results in more oils and liquids, slower pyrolysis produces more syngas. Minimising the oxygen present during pyrolysis optimises the production of biochar.[8]

Pyrolysis can be followed by a second stage: gasification. Gasification liberates more energy-rich syngases from the char (usually hydrogen-based). There may also be a 'gas cleanup' stage to remove some of the particulates, hydrocarbons and soluble matter from the gas.[9]

The biofuel generated from the pyrolysis process can be used to create the electricity needed to power the kiln or secondary stages of the process. So it is possible for the system to run autonomous of external power sources. The pyrolysis process described is summarised in Figure 1.

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5. Slash-and-burn techniques are the cutting and burning of vegetation to make way for agricultural activities.
6. E Ring, 'Amazonion Terra Preta', *www.ecoworld.com*, 27 November 2007, viewed 30 June 2009, http://www.ecoworld.com/blog/2007/11/27/terra-preta/.
7. Hydrogen and heat are other by-products of pyrolysis.
8. To be technically accurate, it should be mentioned that gasification can be used instead of pyrolysis. The difference is that pyrolysis is like baking without oxygen, whereas gasification is direct-heating with a little oxygen, but not enough for combustion.
9. Friends of the Earth, *Pyrolysis, gasification and plasma briefing*, September 2008.

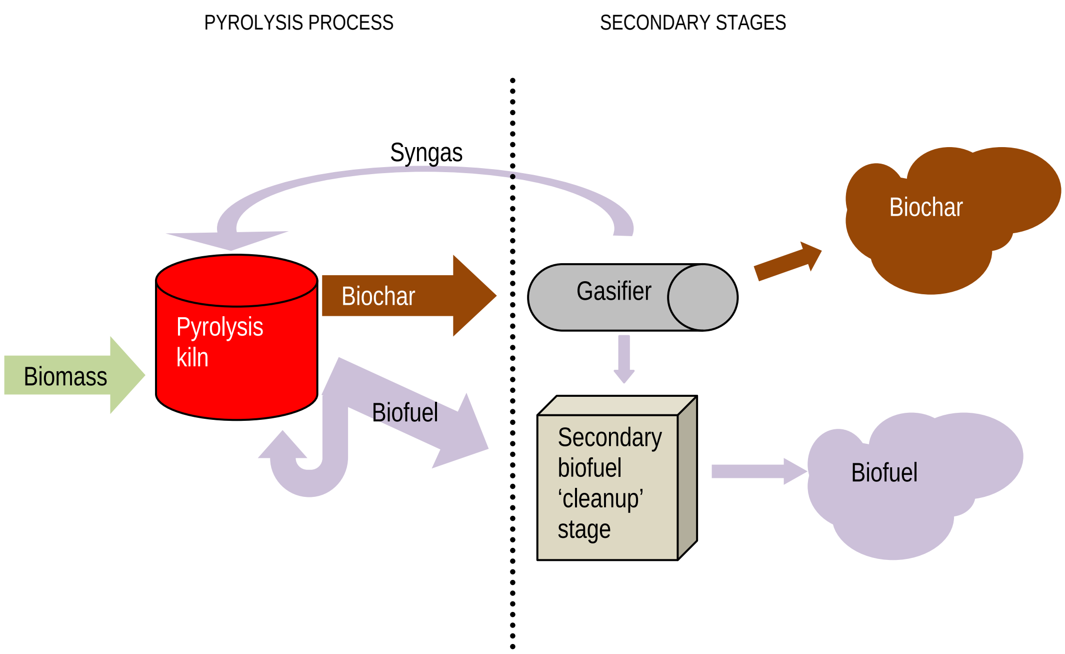

Figure 1: Simplified pyrolysis process flow diagram

An important advantage of biochar is that it can be produced either from small, simple mobile units or from larger, stationary ones. Small-scale systems for biomass inputs of 50 to 1000 kilograms per hour can be used on farms, while large units of up to 8000 kilograms per hour can be operated by large industries.[10]

There are potentially three broad types of pyrolysis systems:

- central pyrolysis plants for processing all the biomass in a region.
- lower-tech pyrolysis kilns for individual farmers or small groups of farmers (these kilns may not include some secondary stages such as the gasification or gas cleanup).
- pyrolysis trucks powered by syngas that could be driven around for processing biomass within a region. The biochar and bio-oil would be transported on the truck back to the customers.

