biofuelwatch

Biochar: a critical perspective

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INTRODUCTION

In 2011, Biofuelwatch published a comprehensive report, "*Biochar: a critical review of science and policy*".[1] In 2020, we provided an update to that report.[2] Given the proliferation of initiatives to develop commercial-scale biochar and burgeoning policy and financial support, we feel compelled to provide this more recent update.

The published literature has dramatically expanded, reflecting great interest and an influx of funding to soil science research. Additionally, there has in recent years been a widening of the scope of proclaimed 'uses' for biochar – no longer just for carbon sequestration or soil and crop improvement, but also for remediation of toxins, as a feed supplement for livestock to reduce methane emissions, for treatment of wastewater and more.

The overarching problem remain as results from biochar studies continue to be highly inconsistent, depending on what feedstock is used, how it is produced, the type of soil to which it is applied, the environmental conditions, what crop is grown, the study duration, and what kinds of measurements are made. Understanding of biochar is far from what would be required to enable reliable control over its influence on the environment. Given the risks discussed further below, it is highly premature to promote biochar as deserving subsidies and other incentives.

Yet those policy support measures for biochar as a 'carbon negative technology' are being put in place. We are not alone in urging precaution, many in the scientific research community express similar reservations. For example: in "Rethinking biochar: black gold or not?" (Tan et al 2023) the authors conclude: "*To date there is no conclusive evidence demonstrating environmental friendliness or long-term cost effectiveness of large scale biochar implementation in soil and climate agro-economic systems, let alone in water purification and energy storage and conversion*."[3] Xiang et al (2021) warn: "*Considering the harmful components, structure and particle size of biochar, the negative effects of biochar application on the environment <u>should not be ignored</u>*."[4]

WHAT IS BIOCHAR?

One reason for the highly inconsistent results is the lack of clarity in definition of biochar. Charcoal, biochar, soot; all are forms of "pyrogenic" carbon that result from incomplete combustion. Biochar made from woody biomass is essentially a fancy new name for charcoal, as clearly stated by Brtnicky et al (2021): "*Chemically, biochar resembles charcoal, although these two materials can be distinguished based on their intended use... charcoal deliberately applied to soils should be referred to as biochar; the term charcoal could then be used to refer to fuel produced during the burning process*."[5] Charcoal production has a very long tradition around the world, mostly for producing cooking fuel and in metal smelting (for example smelting iron). It is a significant source of air pollution and a driver of deforestation. In practice, materials referred to as biochar run across a very wide spectrum, depending on what feedstock is used (wood, agricultural residues, animal manures, sewage sludge, municipal waste among other) and the process used in its' production via pyrolysis or gasification in back yard home-made kilns, pits, or more modern industrial facilities. Given the extremely broad spectrum of materials referred to as "biochar" it is not too surprising that results from studies are so inconsistent.

DOES BIOCHAR RELIABLY SEQUESTER CARBON FOR THOUSANDS OF YEARS?

Far too many, (especially among commercial interests) uncritically accept and repeat the claim that biochar can reliably sequester carbon in soils for thousands of years, and draw comparisons with high fertility ancient Terra Preta soils, which contain charcoal among many other ingredients. Biochar is not Terra Preta; the latter resulted from centuries of complex agroeoclogical practices by indigenous peoples in the Amazon basin.

While there are numerous studies indicating that the carbon contained in biochar can remain stable over varying timescales, claims about long-term stability are mostly based on extrapolation from short term studies – a year or two at most - of a wide range of "biochars" done under artificially controlled laboratory incubation conditions. Azzi et al (2024), having reviewed these incubation studies, concludes: "*… it is debatable whether incubation-based approaches are adequate for extrapolating persistence estimates beyond 100 years because short-term incubations do not capture all the processes that are relevant on long time scales*."[6] Extrapolation to even 100 years is based on the assumption that environmental conditions will remain stable and have no impact over time on soil carbon. In reality, environmental conditions are among the most important determinants of carbon stability in soils and are not static![7]

Numerous studies show a pulse of CO_2 emissions immediately following the application of biochar as a 'labile' fraction of the carbon oxidises. Studies have also shown that applying biochar to soils can stimulate the decomposition of pre-existing soil organic matter, (called "positive priming"), which can ultimately result in an overall reductions in soil carbon content.[8] [9] However, very few studies have looked at the fate of biochar carbon in natural conditions over even a few years, making extrapolation to thousands of years and comparisons with Terra Preta meaningless, and policies supporting biochar as a reliable climate mitigation tool, dangerous.

