A critical review of biochar science and policy

– Executive Summary –

Full report: www.biofuelwatch.org.uk/2011/a-critical-review-of-biochar-science-and-policy/

As the impacts of climate change escalate, efforts to develop new technologies and new approaches to reducing emissions are promoted. One proposal is to sequester carbon in soils using biochar. Biochar is essentially fine-grained charcoal added to soils. Advocates claim that adding biochar to soils will store carbon safely away from the atmosphere for hundreds or even thousands of years, while boosting soil fertility and providing other benefits.

What is the basis of these claims? Is biochar really a viable approach?

This report takes a critical look at the claims made about biochar, reviews the science underlying them and provides an overview of what biochar advocates are seeking in terms of policies and supports.

What is biochar?

The International Biochar Initiative (IBI), the main biochar advocacy group, defines biochar as "*the carbon (C) rich product when biomass, such as wood, manure or leaves, is heated with little or no available oxygen...produced with the intent to be applied to soil as a means to improve soil health, to filter and retain nutrients from percolating soil water, and to provide carbon storage*"(tinyurl.com/c7uktq4). By that definition, the term would include traditional charcoal, char produced through gasification (which turns solid biomass into syngas and leaves around 10% of it behind as char) and modern pyrolysis (which produces syngas and bio-oil, both of which can be captured for bioenergy, as well as varying amounts of char), as well as through two very experimental technologies: Hydro-thermal carbonization and flash carbonization. However, both the science about and the advocacy for biochar generally refer to biochar produced through modern pyrolysis, in which energy is captured and a significant proportion, usually 12-40% of the original biomass, is retained as char – not the same as traditional charcoal. As the IBI's definition shows, biochar is defined by its purpose, not by its chemical properties. Chemically, the only common feature of different biochars is that they are forms of black carbon biomass, defined as the 'incomplete product of combustion'.

It is increasingly evident that the effects of biochar on soils, crops and soil carbon depend partly on different biochars physical and chemical properties, and partly on the highly varied soil and ecosystem properties. Yet few of the studies on which claims about biochar are based actually were studies of char residues from modern pyrolysis – a reflection of the the fact that modern pyrolysis has not so far proven commercially viable. Rather they tend to be studies of traditional charcoal, charcoal and soot remains from wildfires or swidden agriculture, or even soot deposited from fossil fuel burning. Because of the very different characteristics of these materials and their interactions with an even greater variation in soils, it may never be possible to draw general conclusions about the impact of biochar on soils and plant growth.

Field testing – by far the most relevant type of testing – is surprisingly lacking. Only around 13 peer-reviewed field studies, based on 11 different trials have been published; their results vary greatly, even within individual studies, and only two lasted longer than two years. The current evidence base is thus far too small for making reliable predictions about the impact of different biochars on different crops, in different soils and in different combinations with organic or mineral fertilisers.

Climate impacts of biochar: claims versus science

Biochar advocates base their claims that biochar will sequester carbon for hundreds or thousands of years on a combination of 1) laboratory analysis and incubation studies (in which soil samples with biochar are kept under warm to high temperatures and carbon losses are measured over time); 2) studies of old charcoal remains from wildfires and swidden agriculture and from Terra Preta. Terra Preta are soils created by indigenous peoples in the Central Amazon, hundreds to thousands of years ago, which still contain large amounts of black carbon and exhibit a high degree of fertility. Modern biochar however, bears little resemblance to this. Terra Preta soils were made using many different materials and a process no longer known. Simply adding one ingredient, charcoal, to soils, generally in the context of monoculture cropping practices, is very different and the analogy is not supported by evidence. While it is clear that charcoal can in some cases be stable over long periods, it is also clear that this is not always the case, and that the reasons for this variability are neither well understood nor controllable. Nonetheless, biochar advocates claim, for example, that biochar could sequester as much as 2.2 billion tonnes of carbon every year by 2050, that it can be useful for climate geoengineering as a means of "carbon dioxide removal", to "enhance" the global carbon cycle. Such large-scale visions would entail conversion of large areas of lands to grow biochar feedstocks, raising the potential for land grabs and expanding monocultures and deforestation. One recent report published in Nature Communications, co-authored by leading IBI members, claims a theoretical potential for biochar to reduce global emissions by 12% based on "sustainable" levels of biomass harvest – yet this included conversion of 556 million hectares of land.

These claims are alarming, especially given the dearth of scientific studies and the mixed results from those that have been performed.

