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Overview of Biochar Production and Uses

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Abstract

As we work to reduce fire hazards from fuel loads in our forests, converting biomass to bio-char can significantly reduce the amount of GHG emissions and create less air pollution when compared to full combustion of biomass. Biochar can also be a useful soil amendment, but not all carbon “chars” are biochar, and not all biochars are beneficial for soils.

This overview examines what biochar is, how it is produced, various environmental impacts, its use as a soil amendment, and issues surrounding forest fuels reduction.

Table of Contents

What is Biochar?

Biochar is basically nearly-pure carbon that comes from organic matter and is generally in a stable graphite-like structure to some degree, enabling it to persist in the environment. Some other forms of carbon are charcoal, diamonds, and buckyballs.

According to the International Biochar Initiative:

> *"Biochar is a solid material produced by the thermal decomposition of biomass (such as wood, manure, or leaves) under limited supply of oxygen (O2) and at relatively low temperatures (<700°C). This process, called pyrolysis, is a fundamental part of biochar technology; biochar production is modeled after a process begun thousands of years ago in the Amazon Basin, where islands of rich, fertile soils called terra preta ("dark earth") were created by Indigenous people. A primary application of biochar is its use as a soil amendment, with the intention to improve soil functions and to reduce emissions from biomass that would otherwise naturally degrade to greenhouse gases."*[1]

The dark terra preta soils are somewhat uncommon in the Amazon, covering about 10% of the Amazon Basin. Eventually it was realized that the dark terra preta soils occurred at sites of ancient aboriginal communities. Research into the creation of terra preta soils determined that these dark, carbon rich soils had been deliberately created by people burning biomass, and then burying the charcoal in their fields. Apparently this practice has been applied for over nine thousand years![2]

How Is Biochar Made?

Biochar can be made using several different methods, including open pile burning, burning in a pit, or using special pyrolysis containers. Here we are focused on biochar production by pyrolysis. Pyrolysis is the heating of organic materials in the absence of oxygen (versus heating by combustion, which requires oxygen). Materials are generally heated to temperatures in the range of 300°C to 750°C (572°F to 1382°F). At these temperatures, thermochemical decomposition takes place that drives off volatiles and leaves varying amounts of carbon and ash, depending upon the feedstock and the temperatures used.

For example, consider open burning of a wood pile. Initially the volatile gases are driven off and most are combusted. As the typical open-air combustion takes place, the burning material within the fire becomes very heated. If the material is starved of oxygen (such as by being buried within a heap of burning embers with limited air flow), it does not fully combust, leaving black "charcoal" pieces. Depending upon the temperatures and duration of the fire, the

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[1] See: International Biochar Initiative FAQs - https://biochar-international.org/about-biochar/faqs/
[2] See: Terra Preta - https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/terra-preta

end result will be ash and residual pieces that were not completely burned, some of which will be of biochar quality.

The characteristics of biochar vary greatly, depending upon the feedstock, oxygen levels, and the temperatures used in processing, as well as other factors such as heating rate, particle size, etc. Under ideal pyrolysis conditions, the amount of carbon capture can exceed 60%.

Biochar Products and Production

It's useful to look at biochars as an entire family of differing products. Which biochar product is produced should be determined according to its desired end-use, with the final product primarily determined by three main factors: 1) feedstock selection, 2) pyrolysis conditions, and 3) post-processing of the biochar product.

Feed stocks

Biochar can be created from any kind of available biomass. Commonly used feedstocks include wood (often waste wood or timber harvest slash), agricultural waste such as rice straw, corn stalks, nut shells, cow, pig, or chicken manure, or any other biomass sourced from waste.[3] Feedstocks contain differing amounts of carbon. Importantly, biochar can also contain impurities such as heavy metals, dioxins, and Polycyclic Aromatic Hydrocarbons (PAHs). When feedstocks (such as raw sewage) contain toxic contaminants, the resulting biochar should not be used as a soil amendment. Thus feedstock selection is very important and must be tailored to the intended usage of the end biochar product. For soil amendment, many factors must be considered, such as water and nutrient retention, soil microbial communities, fertilizer needs, and soil structure.[4]

Pyrolysis

Before beginning the Pyrolytic process, there is usually some preprocessing of the feedstock that needs to be performed, such as drying the material. Once the feedstock is prepared, pyrolysis variables should be considered, including the temperature, heating rate, and residence time. Temperature is very important for determining the amount of carbon captured from the feedstock, and how much of that carbon is converted into usable biochar.

