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Biochar - reversing the flow of carbon

This is a story about biochar... charcoal by another name but with a much larger story. It is a story that has rapidly evolved in the last 10 years and will expand into the future but it starts a few thousand years ago. *(This article includes terms that may not be familiar or require definition. Selected terms and references are listed at the bottom of each page with links to Wikipedia and other sources.)*

By Trevor RICHARDS

Charcoal[1] and **biochar**[2] are similar in what they are produced from and their methods of production. They differ completely in how they are used. Both are **carbon**[3] based materials derived from the heating of **biomass**[4] in the absence of oxygen (or air). **Volatile**[5] compounds (water, hydrogen, oxygen, nitrogen) are driven off as gases as temperatures rise above ~350^{0}C, leaving behind mainly carbon and some minerals (ash).

This process is called **pyrolysis**[6] and it can occur naturally. Prairie and forest fires from lightning strike or volcanic activity can create charcoal when biomass is smothered before it burns (**combusts**[7]) to ash. It has been created on a geological time scale and we have been picking the stuff out of our fires and drawing our history with it on cave walls for thousands of years.

The History of Charcoal

Charcoal's earliest human uses were probably in cooking/heating, art and medicine. It is very porous, retaining its original plant structure during pyrolysis and therefore has a very high surface area, binding to poisons and promoting healthy gut flora. Animals have probably been selectively munching it for health reasons on evolutionary time scales.

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1 Charcoal: a carbon residue from the incomplete combustion of biomass. A mixture of aromatic (carbon ring) and amorphous (non-crystalline) carbon where crystalline (diamond) and graphite are others forms. Charcoal is principally used as an energy source, reductant in industry or for activated carbon production for filtration.

2 Biochar: is a name for charcoal when it is used for particular purposes, especially as a soil amendment but also as a pathway for carbon sequestration due to its stability in the soil.

3 Carbon: the 4th most abundant element in the universe and essential for all biological life on the planet. Carbon is the basis for an area of science known as organic chemistry. Human activity has released large quantities of carbon into the Earth's atmosphere as carbon dioxide, contributing to global warming and climate change.

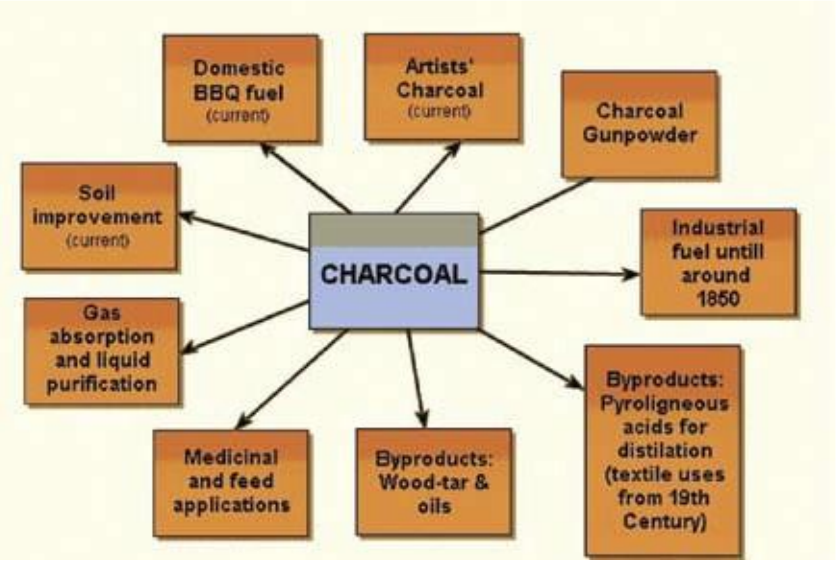
4 Biomass: *"is biological material derived from living, or recently living organisms. It most often refers to plants or plant-based materials which are specifically called lignocellulosic biomass".*

5 Volatile: will vaporize or change to a gas state at low temperatures (much lower than carbon!)

6 Pyrolysis: *"is a thermochemical decomposition of organic material (usually biomass) at elevated temperatures (above ~350^{0}C) in the absence of oxygen"* (or air).

7 Combustion: "In a complete combustion reaction, a compound reacts with an *oxidizing element,* such as oxygen, and the products are compounds of each element in the fuel with the oxidizing element. Process releases heat energy". A simpler description: all of the carbon in a biomass is oxidised to CO2.