Biochar field trials and soil carbon

Is the claim that biochar will remain stable in soils for hundreds or even thousands of years supported by evidence? Even the scant number of relevant field studies that have been done do not support any such a claim. Of the 11 field trials that exist, only 5 looked at what happens to soil carbon when biochar is added and one of those (tinyurl.com/3nvyg66) looked at 'charred soil' rather than what is usually regarded as biochar. The others were based on the application of traditional charcoal in soils, not modern pyrolysis biochar, but nonetheless, results were as follows:

In a 4-year study in Colombia, two years after a large amount of biochar (20 tonnes per hectare) was applied, the plots with biochar held significantly *less* carbon than those without. In a separate two-year study from Colombia, biochar made no significant difference to soil carbon, except when an exceptionally large amount (116 tonnes per hectare) was used.

In an 18-months long trial in Western Kenya, Tithonia leaves, manure, sawdust and biochar were applied to different plots on four different soils (with different levels of existing soil carbon). At the end of the trial, soils amended with biochar had the highest overall carbon levels in only one out of four soil types.

In a study in Central Amazonia, biochar on its own and in most combinations with other fertilisers did not significantly improve soil carbon five months after it had been applied.

In the Philippines, adding biochar to three rice fields did raise soil carbon levels at two locations compared to unamended soil or soil amended with rice husks, but at a third location, the plots with the uncharred rice husks held more carbon than those with biochar.

In summary, field study results so far suggest that biochar is not a reliable way to increase soil carbon. It is not clear what happened to the 'lost' carbon in these different studies. Some biochar carbon might not have been stable. Some biochar may have stimulated soil microbes, which then turned existing soil organic carbon into CO_2 (called "priming"). Some may have been lost through water or wind erosion.

A recent scientific review by 14 soil scientists from 12 research institutes published in *Nature* (tinyurl.com/62xxmmr) points to the role of ecosystem properties in determining the stability of carbon in soils and concludes that it is impossible to predict how stable different forms of carbon will be in soils from looking at their molecular structure or at laboratory studies – yet predictions about biochar carbon being 'stable' strongly rely on doing just that. The article points out that "It remains largely unknown why some SOM [soil organic matter' persists for millennia whereas other SOM decomposes readily". It shows that some cases types of soil carbon which appear particularly unstable in a laboratory can remain stable in soils for long periods whereas types of carbon which appear very 'recalcitrant', including black carbon (i.e. the carbon found in biochar), can sometimes decompose faster than other soil carbon. The authors (amongst them the Chair and an Advisory Board member of the IBI) state: "*Sequestration strategies based on adding recalcitrant material to soils, whether through plant selection for recalcitrant tissues or through biochar amendments must be re-evaluated.*"

Claims about biochar being a reliable means of sequestering carbon in soils are thus borne out by recent scientific findings.

Further, the production of biochar requires massive quantities of biomass since only between about 12-40% of the carbon is retained in char. The climate impacts of harvesting, transporting, pyrolyzing, and ploughing in such large amounts of charcoal into soils would contribute hugely to emissions, even before considering likely direct and indirect impacts of large-scale land-conversion.

Another concern is that biochar particles can be very small, or can break down over time to become very small – small enough to become airborne, and, like soot, contribute to global warming by reducing albedo (absorbing rather than reflecting energy from the sun). This effect could counter and reverse any theoretical gains from carbon sequestration through biochar.

Finally, biochar advocates also claim that biochar will benefit the climate by reducing nitrous oxide emissions from soils, but evidence for this is extremely sparse – based largely on a single field test in which very large amounts of biochar was applied to cow urine in a pasture.

Biochar and soil fertility: claims versus science

The claim that biochar improves crop yields and reduces the need for mineral fertilisers is used to support the idea that biochar is beneficial to climate (lessening fertiliser demand and, if biochar is made from residues demand for land and thus, it is claimed, deforestation) and also that it will benefit peasant farmers (for whom fertilisers are inaccessible). There are a number of possible ways in which biochar could potentially increase or decrease plant growth. These include stimulation of microbes which then outcompete plants for access to limited nitrogen, providing additional nutrients in the ash associated with biochar, altering soil pH, texture or water retention capacity, influencing microbe communities or increasing cation exchange capacity (which enhances the ability of plants to uptake nutrients). Some of these effects are short term, while others occur only over the long term.