In terms of carbon capture, the amount of recovered carbon can range between 60-70% if pyrolysis processing falls in the 300-750°C range. However, at around 450°C there is a large increase in the available surface area of the biochar product, accompanied by an increase in cation exchange capacity. This increase in surface area can be beneficial if the intended usage of the biochar is soil amending. However, the pH also varies and tends to increase along with the temperature increase. As temperatures rise above 550°C, the pH can increase substantially

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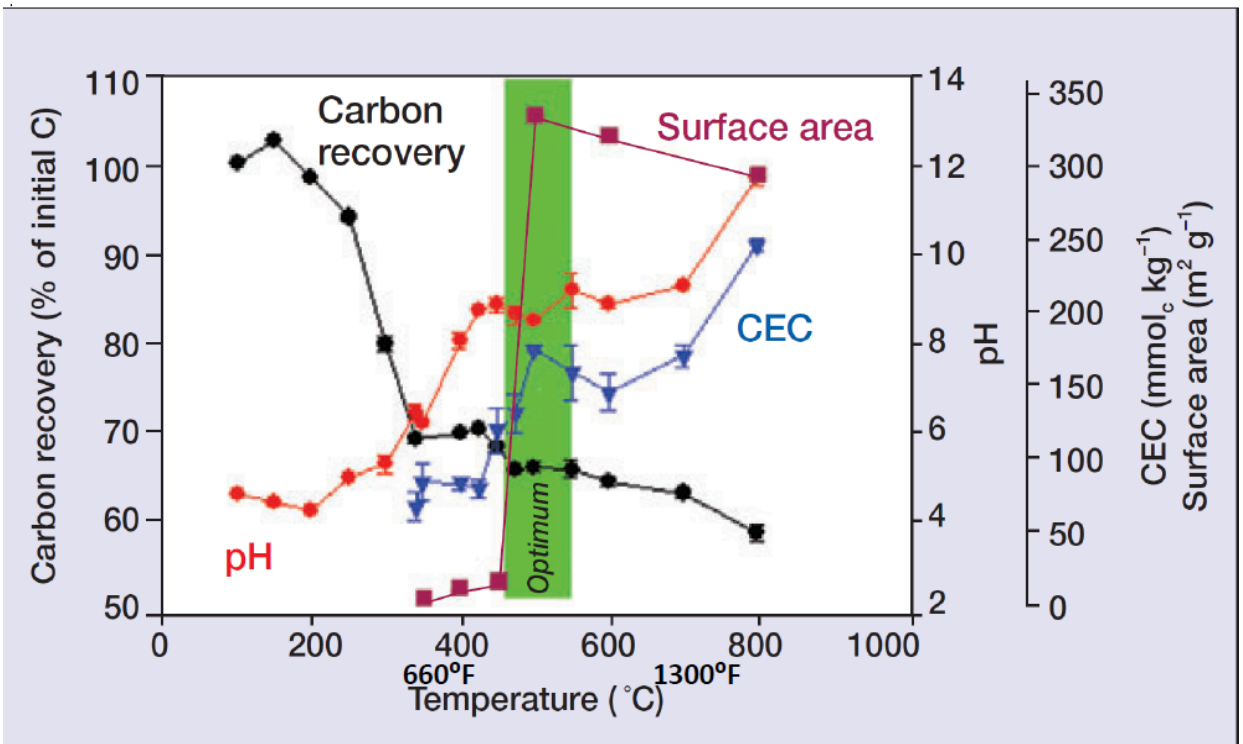
[3] see: https://www.climateactionreserve.org/wp-content/uploads/2024/03/CAR-Eligible-Biochar-Feedstocks-List-2024-03-19.pdf