Vijay et al 2021 note: "*the stability of added biochar in soil remains a contentious topic*". They provide a useful review of field studies, which concludes that biochar can have positive or negative effects on soils, with generalizations being impossible, that the impacts of biochar are soil and site specific, and that the scarcity of field studies that last more than a few months or one year makes it impossible to assess longer term impacts. Some studies included in the review show that effects of biochar may fade over time while others show that they may increase. [10]

Yet, in spite of the lack of consistent results and the poor understanding of biochar impacts on greenhouse gas emissions, proponents assume reliable long term carbon storage and, on that basis, advocate for global-scale implementation in order to reduce atmospheric concentrations of greenhouse gases. (discussed further below).

WHAT OTHER IMPACTS DOES BIOCHAR HAVE ON CLIMATE CHANGE?

Some research has shown decreased N_20 and CH_4 emissions from soils after application of biochar, but again, results are inconsistent and depend on many variable factors.[11] Because it contains black carbon, biochar darkens soils, reducing albedo and causing soils to absorb more heat [12] [13] Also, biochar breaks down over time into smaller and smaller particles, and can become airborne or waterborne to be deposited far from the point of application.[14] [15] Particulates from biochar also presents a health risk when inhaled. He et al (2017) conducted a holistic meta-analysis of greenhouse gas fluxes from soils based on 91 published studies and report that biochar additions to soils "significantly ***increased*** GWP [Global Warming Potential] by 46.22%".[16]

Biochar is sometimes referred to as a 'carbon negative energy' technology, based on greenhouse gas accounting that assumes facilities will produce both 'renewable' energy and biochar. Pyrolysis and gasification processes produce both solid biochar (far less in the case of gasification than pyrolysis) and also a gas (syngas) and, in the case of pyrolysis, a liquid (bio-oil), which, in theory, can be used to generate heat and power. However, there is an inherent trade-off – with processes designed to maximize either production of syngas/bio-oil, or the production of biochar – not both. Industrial-scale pyrolysis with energy generation remains fraught with technical challenges, and to date most attempts to scale it up have proven to be inefficient and largely unsuccessful.[17]

DOES BIOCHAR IMPROVE SOILS AND CROP YIELDS?

Results vary from increases to decreases in crop yields following applications of biochar, depending on the soil, the biochar, the environment, the crop, and the timing of measurements. Crop yield increases may occur because of nutrients contained in fresh biochar, or improved nutrient uptake resulting from biochar effects on cation exchange, from changes in soil pH, structure, or water retention capacity. Biochar can also result in decreased crop yields, or in an initial crop yield increase followed by a decline over time. Viger (2015) found a reduction in plant defenses against insects, pathogens and drought when grown in biochar amended soils.[18] Again, short-term laboratory studies are of limited utility. A review of longer-term field studies concludes: "*The inconsistent impacts of biochar application on crop yield necessitate improved understanding of the underlying mechanisms of biochar towards promoting crop productivity*."[19]

IS BIOCHAR SAFE FOR PUBLIC HEALTH?

A growing body of research is revealing numerous problematic toxins found in biochar. Those include polycyclic aromatic hydrocarbons (PAHS), heavy metals, dioxins and furans, environmentally persistent free radicals (EFPRs) and more. The presence of toxins depends on the biochar feedstock and mode of production. Alarmingly, with virtually no regulatory guardrails, companies eager to capitalize on subsidies for renewable energy are promoting pyrolysis of a wide variety of waste streams (so called "waste to energy") and recognize the additional profits that can be made from characterizing the charred byproducts as "biochar". Thus, biochar may be derived from wood or crop residues, sewage sludge, animal manures, or in some cases used tires, plastics, municipal waste and more (though not all feedstocks are eligible for certifications). Each of these has its own associated toxins and risks to the environment and to public health including through the accumulation of toxins in food grown on biochar-amended soils or the inhalation of particles. (See references [20] [21] [22] [23] [24] [25] and many more).

