Biochar and climate change

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Summary

- This note briefly introduces biochar as a measure to tackle climate change.
- Biochar is created by burning organic material to produce a charcoal-like substance.
- When buried in soil the carbon contained within biochar may be isolated from the atmosphere for long periods.
- Some commentators believe that biochar will have an extremely important role in reducing atmospheric concentrations of greenhouse gases—helping to avoid dangerous climate change and improving agricultural productivity.
- Other commentators believe that the benefits are overstated and that there could be negative environmental impacts.
- Some countries are seeking biochar mitigation to be included in the international climate change framework being negotiated in 2009.

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1 What is biochar?

Biochar is produced by treating organic matter with heat in low or zero oxygen environments. The process, which is also known as pyrolysis or gasification, draws off a portion of the material as a gas and liquid leaving behind carbon as a solid. This solid is known as biochar. The same process is used to create charcoal from wood.

Biochar as a climate mitigation technology has benefits over other technologies, such as carbon capture and storage, as it already exists and can be applied at a range of scales. For example, small stoves could be used to generate biochar from food and smallholder agricultural waste or technologically advanced systems could be used to generate electricity, fuel and biochar from municipal waste streams.

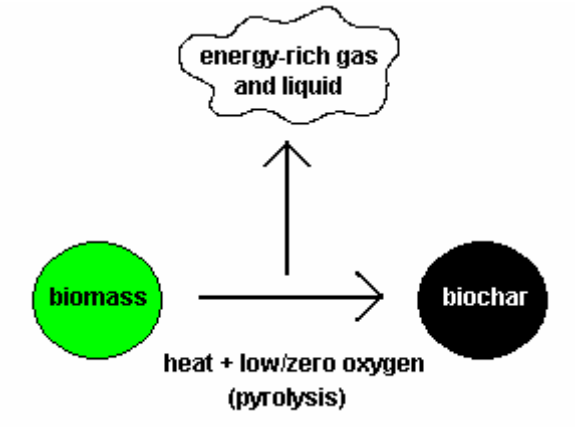

Figure 1: Production of biochar

2 Role of biochar in mitigating climate change

Untreated organic matter normally decomposes in soil within a few years, releasing the carbon it contains back into atmosphere.[1] When this material is treated to form biochar it might take hundreds or thousands of years for the carbon to re-enter the atmosphere.[2] Due to its chemical stability, biochar has been mooted as a way to reduce atmospheric concentrations of carbon dioxide to tackle climate change. This technique could be used to remove large amounts of carbon from the atmosphere, sequestering it for long periods.

This climate mitigation technique has garnered support from a number of scientists and commentators who believe that it could have a significant role to play in avoiding dangerous climate change. James Lovelock described biochar burial as the “one way we could save ourselves”. He explained his views in a New Scientist interview:

> It would mean farmers turning all their agricultural waste - which contains carbon that the plants have spent the summer sequestering - into non-biodegradable charcoal, and burying it in the soil. Then you can start shifting really hefty quantities of carbon out of the system and pull the CO2 down quite fast.
>
> Would it make enough of a difference?
>
> Yes. The biosphere pumps out 550 gigatonnes of carbon yearly; we put in only 30 gigatonnes. Ninety-nine per cent of the carbon that is fixed by plants is released back

[1] An exception to this is peat soils, which can accumulate large stores of carbon.
[2] Longevity of biochar carbon storage, UK Biochar Research Centre, 5 August 2009

> into the atmosphere within a year or so by consumers like bacteria, nematodes and worms. What we can do is cheat those consumers by getting farmers to burn their crop waste at very low oxygen levels to turn it into charcoal, which the farmer then ploughs into the field. A little CO2 is released but the bulk of it gets converted to carbon. You get a few per cent of biofuel as a by-product of the combustion process, which the farmer can sell. This scheme would need no subsidy: the farmer would make a profit. This is the one thing we can do that will make a difference, but I bet they won't do it.[3]

Many other scientists and commentators have indicated support for the technology. A report commissioned in 2009 by the Guardian newspaper rated biochar as one of the top 10 climate change solutions.[4] In addition, researchers at the University of East Anglia:

> …recently rated biochar as one of the best technological fixes for cooling the planet… biochar has the potential to sequester almost 400 billion tonnes of carbon by 2100 and to lower atmospheric carbon dioxide concentrations by 37 parts per million.[5]