[4] For more information about feedstocks and post-pyrolysis treatments, see: https://www.mdpi.com/2077-0472/13/10/2003

as carbon converts more to ash than to biochar, so 450-550°C is a more desirable temperature range for the production of biochar.[5]

The graph below shows the effect of temperature on a Black Locust feedstock:

Effect of Pyrolysis Temperature on Biochar Conversion Rate and Product Surface Area



Temperature effects on Black Locust (Robinia pseudacacia L)

Heating rate can be slow, fast, or ultra-fast (also known as flash pyrolysis). Fast pyrolysis quickly heats biomass to high temperatures, leading to more liquid products (bio-oil). Slow pyrolysis, on the other hand, involves slower heating rates, resulting in higher biochar yield.

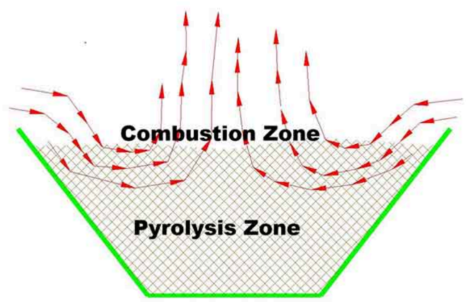
[5] From: Page 13 of USBI Practical Implementation Biochar Production AFT ARS NRCS 11 28 23 | US Biochar Initiative - https://biochar-us.org/sites/default/files/presentations/USBI%20AFT%20ARS%20USBI%20Practical%20Implementation%20Biochar%20Production%2011%2028%2023.pdf

Equipment

There are a number of different pyrolysis vessels that can be used to produce biochar, including:

a. Cone stove or kiln
b. Barrel
c. Pit
d. Top Fed Open Draft (TFOD)
e. Commercial pyrolysis units[6]

A Cone Stove (also sometimes called a Kiln) is a large conical steel vessel with a flat bottom. Biomass is piled into the conical container, then fire is started at the top of the mass. The heat produced from burning the top causes the oxygen-starved material underneath to pyrolyze.

Above photos from: https://bestbiocharkiln.com/

A Barrel can be used in a similar fashion - add the biomass material, and fire the top of that material, allowing the heat to cause pyrolysis to the material beneath the burning top layer of material.

Above photo from: https://biocharstation.com/products/biochar-station-stainless-steel-biochar-kiln

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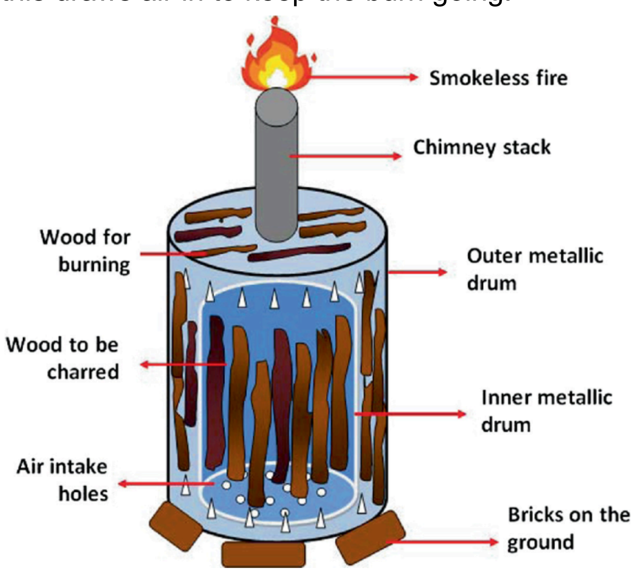
[6] Commercial pyrolysis units, see: https://biochar-us.org/biochar-systems-and-equipment-manufacturers

A Pit is typically constructed as a cone dug out of the ground. It can either be left open at the top, or covered after the biomass material is added and fired. On the left is an open pit in use; on the right, a covered pit.