Field trials looking at biochar impacts on soil fertility impacts to date are all short or medium term (up to four years) and therefore not representative of the impacts over time. Seven of the eleven field trials that we found looked at impacts on crop yields. Results were highly variable – in some cases biochar appeared to increase yields, in others it reduced them - depending on the type of biochar, the soil, the type of crops tested and what else was also added to the plots (fertilisers, compost etc). Results also varied over time from year to year following biochar application. Overall, there is little support for any assumption that biochar can reliably increase crop yields. Farmers who seek to improve yields using biochar are therefore taking a significant risk, especially since that they must first invest in producing, or purchasing the biochar. So far, very little commercial production of biochar is underway. Efficient pyrolysis units are costly, difficult to operate and control and there is scant evidence of any practical benefits from biochar use.

Biochar policy trends

What does the biochar lobby seek? The push for commercial scale biochar production continues to focus largely on securing funding to scale up production and securing carbon offsets, subsidies, public loan guarantees, public-private finance and private investments for biochar research, development and deployment.

The main lobby group is the IBI, along with numerous regional biochar initiatives. These groups are comprised of academic researchers, business entrepreneurs, consultancies, bioenergy interests and a host of other "enthusiasts." They promote a range of biochar applications - from biochar for backyard gardening, to pyrolysis cook stoves or "slash and char" as a replacement for traditional "slash and burn" (swidden) practices, to global scale deployment for climate geo-engineering. All have in common the need for public and private finance and supports to ramp up production.

Biochar as "good for the poor"

Based on the, unproven, assumption that biochar does in fact reliably improve soils fertility and therefore crop yields, biochar has been promoted as a technology for improving the livelihoods of subsistence farmers in the developing world.

Dozens of biochar projects – dubbed trials without constituting scientific field trials - are underway in Southern countries, most of them initiated by Northern companies or organisations, some with open support from the IBI. A separate report by researcher Benoit Ndameu and Biofuelwatch (tinyurl.com/d26d3o3) assessed one such trial by the Biochar Fund, in south-western Cameroon, to understand the perspective of participating farmers. The trials, which turned out to have involved a small fraction of the number of participants publicly claimed, had been abandoned after a single harvest, with only preliminary data made available. Some 18 months on, many participants were still expecting a continuation of the project and financial rewards from it – they had invested a lot of work for free and in some cases appear to have rented the land for the trial plots. They had been made to expect to benefit financially from the imminent sale of carbon credits from the project, even though no carbon markets yet offer such credits and no evidence of any efforts by Biochar Fund to secure further funding for the project was found. Nonetheless, Biochar Fund had used proclaimed success in Cameroon to obtain funding for another biochar project – linked to REDD (reducing deforestation and forest degradation) in DR Congo. As in Cameroon, that project proposal, too refers to "reducing deforestation from slash-and burn" by improving soil fertility.

Some companies and advocates, such as WorldStove promote use of 'micro-gasifier' cook stoves that retain biochar, as an alternative to open fire cooking. However, peer-reviewed data comparing different modern cook stoves are scarce. Interim results from a stoves testing programme by the US Environmental Protection Agency show that efficiencies and emissions differ substantially between different stove models (including ones using the same general principle) and according to the moisture of the fuel burnt. Some micro-gasifier stoves can achieve high levels of efficiency with low emissions, however those which gasify the char as well make more of the energy in biomass available for cooking. Furthermore, 'biochar cook stoves' are still in the early development stages and serious challenges remain with designing clean, fuel-efficient stoves that meet practical needs for cooking.

The "pro-poor" rhetoric adopted by some leading biochar advocates fits neatly into the current discourse about an African Green Revolution or 'Evergreen Revolution' both of which seek to liberalise agricultural trade while further replacing traditional farming knowledge and agrobiodiversity with top-down 'knowledge' and 'expertise', including GMOs and a range of, largely unproven 'soil carbon conservation' techno-fixes and carbon marketing approaches.

