Biochar and its role in carbon sequestration

Article written by Théa Allary, February 2025

Introduction

The unchecked and ongoing buildup of greenhouse gases (GHGs) in the atmosphere poses an unparalleled danger to both humanity and the environment. The planet is warming at a rate that prohibits natural adaptation, and which is leading to catastrophic loses of biodiversity. Changes in temperatures and weather patterns have increasingly destructive impacts on soils and oceans, threatening the safety of millions across the globe.

Responding to this threat calls for a multifaceted action that includes adaptation and mitigation. Mitigation focuses on reducing greenhouse gas emissions through renewable energy adoption, energy efficiency, sustainable land use, and transitioning to low-carbon technologies.

Alongside efforts to reduce emissions of greenhouse gases to the atmosphere, the international community is developing strategies to "trap" and sequester gases that have already been emitted, essentially creating "sinks" in which GHGs can be contained for long periods of time.

A carbon sink is broadly defined as "anything that absorbs more carbon from the atmosphere than it releases into it"[1]. Typical examples of natural carbon sinks are entire ecosystems such as forests, oceans and soils, within which smaller units of living organisms absorb carbon (e.g. trees, crops, microorganisms and animals). However, those naturally occurring carbon sinks are facing threats of their own, often being depleted or reaching carbon content capacity[2]. In response, the creation of artificial carbon sinks is being put forward as a tool for additional carbon removal from the atmosphere. Technologies designed to actively remove carbon from the atmosphere are being developed.

Biochar is a highly carbon-rich material produced from the anoxic pyrolysis of biomass feedstocks. During the production process – through which organic material is slowly exposed to temperatures typically ranging from 400 to 700°C – gases such as oxygen, methane and hydrogen are burnt off or captured to produce syngas, while liquids (also called bio-oils) are collected to be used for further energy generation or product manufacturing[3,4]. The resulting char material is extremely stable and can reach up to 90% carbon content, making it an excellent carbon sink. Biochar is also highly porous, conferring it high absorption properties which can be used for a number of applications.

Thanks to its chemical and physical characteristics, biochar proponents believe it will play a critical role in carbon sequestration objectives in the coming decades. This article explores the opportunities and limitations associated with biochar and its widespread use within the global agricultural sector.

The benefits and uses of biochar

Traditionally, biochar has mainly been used as a soil quality enhancer, leading to higher crop yields. Biochar's chemical properties have been shown to neutralise soil acidity. Its physical characteristics can improve water and nutrient retention, while also boosting drainage and aeration, and limiting nutrient

[1] ClientEarth Communications. 2020. What is a carbon sink?
[2] Friedlingstein et al. 2020. Global Carbon Budget 2020. *Earth System Science Data.*
[3] Khater et al. 2024. Biochar production under different pyrolysis temperatures with different types of agricultural wastes. *Scientific Reports* **14.**
[4] US Biochar Initiative. Biochar production.

run-off (and associated emissions)[5]. Thanks to the material's stability, it is also important to note that one single biochar application to soil will provide benefits for hundreds of years thereafter.

Research has also been performed on biochar's ability to remediate soils contaminated with toxic compounds. In petroleum polluted soils, biochar has been shown to promote microbial activity and diversity, leading to the presence of hydrocarbon-degrading microorganisms and the ultimate reduction of petroleum content[6]. There is additional evidence that biochar may improve the innate phytoremediation abilities of certain plant species, especially in the case of the stabilisation of heavy metals and metalloids such as arsenic, copper and lead[7].

More recently, the potential of biochar as a carbon sink has been increasingly put forward in scientific literature, the media and within national and international sustainable development strategies. Biochar offers a stable and long-term solution for the sequestration of carbonaceous biomass (i.e. it is estimated that, in soils, the material retains 97% of its carbon content for an average 556 years[8]), while providing valuable ecosystem services which align directly with key sustainability and regenerative agriculture goals.

Finally, the production of biochar itself produces energy from the primary pyrolysis of the biomass and fuel in the form of bio-oil and captured syngas which can be used to produce electricity, heat, upgraded fuel or even chemicals[9]. Overall, the production of biochar via pyrolysis emits half as much GHG emissions compared to the same biomass being left to degrade on its own.

Is biochar sustainable?

Since 2020, NNFCC has been an active partner within the European-funded BeonNAT project. Sixteen collaborators, representing six European countries, have joined expertise to propose commercially viable uses for millions of square kilometers of underused forest and agricultural marginal land within the EU. The project aims to sustainably obtain forest biomass for the production of eight products based on new biobased value chains: essential oils, herbal extracts, wood paper, particleboard, bioplastics, activated carbon, absorbents and biochar. Ultimately, the project aims to propose a novel business model for a biorefinery which will produce products and co-products from the sustainably grown marginal land biomass, including biochar. Just like with any biomass-derived product or service, the use of sustainably sourced biomass is key for the production of sustainable biochar. Echoing the feedstock criteria from overarching sustainable policies such as the EU's RED II, virgin food and feed crops which are grown for the purpose of being converted into biochar cannot be considered sustainable. Biomass dedicated to biochar production can only be considered sustainable if its use does not negatively impact existing social or environmental activities, whether that is by displacing the biomass itself or by using land which could be used for a more important purpose.