Even if one was to ignore toxins, biochar can negatively impact soils. In “The Dark Side Of Black Gold”, Godleska et al 2021 state: “*In addition to containing environmental toxins, biochar can substantially influence the conditions of the environment where it is located (e.g., soil), causing changes in the physical, chemical, or biological properties of the environment that can have an indirect harmful effect on organisms*.”[26] Pyrolysis facilities co-producing biochar also emit pollution into the air and water of surrounding communities. For example, developers of a facility proposed in Saratoga, New York State, which would produce biochar from sewage sludge sought permits to emit pollutants including but not limited to: Per- and Polyfluorinated Substances (PFAS), naphthalene, arsenic, cadmium, lead, mercury, hydrogen fluoride, and particulate matter.[27] Note that the application of biochar from sewage sludge on soils has been prohibited in the EU. Pyrolysis and gasification facilities have been plagued by fires and explosions, contributing to the risks for communities nearby.[28]

WILL CERTIFICATION AND TESTING ENSURE SAFETY AND SUSTAINABILITY?

Commercial biochar producers are under no obligation to comply with testing, or certification, or to otherwise offer transparency about their products. Some biochar advocates, recognizing the potential risks, have worked toward developing testing and certification tools. The International Biochar Initiative has developed a “Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil”, as well as a Biochar Certification Program. Currently the website informs that the certification program is under revision and only 9 biochar producers are listed as having current certifications at this time.

The European Biochar Certificate, (EBC) along with the its’ partnered World Biochar Certificate (WBC), are implemented by Carbon Standards International. EBC certification is mandatory in Switzerland for biochars applied to soils but voluntary elsewhere. It is unclear how many producers have been certified.

These certifications provide no guarantee that biochar is safe or sustainable. Only a limited number of producers bother to obtain certification, which is voluntary. Like other similar certification schemes, for example for biomass, they fail to effectively prevent unsustainable practices. A study done in 2021 found numerous significant toxins still remaining in certified biochar.[29]

WHAT ARE LAND USE IMPLICATIONS OF LARGE SCALE BIOCHAR?

Central to our concerns are the land use implications of large-scale biochar implementation which would necessitate using vast quantities of biomass. This has already been highly problematic in the case of large scale biomass energy or biofuel use. Some advocate for massive global-scale implementation, basing projections on infeasible and dangerous assumptions. Woolf et al (2010) claimed that biochar could reduce global emissions of greenhouse gases by 12% annually, a claim that continues to be widely cited.[30] Though the authors of that paper claimed to control against food insecurity, loss of habitat and land degradation, they assumed the conversion of about 556 million hectares of ‘abandoned cropland’ to produce dedicated crops and trees for biochar feedstock, as well as the conversion tropical grasslands. Such massive scale land conversion would have very significant negative consequences on ecosystems and thereby the climate, on biodiversity and on communities dependent on the lands being converted.[31]

Any global-scale biochar initiative would also require massive infrastructure to harvest, transport, pyrolyze, apply biochar over vast tracts of land. Lehmann et al 2021 (see fig. 1) claim that globally, biochar could theoretically contribute emissions reductions as high as 8.2 billion tonnes CO_2 equivalent per year.[32] Worryingly, these projections are based on the assumption that biochar is effective, as well as highly unrealistic assumptions about land use: that all abandoned croplands globally can be used to produce biochar crops, that logging forests for biochar feedstock has no impact on forest carbon stocks as long as the forests are 'sustainably managed', that biochar reliably improves crop yields so much so that less land will be required for agriculture (so-called 'land sparing'), that biochar production will also provide energy, displacing other more carbon polluting sources, that using biomass for biochar rather than allowing plant residues to decompose is advantageous, and that the carbon emissions from facilities that produce power and char can be captured and buried below ground (CCS). This array of assumptions is simply not based in reality.

Biochar advocates primarily refer to using 'wastes and residues'. But we have already witnessed what that leads to in the context of biomass power and heat generation. Repeatedly it is shown that when demand escalates, biomass is sourced from forests, even from primary and old growth forests and nature reserves.[33] [34]

True wastes and residues may be available on small local scales, but once commercial interests, subsidies and policy supports are put in place, scaling up biochar production will increase demand irrespective of negative impacts.