Above photos from: https://pacificbiochar.com/open-pit-biochar-production/

Top Fed Open Draft (TFOD) units are a type of biochar production equipment that utilizes a top-feed, open-draft design. They are known for their simplicity and ability to produce biochar from various biomass feedstocks. A TFOD is made with two concentric metal cylinders, one inside the other. Both cylinders are filled with wood, et al, but the principal cylinder is the internal chamber which houses the biochar feedstock. A fire is lit at the top of the cylinder and this draws air in to keep the burn going.



Above photo from:
https://media.springernature.com/lw685/springer-static/image/chp%3A10.1007%2F978-3-031-04931-6_17/MediaObjects/499113_1_En_17_Fig3_HTML.png

Grass Valley Biochar Project

There are a large number of different commercial biomass-to-biochar processing units covering a wide range of sizes. One commercial unit that produces biochar while using the surplus energy to generate power is a 3-Megawatt system from West Biofuels. This unit is under consideration for use by the City of Grass Valley. One potential site for the installation of this unit is at the Loma Rica project near the corner of Idaho-Maryland Road and Brunswick Road.

Photo from https://www.westbiofuels.com/hat-creek
West Biofuel's Hat Creek Project, Burney, CA

Post Processing

Post pyrolysis processing can be used to change important physical properties such as porosity and surface area of the biochar product to better match the intended usage. The US Biochar Institute (USBI)[7] and the International Biochar Institute (IBI)[8] both have good guides to commercially available post processing units.

Biochar producers, ranging from large-scale industrial operations to those at the farm or garden scale, commonly perform post-processing steps intended to improve biochar performance. Perhaps the most common example of biochar post-processing in the nascent biochar industry, and in small-scale operations, is manipulation of particle size. Grinding and/or

[7] Biochar Systems and Manufacturers - https://biochar-us.org/biochar-systems-and-equipment-manufacturers
[8] Biochar Production Technologies - https://biochar-international.org/about-biochar/how-to-make-biochar/biochar-technology/#:~:text=The%20feedstock%20'chamber'%20of%20these,biochar%20for%20gardens%20and%20landscaping.

sieving of raw biochars is common to increase product uniformity and to reduce particle size, under the assumption that fine particles will have better mixing properties with soil. Conversely, increasing particle size through pelletization or granulation is also done in an effort to reduce wind transport of fine particles during and after biochar applications.

A wide variety of post-processing methods other than manipulations of particle size have also been employed, including physical and chemical activation techniques[9]. Physical activation utilizes oxidizing agents like steam (H_2O) or carbon dioxide (CO_2), which can be used to enhance its adsorption capacity. Chemical activation can be accomplished by mixing biochar with a chemical agent (like potassium hydroxide (KOH), phosphoric acid (H_3PO_4), etc.) and then subjecting the biochar to thermal treatment. This can be used to achieve higher porosity and surface area compared to physical activation when processing biochar at lower temperatures and when using shorter time periods.

Prior to using biochar as a soil amendment, the biochar product is often “inoculated” with organic materials or microbes such as mycorrhizal fungi or bacteria in order to improve its soil amending properties.

Characterizing and Testing

As noted, the characteristics of biochar vary widely depending upon feedstock, method of production, and final processing. Because there are many different uses for biochar, it is important to specify the objectives for biochar use, and then tailor the production of biochar to meet the objectives. It is important to analyze the resulting biochar product to be certain that it is correct for its intended application.

The key attributes of biochar include carbon content, surface area, porosity, pH, salt content, elemental composition, and particle size distribution. For carbon content, the H/Corg (hydrogen to organic carbon) and O/Corg (oxygen to organic carbon) ratios are important indicators of biochar stability and carbon sequestration potential, with lower H/Corg ratios generally indicating greater stability.