The past fifteen years have seen pyrolysis become one of the most prominent fossil-free biomass-conversion technologies for the production of energy and fuels[10]. This is primarily due to the versatility

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5 Royal Horticulture Society. Biochar.
6 Karppinen et al. 2017. Petroleum hydrocarbon remediation in frozen soil using a meat and bonemeal biochar plus fertilizer. *Chemosphere* **173**: 330–339
7 Narayanan & Ma. Influences of biochar on bioremediation/phytoremediation potential of metal-contaminated soils. *Frontiers in Microbiology* **13**.
8 The Chartered Institute of Ecology and Environmental Management. 2023. Biochar-based Carbon Sequestration: Opportunities, Challenges and the Way Forward – by David Kesner.
9 Gas Data. Syngas: What is it, how is it made & where is it used?
10 Omulo et al. 2018. Optimizing slow pyrolysis of banana peels wastes using response surface methodology. *Environmental Engineering Research* **24**.

of the process and the ease of transport of the resulting products. Pyrolysis remains an active area for innovation, with several new processes being trialed with the objective of reducing some of the current drawbacks of industrial pyrolysis, which can undermine sustainability aims[11]. These include high energy intensity to conduct the process itself, as the biomass is treated under very high temperatures. Additionally, pyrolysis produces greenhouse gases such as CO_2, NOx and methane, as well as other pollutants such as particulate matter. Although these emissions are often reduced through adequate gas cleaning methods[12], there is room for improvement.

Overall, biochar is considered to be a sustainable material which could occupy a crucial role within the international fight against climate change. However, in an effort to further biochar's potential, along with reducing its overall impact on the environment, research is continuously being done to improve its sustainability credentials.

What difference can biochar really make?

In 2023, the global market value for biochar was estimated at around $541 million, with a projected growth to 2030 of nearly 14%, showing the keen interest that industry and nations across the globe have in the material[13]. The benefits of biochar are clear and well-understood, sparking global scientific interest and pushing it forward onto the political stage. However, in addition to those advantages it is important to ascertain the "true" magnitude of biochar's potential within the context of carbon sequestration and GHG emissions mitigation.

On a logistical basis, biochar production will be limited by two main factors: the quantity of and rate at which biomass can be obtained; and the sustainable sourcing of biomass without negatively impacting food production and global ecosystem services. Within this context, Woolf et al. investigated the impact that biochar could have on global climate change, within the bounds of its sustainable production and use, without threatening food security, habitat and soil conversation. The study found that a maximum of 12% of current annual anthropogenic emissions of CO_2, CH_4 and N_2O could be eliminated (i.e. 1.8 Gt CO_2-C equivalent). It also concludes that biochar production often has a larger climate-change mitigation potential than the alternative combustion of the same biomass feedstocks for bioenergy[14]. More recent estimates place the emissions mitigation potential of biochar between 1 and 35 Gt CO_2-C equivalent on an annual basis (the large range of values likely reflects different assumptions on sustainable supply. In any case, should even the lowest value in the projected range be achieved, this will still represent a significant reduction in GHG emissions (as long as efforts continue to be made to reduce primary GHG emissions).

Further research is also being done to assess the impact that biochar could have on social sustainability development goals, especially in areas within the sub-Saharan region of Africa which has been consistently underserved and under-researched in that respect. Over the past few years, multiple research and review projects have highlighted the unutilised biomass resources held within several countries in the sub-Saharan region, as well as the opportunities that could be drawn from producing the material and which could significantly alleviate poverty and famine[15,16]. Such reviews have shown

[11] Azeta et al. 2021. A review on the sustainable energy generation from the pyrolysis of coconut biomass. *Scientific African* **13**.
[12] Henan Doing. 2024. What is the gas treatment/recovery system you have for pyrolysis machine?
[13] Afshar & Mofatteh. 2024. Biochar for a sustainable future: Environmentally friendly production and diverse applications. *Results in Engineering* **23**.
[14] Woolf et al. 2010. Sustainable biochar to mitigate global climate change. *Nature Communications* **1**(5).
[15] Gwenzi et al. 2015. Biochar production and applications in sub-Saharan Africa: Opportunities, constraints, risks and uncertainties. *Journal of Environmental Management* **150**(1).
[16] Zanli et al. 2022. A review of biochar potential in Cote d'Ivoire in light of the challenges facing Sub-Saharan Africa. *Biomass and Bioenergy* **165**.

that in spite of all the known benefits of biochar, the sub-Saharan region suffers from a lack of funding in such technologies and a poor public perception regarding biochar itself. Subsequently, they call for further research to demonstrate the benefits of biochar, and for the development of adequate policy frameworks and criteria for its production and use. In March 2024, a new UN-funded community project was launched by Omiti Biochar Ltd to evaluate the impact that the production of biochar from invasive bush species biomass, could have on local communities in Namibia. The project – which is designed to end in 2031 – will assess the impact that biochar production and use has on local ecosystem services, on local communities including job creation, livelihood opportunities and food security, and on climate resilience strategies such as food production and irrigation[17].

There is ample evidence that biochar has the potential to play a crucial role within key Sustainable Development Goals, both within the environmental and the social aspects of sustainability. However, it is important to note that while biochar has the ability to make a significant contribution towards climate change mitigation, it must be used in conjunction with primary GHG emissions practices that are designed to prevent emissions in the first place.

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[17] UN Department of Economic and Social Affairs. 2024. Omiti Community Based Biochar Project in Namibia.