Biochar applications

Biochar has been popularised by its potential role in climate change mitigation. Biochar is rich in carbon and, depending on its ultimate use, the biochar may retain the carbon, thereby

10. Best Energies website, http://www.bestenergies.com/companies/bestpyrolysis.html, accessed 26 June 2009.

delaying or completely preventing the release of the carbon back into the atmosphere in the form of carbon dioxide gas. The benefits of biochar go beyond this, however, extending to the agricultural sector and to various types of waste management. Furthermore, as outlined above, its production process co-generates biofuel, a sustainable renewable energy source.

Benefits to the agricultural sector and waste management

The agricultural sector can benefit from biochar in two ways: soil improvement and animal and crop waste disposal. Soil improvement, and therefore increased productivity, can be the driver behind biochar production and use. Since 1980, field trials have been taking place around the world experimenting with the application of biochar types on specific soils.

The type of biochar varies with biomass type—in many cases rice, wood or bark has been used—and production parameters, such as the rate of pyrolysis and kiln size. In most of the studies, acidic soils have been the subject of research, and these have generally been in tropical or semi-tropical regions. Experiments have also employed differing treatments, applying relatively more or less biochar, with and without the use of other fertilisers.[11]

Results of trials have ranged from no increase in productivity (the case of banana plantations in Brazil) to as much as a 151 per cent increase in soybean yield in one project.[12] In many cases it was noted that soil acidity was reduced and mineral uptake increased, with residual effects sometimes lasting through to the following season or two.[13] Research is still required into the use of biochar for pastures or tree plantations, and for soils in dry and/or temperate regions.

A second benefit of biochar production to the agricultural sector (and some industries, such as the paper industry) is the fact that it uses organic waste. Left to accumulate, animal and crop waste can contaminate ground and surface waters. Waste management practices are aimed at preventing such contamination, but they can become costly. Biochar presents an attractive alternative if the economic costs can be kept below those of waste management.[14]

By accepting organic material as its input, the biochar production process transforms waste into a resource. The pyrolysis process reduces the weight and volume of the feedstock, and by operating at a temperature above 350˚C, it also removes potential pathogens that can be a

11. J Lehmann and S Joseph, pp. 209–11.

12. C Steiner, *Slash and char as Alternative to slash and burn: English summary*, Dissertation, University of Bayreuth, Germany, 2006, p. 27, and S Sohi, E Lopez-Capel, E Krull and T Bol, *Biochar, climate change and soil: A review to guide future research*, CSIRO Land and Water Science Report 05/09, February 2009.

13. See for example J Lehmann and S Joseph, pp. 209–11.

14. 'Waste management solutions', CSIRO online, viewed 29 July 2009, http://www.csiro.au/org/WasteManagementOverview.html

problem if directly applied to soils.[15] Green urban waste and waste from some industrial processes, such as paper milling, can also be used. [16]

Climate change mitigation

Biochar has been given a lot of attention recently as one means of addressing climate change. It has the capacity to do so in three ways: the storage of carbon over long periods; the reduction of greenhouse gases such as methane (CH_4) and carbon dioxide (CO_2) that can be generated from waste disposal, waste processing or recycling; and the production of renewable energy.

Through the production process, around 50 per cent of the feedstock's carbon content is retained in the biochar. This compares to the 10 to 20 per cent that remains in biomass after 5 to 10 years of natural decay, and the less than 3 per cent that remains in ash after complete burning. [17] Some analyses have suggested that 'up to 12% of the total anthropogenic [carbon] emissions by land use change can be off-set annually in soil, if slash-and-burn is replaced by slash-and-char'. [18] If it proves practicable to replace traditional slash-and-burn practices with slash-and-char methods, biochar may present a real quantifiable and verifiable option for storing carbon in the long term.

At the same time, it has the potential to reduce emissions from other activities that might need to take place in the absence of the biochar option. These other activities are the waste disposal process described above and any recycling process. Both can be sources of greenhouse gas emissions, either as carbon dioxide from transport and processing, or methane from landfill sites.

Finally, the pyrolysis process also produces viable forms of renewable energy. The syngas and bio-oils that result from the biochar production process, and the generated heat, can be used either to produce electricity, or as fuel. [19] Not only does this represent a renewable energy alternative but it also improves the energy efficiency of the pyrolysis process. [20]

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15. K Cantrell, K Ro, D Mahajan, M, Anjom and P, Hunt, 'Role of thermochemical conversion in livestock waste-to-energy treatments: obstacles and opportunities', *Industrial and Engineering Chemistry Research*, no. 46, 2007, pp. 8918–27.
16. J Lehmann and S Joseph, p. 6.
17. J Lehmann, J Gaunt and M Rondon, 'Bio-char sequestration in terrestrial ecosystems—a review', *Mitigation and Adaptation Strategies for Global Change*, no. 11, 2006, pp. 403–27
18. J Lehmann, J Gaunt and M Rondon, p. 403.
19. J Lehmann, 'Bio-energy in the black', *Frontiers in Ecology and the Environment*, 2007, vol. 5, pp. 381–7
20. J Lehmann and S Joseph, p. 7.