During pyrolysis, as the temperature increases from 350°C range upwards, the carbon structures change from open-chain molecules, which have a shorter lifespan in soil, to closed ring molecules, forming a graphitic-like structure which is more persistent in soils. Higher temperatures, in the range of 500°C + , produce fused closed-ring structures which have even higher persistence, lasting centuries.

The temperatures in this range also generate a more porous structure. Surface area and porosity are important in determining how well the biochar product functions in a particular application. Higher surface area usually means better adsorption. Pore size affects nutrient and water retention.

[9] Note that activation techniques can be applied as either pre or post processing steps.

Certified testing includes an analysis of general properties (e.g. carbon content, ph, electrical conductivity,...), particle size distribution, primary nutrients, secondary nutrients, proximate analysis (e.g. % carbon, hydrogen, nitrogen, ash, etc), EPA 503 metals (e.g. arsenic, lead, mercury) and other elements.

For a list of biochar certification test labs, see:
https://biochar-us.org/labs.
For a list of IBI certified labs, see:
https://biochar-international.org/testing-laboratories-for-ibi-biochar-certification/
For California the nearest IBI certified test vendor is:
Control Laboratories
42 Hangar Way, Watsonville, CA 95076
www.biocharlab.com Tel: 831-724-5422

Soil amendment and agriculture uses

Biochar is a popular soil amendment, enhancing soil structure, water retention, and aeration. It can improve nutrient availability and reduce nutrient leaching, leading to increased soil fertility and agricultural productivity. Biochar can be used as a slow-releasing nutrient material, reducing the need for synthetic fertilizers. Biochar can also help buffer soil pH, making it more suitable for plant growth, and can provide a habitat for beneficial microorganisms. Biochar can also be used to store carbon that would otherwise be released into the atmosphere, thus helping to mitigate climate change.

Biochar also has additional environmental applications. It can be used to remove pollutants and heavy metals from wastewater. Biochar can help reduce pollution from agricultural runoff by improving soil health and nutrient retention. Similarly it can also be used to remediate contaminants and toxicants from the soil and water environment. Biochar is useful as well for biogas production and for nanotechnology applications.

Opportunities

Fuel reduction

Forest fire fuel reduction projects in the Sierra continue to remove large amounts of flammable biomass material. These materials are primarily soft wood (pines, cedars, and firs), hardwoods (such as oaks), and understory shrubbery (manzanita, ceanothus, etc.). These varieties of woody debris are ideal for processing into biochar as an alternative to open burning, thus reducing the overall volume of material, and capturing much of the carbon within the material. However, about 40% of the carbon is still being released from biochar production, even with efficient pyrolysis processing. Capturing the excess heat for energy production further reduces the long-term carbon emissions as a renewable energy source.

Carbon sequestration

Open air combustion releases most of the carbon in a feedstock by converting the carbon into the gases carbon monoxide, carbon dioxide, and methane. By comparison pyrolysis (heating in the absence of oxygen) can capture 30-70% of the feedstock carbon as biochar.

Energy production

During pyrolysis energy is released as heat and as volatile gases. The heat can be used directly for heating, or to drive turbines to generate electricity, while the bio-fuel gases can also be burned.

Biochar Quality Concerns

Soils

Although biochar has been widely regarded as an environmentally friendly soil amendment, harmful components (such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), environmentally persistent free radicals (EPFRs), dioxins, and perfluorochemicals (PFCs)) may be produced because of the improper selection of biomass feedstocks, preparation conditions, and preparation methods[10].

For example, samples that were assessed from Oak Woodlands in Wisconsin found that Lead concentrations were over 20 mg/kg, and Chromium was over 15 mg/kg. While it is true that this was a single study and shouldn't be generalized, it highlights the potential for biochar to introduce hazardous substances into soil[11].

It is therefore important to test and characterize biochars before use, as they will carry any toxins that result from biochar processing into the soils where they are distributed.

Researchers have reported that in some cases biochar added to soils has caused a significant decrease in mycorrhizal fungi (that function to extend plant roots and make nutrients more available to plants)[12]. There have also been reports of decreases in soil microbial communities.