Biochar advocates policy aims

High hopes were placed on funding for biochar from carbon markets – despite growing awareness of the failures of carbon trading, which can at best offer a 'zero sum game' – allowing for additional fossil fuel burning and emissions in the North in exchange for presumed 'greenhouse gas savings', mainly from projects in the South. In reality, the effects have been even worse: Carbon trading has rewarded some of the most polluting industries in Southern countries, from coal and steel companies to oil palm and industrial livestock companies with extra profits from carbon finance and has been subject to fraud. Carbon markets are facing an increasingly uncertain future. The Clean Development Mechanism (CDM), on which the IBI had initially focussed much of its attention, has shrunk by half since 2009 and there are serious questions whether it can survive without a comprehensive post-2012 UN climate agreement. 97% of carbon trading worldwide is linked to the EU Emission Trade Scheme, which specifically excludes land based "sinks" including soils until at least 2020 – and industry analysts are predicting a collapse of that market, too. Voluntary and other regional carbon trading schemes are very small and proposals to include biochar have not been seriously considered by any of them. Prospects for significant carbon market finance thus appear to be dim, despite World Bank efforts to promote the development of new carbon trading mechanisms and the inclusion of soils and agriculture within them. While efforts to get carbon finance for biochar continue, new avenues for potential support are also being explored. These include:

1) Taking advantage of the growing impetus within climate policy to broadly include agriculture, forestry and 'other land use', in a 'landscape approach', with numerous, often market- based initiatives within and outside of the UN process. For example, the inclusion of soils and agriculture in general into REDD (Reducing Emissions from Deforestation and Degradation) has been proposed. Particularly prominent are proposals for 'Climate-Smart Agriculture' put forward by the UN Food and Agriculture Organisation (FAO), World Bank and other institutions. This concept, discussed in some detail in Chapter 4, seeks to leverage a range of funding mechanisms, both from public and private-sectors, including carbon finance amongst other sources – for 'transforming' agriculture, placing particular emphasis on (supposedly) quantifiable greenhouse gas emission reductions and carbon sequestration, including in soils. Although biochar has not so far played a prominent role in those proposals, those developments could eventually offer supports for biochar.

2) Developing biochar carbon offset methodologies for unregulated and small-scale carbon offset schemes with a view of using those as a springboard for accessing larger (future) carbon markets. So far however they have had no apparent success in this quest. However, ConocoPhillips has become the first corporation to offer consistent support for biochar, apparently in the hope of creating future biochar carbon offsets for the Alberta Offset System, which is effectively an offset scheme for the tar sands industry.

3) Promoting biochar as a climate geoengineering technology. Biochar features in many climate geoengineering reports and debates as a means of "carbon dioxide removal", though it has generally been met with some reserve, although it is attracting growing interest from some corporate interests and 'philanthropists', including Shell, Richard Branson (including through his Carbon War Room) and the Gates Foundation. The Carbon War Room and the Gates Foundation have supported biochar as well as geoengineering in general.

4) Obtaining funding for research and development: Biochar research and development and, to a lesser extend, deployment, have attracted relatively modest public finance, for example in US, Australia, New Zealand and UK.

5) Developing industry standards with the intent that anyone investing in or purchasing biochar can know approximately what they are buying – an essential first step towards commercialization as well as attracting finance for deployment.

Biochar companies

Several of the start-up companies involved with biochar, are more fundamentally in the business of bioenergy – producing ethanol, biodiesel, bioproducts, bioelectricity etc. Biochar is not necessarily the central focus of their mission, but may be produced as a by-product or secondary product, in hopes that it can also be made profitable or that it can be used to make claims about 'carbon negative energy' for PR purposes. This is clear from a review of some of the existent companies. CoolPlanet Biofuels, for example, seeks to develop second-generation liquid biofuels along with small quantities of biochar. The char by-product is not a "waste" but rather Cool Planet aims to market it, and uses it as the basis for claiming its process to be "carbon negative". Alterna bioenergy makes "biocarbon" for use as coal substitute and is co-owned with AllWoodFibre – a woodchip procurement company. For industrial agribusiness, plantation and forestry industries interest in biochar hinges on whether or not it can provide revenues from "waste" materials and by-products otherwise of little or no value. Malaysian and Indonesian palm oil industry and Indonesian pulp and paper companies, as well as by the Brazilian Agricultural Research Corporation, Embrapa, and the International Rice Research Institute have demonstrated interest.

Furthermore, biochar companies and advocates have been working to link up with fossil fuel interests – most prominently ConocoPhillips, but also coal companies interested in land reclamation, carbon offsets or, potentially, mixing byproducts from coal production with biochar.

Overall, biochar has remained a "nascent industry". Its' future will likely play out as a contest between opposing forces of massive hype, a growing body of research which largely fails to support the hype, and on the ground experience. Making biochar economically viable is unlikely without massive subsidies, which so far have not materialised, but future potential exists, and vigilance is needed.