3 Other benefits of biochar

3.1 Soil fertility and food production—terra preta

Charcoal has been used to improve soils for agriculture for millennia. In Amazonia, terra preta[6] soils were created by pre-Columbian populations who mixed charcoal and other organic wastes into soils to increase crops yields. Some of these characteristically dark soils are 7000 years old.[7]

One study estimated that terra preta soils are twice as productive as other soils in the area.[8] Other research:

> …suggests that in most cases the addition of charcoal improves soil productivity, and although the reasons for the increased fertility still aren't entirely understood, several things seem to be going on. First, the biochar itself contains some nutrients such as phosphorus, potassium and zinc. But the biochar also seems to help the soil retain some nutrients that would otherwise leach out, as well as helping it to retain water. In addition, biochar might encourage soil microbes that increase crop productivity. And the productivity gains seem to continue to increase even when very high levels of carbon have been added to the soil — up to 140 tonnes per hectare in sandy, weathered soils, and up to about 50 tonnes per hectare on average.[9]

A significant additional benefit of improved soil fertility through biochar application would be a reduction in the need for fertiliser application. Fertilisers can contribute to greenhouse gas emissions and other environmental impacts.

The potential for biochar to increase agricultural productivity makes the process very attractive in light of two possible future global challenges:

- A decline in agricultural productivity due to climate change. Weather patterns are predicted to shift over time leading to a decrease in agricultural productivity across

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[3] "Interview: James Lovelock; The man behind the Gaia theory thinks that climate change will wipe out most of us this century - but there's one last way to save ourselves", *New Scientist*, 24 January 2009
[4] "Locking up carbon with biochar", *The Guardian*, 13 July 2009
[5] " The bright prospect of biochar", *Nature Reports*, 21 May 2009
[6] From "dark earth" in Portuguese
[7] " The bright prospect of biochar", *Nature Reports*, 21 May 2009
[8] ibid
[9] ibid

many regions.[10] Biochar use may help to counteract this decline both by improving yields and by mitigating climate change.

- Food security concerns. Global human populations are predicted to increase to 9 billion by 2050, placing increasing strain on food supplies. If biochar and other low-carbon agricultural measures can substantially increase yields, there will be less pressure to convert forests to farmland. This is critically important given that it appears as though deforestation must be halted and reversed if dangerous climate change is to be avoided.[11]

3.2 Bioenergy

During the creation of biochar, energy rich gases and liquids are released that can be used to generate low-carbon energy. However, there is a trade-off between energy generation and biochar production. Maximising the volume of biochar that can be produced from biomass material lowers the overall amount of energy that can be extracted from it.

Nevertheless, a reduction in the amount of energy generated from biomass might be justified in terms of overall emission reductions. A study that looked at the lifecycle emissions of systems maximised for either biochar or energy production found that:

> …the avoided emissions are between 2 and 5 times greater when biochar is applied to agricultural land (2–19 Mg CO_2 ha^{-1} y^{-1}) than used solely for fossil energy offsets. 41–64% of these emission reductions are related to the retention of C in biochar, the rest to offsetting fossil fuel use for energy, fertilizer savings, and avoided soil emissions other than CO_2. Despite a reduction in energy output of approximately 30% where the slow pyrolysis technology is optimized to produce biochar for land application, the energy produced per unit energy input at 2–7 MJ/MJ is greater than that of comparable technologies such as ethanol from corn.[12]

4 Criticism of biochar

Although biochar could have significant benefits, some are concerned that a policy to stimulate the large scale application of the technique could have unintended or unknown consequences.