PROFITING FROM RHETORIC:

Synergies with industrial biomass power and biochar are already evident. Ash from biomass power stations even though it is not necessarily referred to as "biochar" is sometimes marketed for agricultural uses, contributing new revenue to their (already heavily subsidized) operations.[35] Differentiating between ash and biochar is not always clear. In a study of agronomic and environmental performance of bottom ash from biomass power plants, the authors concluded that the physicochemical and structural properties of ash from a biomass power plant were similar to those of wood-pellet-based biochar and could be marketed to provide an effective soil amendment.[36] Some report benefits of adding ash to biochar to enhance fertilizer effects[37], or to add ash to biochar production processes to increase yield.[38] Others seek to retrofit biomass power plants to produce biochar.[39] Or claim to improve the low efficiency for biomass electricity production by adding biochar production to the facility.[40] Destructive industries including palmoil production are finding that unsubstantiated claims about biochar as a viable climate solution provide convenient new PR and revenue streams.[41] In sum, existing dirty biomass industries are poised to profit from markets for ash/biochar. Yet scientists and activists have long opposed biopower for its damaging impacts on climate, biodiversity and environmental justice.

In spite of highly inconsistent results and the serious concerns that have been raised about biochar, support for commercial production continues to grow, with biochar now featuring in markets for carbon offsets, via so-called carbon dioxide removal (CDR). Just a few examples: Carbonfuture sells biochar credits to Microsoft, Swiss Re and Klarna Bank, claiming 'Zero Uncertainty'. Puro.earth offers biochar offsets to customers Shopify and Microsoft. The most widely used voluntary carbon offset programme, Verra, has developed an offset methodology for biochar. Carboculture, offers to "*assist photosynthesis*" with its "*proven patented carbon removal technology*" that "*locks carbon safely away for centuries and generates renewable energy in the process*". Rothschild &Co is purchasing credits from biochar projects. NetZero, another biochar producer, just won an 18 million Euro grant from the French development fund STOA, to scale up biochar production in the tropics. Biochar is featured as a 'carbon removal' pathway in the "Science Based Target" initiative for land sector emissions reductions. The race is on to scale up biochar.

CONCLUSION:

A vast and worrying disconnect is growing between the science on biochar and the policymaking and commercialization. Results from studies of biochar are highly inconsistent. Biochar should not be granted subsidies and other support intended for urgently needed reliable and effective climate mitigation. This is especially true given the risks from toxins and potential for serious negative impacts of land use change that could result from a large added demand for biomass. Many in the scientific community have raised concerns urging precaution.[42]

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[31] At the time this paper was published, Biofuelwatch confirmed the above figures with the authors and a press release condemning potential land grabs for biochar was put forward by 23 organizations. https://www.biofuelwatch.org.uk/2010/biochar-joint-pr/
[32] Lehmann et al (2021) Biochar in Climate Mitigation. Nature Geoscience (14)
[33] https://www.biofuelwatch.org.uk/2024/drax-bc-pellets-investigation/
[34] https://us.eia.org/report/the-eus-renewable-energy-policies-driving-the-logging-and-burning-of-europes-protected-forests/
[35] https://www.burlingtonelectric.com/mcneil/ "What is done with the ashes?
Wood ash, the end-product of burning wood fuel, is temporarily placed on site in a landing area. BED works with a private contractor who transports the ash and markets it as a soil conditioner for pH control and a source of potash and potassium. McNeil ash is

approved as a soil conditioner for organic crops. The heavier portion of the ash (bottom ash) is used as a base for building roads or an additive for manufactured topsoil."

[36] Jong-Hwan Park, Jim J. Wang, Dong-Cheol Seo, 2023. Agronomic and environmental performance of bottom ash discharged from biomass-based thermal power plant,
Sustainable Chemistry and Pharmacy,Volume 33,

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[38] https://pubs.acs.org/doi/full/10.1021/acssuschemeng.1c07694

[39] see: https://www.youtube.com/watch?v=wDSocizaBrA

[40] The Ryegate biomass power plant in Vermont, having been required by legislation to improve efficiency, proposed to retrofit for addition of biochar production.
https://legislature.vermont.gov/Documents/2022/WorkGroups/House%20Energy%20and%20Technology/Bills/S.161/Witness%20Documents/S.161~Bill%20Harrington~Biochar%20Project%20Diagram~3-31-2022.pdf

[41] Saharudin et al 2024. Biochar from agricultural wastes: environmental sustainability, economic viability and the potential as a negative emissions technology in Malaysia. Science of the Total Environment (claiming biochar can reduce agricultural emissions by 54% annually!).

[42] We note that pro-biochar articles promoting biochar as a climate mitigation tool are often published in journals such as Nature Geoscience, where climate policymakers are likely view them, whereas literature on toxics, for example, is more likely published in the Journal of Hazardous Materials, less likely for those concerned with climate change to encounter.