Moreover, it has been calculated that 'the emission reductions associated with biochar additions to soil appear to be greater than the fossil fuel offset in its use as fuel'. [21]

Limits to the 'biochar solution'

Despite the potential benefits that biochar presents, there are limits to its potential production and usage. A major limitation to the production of biochar is that the biomass used cannot be drawn from just any agricultural (or industrial or urban) waste. Some studies have estimated that no more than three per cent of available biomass is suitable for producing biochar.[22] On a global scale, using all aboveground biomass would sequester only 0.56 gigatonnes of carbon per year, just one third of what is emitted each year from land use change, or less than a tenth of annual fossil fuel emissions. [23]

If plants are grown specifically for the production of biochar (instead of using waste), then the plants must have a growth rate matched to the rate of planned biochar production. Fast growing plants deliver the best productivity, but these also mature earlier and may begin to decay sooner. The most efficient way to capture the carbon used by the plant in photosynthesis would be to harvest it before the growth rate begins to taper.[24]

Also, the purpose for the produced biochar will change the potential benefits, so it must be clear from the beginning whether the goal is to improve soil nutrient retention, sequester carbon or manage waste. Whatever the objective, the process will be optimised for that purpose in order to maximise financial return. This is often to the detriment of other benefits. By targeting soil improvement, the resulting biochar may not produce any usable renewable energy; or if bio-energy production is the main objective, the resultant biochar may be too unstable to store any carbon long-term[25]. Such trade-offs are not to be neglected as the ultimate profitability of the process will determine its potential net benefit.

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21. J Gaunt & J Lehmann, Energy Balance and Emissions Associated with Biochar Sequestration and Pyrolysis Bioenergy Production, Environmental Science & Technology, 2008, vol. 42, pp. 4152–8

22. J Lehmann, J Gaunt and M Rondon, p. 407.

23. J Lehmann, J Gaunt and M Rondon, p. 408 and K Denman, G Brasseur, A Chidthaisong, P Ciais, P Cox, R Dickinson, D Hauglustaine, C Heinze, E Holland, D Jacob, U Lohmann, S Ramachandran, P da Silva Dias, S Wofsy and X Zhang, *Couplings Between Changes in the Climate System and Biogeochemistry.* In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* 2007: [Solomon, S, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor and HL Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

24. J Lehmann and S Joseph, p. 8.

25. J Lehmann and S Joseph, p. 148.

Unfortunately, the profitability of biochar is an area where little study has been undertaken. While numerous research projects and pilot studies have looked at the possible increases in agricultural productivity from various sorts of biochar, it seems that the cost-benefit analyses needed to ascertain the ultimate bottom line are lacking. [26] The increased profits from improved productivity may be completely offset by the costs incurred through the biochar production process—this could also be influenced by any eventual price on carbon. [27] Generally, more research is needed in this area.

It appears that the biggest limitation to the immediate major deployment of biochar is the need for further research. The CSIRO has identified at least eight research gaps, including predictive biochar knowledge, biochar interactions on the microbial level, water retention capacity, and assessment of potential soil carbon.[28] It could be three to five years before biochar can be seriously considered for carbon storage on any large scale. [29]

Conclusion

The overall concept of biochar is now well understood. Take the farmyard scraps, feed them into a pyrolysis kiln, apply the material produced back to the land and in doing so, improve soil health, lock away carbon, and generate renewable energy. But not all biochar is the same. Production process, applications, benefits and costs vary with the biomass, soil-types and ultimate purpose. The scientific, financial and societal factors of biochar have yet to be assessed on any significant scale. Biochar has a role to play in the capture of terrestrial carbon, but its capacity to mitigate climate change should not be overstated. It should be seen as a complementary measure to attempts at reducing emissions.

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26. J Lehmann and S Joseph, p. 208.
27. S Sohi, E Lopez-Capel, E Krull and R Bol.
28. S Sohi, E Lopez-Capel, E Krull and R Bol.
29. A Salleh, Biochar needs 'years more research', *ABC Science online*, 4 March 2009, viewed 11 August 2009, http://www.abc.net.au/science/articles/2009/03/04/2507238.htm