4.1 Competition for land

The debate surrounding biofuels clearly demonstrates the complex and sometimes unintended consequences associated with policies that alter the way in which land is used and commodities produced. Biofuels were promoted to reduce emissions from transport, but some claim that the stimulation of agriculture that it lead to gave rise to greater overall emissions due to the conversion of forests to farmland and the application of more intensive farming techniques.[13] George Monbiot argued that:

- natural ecosystems could be replaced by tree plantations to create the biochar;

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[10] Environmental Audit Committee, *Reducing greenhouse gas emissions from deforestation: No hope without forests*, 16 June 2009, HC 30, 2008-09

[11] ibid

[12] "Energy Balance and Emissions Associated with Biochar Sequestration and Pyrolysis Bioenergy Production", College of Agriculture and Life Sciences Cornell University, 7 January 2008

[13] Environmental Audit Committee, *Are biofuels sustainable?*, 15 January 2008, HC 76-I, 2007-08

- there might be food security issues if agricultural land is given over to biochar production; and,

- there might be human rights issues if vulnerable people are moved off their land to make way for biochar plantations.[14]

4.2 Lack of evidence on soil/biochar interactions

George Monbiot also pointed out that biochar may not have the expected benefits for agricultural productivity:

> In some cases charcoal in the soil improves plant growth, in others it suppresses it. Just burying carbon bears little relation to the farming techniques that created terras pretas Nor is there any guarantee that most of the buried carbon will stay in the soil. In some cases charcoal stimulates bacterial growth, causing carbon emissions from soils to rise.[15]

This last point, that it may be too early to say how biochar will behave in soils, was made in an article published by Nature magazine:

> Soil scientist David Wardle reported in Science last year that, in Swedish forests at least, charcoal may cause carbon to disappear from the soil much more quickly than expected. Wardle and his team left mesh bags containing either humus, charcoal or a mixture of both on the forest floor and recorded how much mass was lost from each over a ten-year period. They found that the mixtures of humus and charcoal lost more mass than the controls of humus and charcoal alone. Wardle thinks that the charcoal promoted microbial breakdown of the humus, accelerating the release of CO2 back into the atmosphere. It's also possible that some microbes could degrade biochar directly. Although the black carbon that makes up the bulk of biochar is thought to be biologically unavailable to most microbes, research suggests that some microbes might be able to metabolize it. If so, it would be less stable in soil than currently thought.
>
> Another outstanding issue is to what extent modern-day biochar application will fulfil the promise of terra preta in improving soil fertility.[16]

4.3 Other issues

There is a lack of information on certain aspects of biochar application. For example, biochar darkens the appearance of soil, which could lower the amount of solar radiation reflected from the planet's surface. This could contribute to increases in global temperature, although the changes in albedo that may result from a switch to biochar have yet to be quantified.[17]

Biochar could also have negative implications for health if its incorporation into soil led to the accumulation of heavy metals and undesirable compounds[18] in the soil.[19]

There are also questions surrounding the technological and economic feasibility of incorporating biochar into soils to the extent that it would have an impact on climate change, although some contend that "none of the potential problems seem insurmountable".[20]

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[14] "Woodchips with everything. It's the Atkins plan of the low-carbon world", *The Guardian*, 24 March 2009
[15] ibid
[16] " The bright prospect of biochar", *Nature Reports*, 21 May 2009
[17] Biochar, climate change and soil: A review to guide future research, CSIRO, February 2009
[18] Such as polycyclic aromatic hydrocarbons (PAHs) that may have carcinogenic and other undesirable qualities
[19] Biochar, climate change and soil: A review to guide future research, CSIRO, February 2009

4.4 Distraction from emission reductions

Some are concerned that biochar sequestration could distract from the need to reduce greenhouse gas emissions:

> Alan Robock, a climate scientist at Rutgers University, also worries that methods to sequester carbon, including biochar production, could distract attention from the need to reduce emissions. "The people who created the problem like the idea. They can keep using the atmosphere as a sewer and let other people clean up the mess," he says.
>
> Most biochar researchers agree that the technology needs more study and that the most important thing is to reduce emissions in the first place. "Biochar is not a silver bullet for sequestration," Lehmann says. "We cannot continue the emissions that we generate today and anticipate that any technology or combination of technologies could compensate." Nevertheless, it's possible that biochar could help mitigate those emissions, he says.[21]

5 Reviews of biochar research

A review of biochar research was published in January 2009. Prepared by research institutions in the UK and Australia it sought to bring together existing knowledge and to identify key knowledge gaps. It came to a number of conclusions—here is a selection:

- there is global *potential* for annual sequestration of atmospheric CO2 at the billion-tonne scale (109 t yr-1) within 30 years;
- however, the underlying published evidence arises mainly from small-scale studies that do not currently support generalisation to all locations and all types of biochar;
- at the moment there is no established method to artificially-age biochar and assess likely long-term [stability in the soil];
- An environmental risk assessment that includes the impacts of these on terrestrial or aquatic ecosystems is outstanding. Given the stability of biochar, safe rates of applications need to be determined for individual soil types to avoid possible detrimental effects due to over-application;
- a large number of studies have been conducted where biochar application has shown significant agronomic benefits with a minor number of studies showing no significant effects of biochar application on crop productivity and some studies reporting adverse effects. This suggests that the extent of the effect of biochar on crop productivity is variable, due to the different bio-physical interactions and processes that occur when biochar is applied to soil, which are not yet fully understood.[22]

6 The way forward?

To determine the future of biochar as a climate change mitigation technique will require the knowledge gaps outlined above to be filled. There may also be a need to develop international standards and agreements in order to prevent negative environmental impacts—such as the replacement of natural ecosystems with tree plantations to produce

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[20] "The Charcoal Vision: A Win–Win–Win Scenario for Simultaneously Producing Bioenergy, Permanently Sequestering Carbon, while Improving Soil and Water Quality", *Agronomy Journal*, 11 January 2008

[21] " The bright prospect of biochar", *Nature Reports*, 21 May 2009

[22] Biochar, climate change and soil: A review to guide future research, CSIRO, February 2009

biochar.[23] The House of Commons Environmental Audit Committee has called on the Government to work towards sustainability standards for forest protection and the production of commodities more widely.[24]

The Royal Society in its September 2009 report on *Geoengineering the climate* also found that more research was required:

> …biomass for sequestration could be a significant small-scale contributor to a geoengineering approach to enhancing the global terrestrial carbon sink, and it could, under the right circumstances, also be a benign agricultural practice.
>
> However, unless the sustainable sequestration rate exceeds around 1 GtC/yr, it is unlikely that it could make a large contribution. As is the case with biofuels, there is also the significant risk that inappropriately applied incentives to encourage biochar might increase the cost and reduce the availability of food crops, if growing biomass feedstocks becomes more profitable than growing food.
>
> Biochar and other forms of sequestered biomass have not yet been adequately researched and characterised, and so should not be eligible for carbon credits under the UNFCCC flexible mechanisms until there is a reliable system in place for verifying how much carbon is stored, and the wider social and environmental effects have been determined. Substantial research will be required to achieve these conditions…[25]

Although there remain uncertainties surrounding this technology, some countries are seeking its inclusion in the international climate change framework negotiated in 2009.[26]

7 UK Government action

In July 2009, the Department for Environment, Food and Rural Affairs commissioned the UK Biochar Research Centre to conduct a study and questionnaire into "the Potential Benefits, Costs and Issues Surrounding the Addition of Biochar to Soils". This will report by the end of 2009 and has the following objectives:

> To review evidence on the nature of biochar and the effects of different feedstocks and variations in the pyrolysis process on the final composition and properties of biochar.
>
> To assess and review evidence on the methods by which biochar could be incorporated into soils and how this may affect, or be affected by, land use, land management practices and regulations, and the addition of other organic materials.
>
> To assess and review evidence on the subsequent fate and behaviour of biochar in soil, including its interaction with other soil components.
>
> To assess and review evidence on the impact of biochar on soil properties and functionality and the benefits and disbenefits associated with biochar addition - including consideration of wider environmental effects.
>
> To assess and review the effects, and implications, of biochar addition on soil carbon monitoring.

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[23] The bright prospect of biochar", *Nature Reports*, 21 May 2009

[24] Environmental Audit Committee, *Reducing greenhouse gas emissions from deforestation: No hope without forests*, 16 June 2009, HC 30, 2008-09

[25] Geoengineering the climate: science, governance and uncertainty, Royal Society, 1 September 2009

[26] Biochar: Is the hype justified?, BBC News, 16 March 2009

To evaluate, review and develop life cycle assessments of biochar, including its various possible feedstocks, land-use and energy system applications, for the UK context as far as is feasible given current data availability.

To evaluate the costs of biochar from different configurations of feedstocks, energy conversion technologies and biochar utilization, including regulatory and quality assurance issues.[27]

[27] "Review of the potential benefits, costs and issues surrounding the addition of biochar to soil: an expert elicitation approach", UK Biochar Research Centre, 1 September 2009