The pH of soils are generally increased by application of biochar (and especially ash), which may cause already alkaline soils to become excessively alkaline. Increasing pH could have negative effects on plants and crops that prefer acidic soils (like blueberries).

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[10] Potential hazards of biochar: The negative environmental impacts of biochar applications - https://www.sciencedirect.com/science/article/abs/pii/S0304389421015764
[11] Ibid, Potential hazards, Table 2.
[12] Influences of non-herbaceous biochar on arbuscular mycorrhizal fungal abundances in roots and soils: Results from growth-chamber and field experiments - https://www.sciencedirect.com/science/article/abs/pii/S0929139310001654?via%3Dihub

It is also possible for biochars to attract and retain nutrients such as Nitrogen and Phosphorus, robbing the soil of these necessary minerals, making fertilizers less effective and making soils less fertile. Biochars can also neutralize pesticides and herbicides in soils, making them less effective.

Air quality impacts

There are four principle gases released during biochar pyrolysis: CO (Carbon Monoxide), CO2 (Carbon Dioxide), H2 (Hydrogen), and CH4 (Methane). In addition, the following pollutants can be released as well: PM (Particulate matter), N2O (Nitrous Oxide), VOCs (Volatile Organic Compounds), and PAHs (Polycyclic Aromatic Hydrocarbons). Also, depending on the feedstock and process, potentially toxic air pollutants like acrolein, formaldehyde, acetaldehyde, benzene, trace metals, dioxins, furans, hydrogen chloride, and ammonia may be emitted during the pyrolysis process[13].

Conclusion

Biochar products provide a wide variety of uses and represent a diverse and burgeoning field. Some caution is warranted, however, in assuming that all biochars are equal, and that all charcoal-like substances are biochar. If used for agriculture, it is wise to have a fair understanding of the particular soil needs before the application of biochar. Other than casual production of biochar by individuals for use around their home or small farm, biochar products that are freely distributed by organizations or are offered for sale should be tested under the guidelines of the IBI or other agencies with high professional standards.

Resources

International Biochar Initiative FAQs - https://biochar-international.org/about-biochar/faqs/

Terra Preta -
https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/terra-preta

Commercial pyrolysis units -
https://biochar-us.org/biochar-systems-and-equipment-manufacturers

USBI Practical Implementation Biochar Production AFT ARS NRCS 11 28 23 | US Biochar Initiative -
https://biochar-us.org/sites/default/files/presentations/USBI%20AFT%20ARS%20USBI%20Practical%20Implementation%20Biochar%20Production%2011%2028%2023.pdf

How to make Biochar - https://biochar.co.uk/how-to-make-biochar/

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[13] See: https://www.mdpi.com/2071-1050/16/3/1169

Eligible Biochar Feedstocks List - https://www.climateactionreserve.org/wp-content/uploads/2024/03/CAR-Eligible-Biochar-Feedstocks-List-2024-03-19.pdf

Biochar Functions in Soil Depending on Feedstock and Pyrolyzation Properties with Particular Emphasis on Biological Properties - https://www.mdpi.com/2077-0472/13/10/2003

USBI Biochar Labs - https://biochar-us.org/labs

IBI Biochar Labs information -

https://biochar-international.org/testing-laboratories-for-ibi-biochar-certification/

Potential hazards of biochar: The negative environmental impacts of biochar applications -

https://www.sciencedirect.com/science/article/abs/pii/S0304389421015764

Influences of non-herbaceous biochar on arbuscular mycorrhizal fungal abundances in roots and soils: Results from growth-chamber and field experiments - https://www.sciencedirect.com/science/article/abs/pii/S0929139310001654?via%3Dihub

(IBI) Biochar Production Technologies - https://biochar-international.org/about-biochar/how-to-make-biochar/biochar-technology/#:~:text=The%20feedstock%20'chamber'%20of%20these,biochar%20for%20gardens%20and%20landscaping.

(USBI) Biochar Systems and Manufacturers - https://biochar-us.org/biochar-systems-and-equipment-manufacturers

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