Charcoal making was probably one of the first human activities defining the beginning of the **anthropocene epoch**[8,9]. The change from hunter-gatherer to farmer may have been earlier but we cleared the forests of Europe to make charcoal for our swords and shields. Charcoal was essential for providing the heat required to forge metals—wood fires do not burn hot enough to melt most metals.



Uses of charcoal

As charcoal making became more sophisticated, **wood distillation**[10] became an important industrial process, providing many products and chemicals (that would eventually be replaced by the fossil fuel and petrochemical industries). These products included charcoal for activated carbon and metallurgical processes.

So why the hype around biochar?

Many readers may not be aware of any hype or have even heard of biochar. It still flies under the radar for most folk. But biochar has ruffled some feathers in a number of specialist fields, mainly around agriculture and soil science. Some interesting claims about biochar:

- Many supporters suggest that it could revolutionize worldwide agriculture practices by
  - restoring degraded and damaged soils (including greening the deserts!)
  - redirecting industrial agriculture from unsustainable, mineral (fossil) based practices to sustainable, biology based systems that can meet 'triple bottom line' business, environmental and social needs
  - uplifting developing world agriculture from subsistence, dependence and failure
  - buffering some of the impacts of climate change such as drought stress, erosion, disease.

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8 Anthropocene: *"is an informal geologic chronological term that marks the evidence and extent of human activities that have had a significant global impact on the Earth's ecosystems".*

9 FAO Forestry Paper 41, *"Simple technologies for charcoal making"* provides a detailed historical review of charcoal production technologies (http://www.fao.org/docrep/x5328e/x5328e00.htm)

10 Wood distillation: *"Destructive distillation is the chemical process involving the decomposition of feedstock (any biomass) by heating to a high temperature; the term generally applies to processing of organic material in the absence of air or in the presence of limited amounts of oxygen... It is an application of pyrolysis. The process breaks up or 'cracks' large molecules".*

m managing environment pollution: land, water and air.

- Some supporters are promoting biochar as one of only a hand-full of sensible climate change salvations for the planet based on its carbon sequestration potential.
- Yet others are focused on biochar production links with renewable energy.

We will take a closer look at some of these claims later in this article but here is a fact...

Biochar is attracting a lot of interest from the science community. I don't know if the researchers are following the money or the money follows the research interest but the **International Biochar Initiative**[11] lists over 2,100 biochar related papers in their bibliography. 60-80 new items are being added each month with much of this research now emanating from China.

Some environmental groups and NGO's have red-flagged biochar as over-hyped and a threat to indigenous land use. They fear that big business will move in where poor, weak and corrupt governments provide access to land. They foresee biomass mono-cropping on a massive scale to provide the carbon for soil sequestration in a future battle against climate change.

A Short History on Biochar

Much of the current interest in biochar is linked to highly fertile soils in the Amazon region that have been given the Portuguese name, **Terra Preta**[12] (TP). These soils are very different to the majority of soils found in the Amazon and other tropical regions around the world. TP soils are thick, fertile, dark, very high in charcoal and contain much evidence of human interaction or modification. The surrounding natural soils are the opposite of this. Natural tropical soils often require high levels of intervention (slash/ burn, fertilizer, organic matter, other inputs) to maintain agricultural performance. Scientists and researchers studying biochar believe that the key ingredient in the TP soil is stable organic carbon in the form of charcoal (biochar).

Archaeological studies have dated some TP soil as being over 2000 years old. Tales of Amazonian super-cities—the fabled El Dorado—date back to 15th century Spanish explorers. Anthropological and archaeological studies have hypothesized that these TP soils supported large agrarian civilizations until they were wiped out by introduced European diseases. Most traces of these cultures have been lost in the subsequent 500 years as the jungles reclaimed the cities. Stone was not a commonly available

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[11] IBI Mission Statement: *"IBI promotes good industry practices, stakeholder collaboration, and environmental and ethical standards to foster economically viable biochar systems that are safe and effective for use in soil fertility and as a climate mitigation tool."*

[12] Terra Preta: "is a type of very dark, fertile anthropogenic soil found in the Amazon Basin. Terra preta owes its name to its very high charcoal content, and was made by adding a mixture of charcoal, bone, and manure to the otherwise relatively infertile Amazonian soil. It is very stable and remains in the soil for thousands of years"

building material in the floodplains of the Amazon but earth mounds, dikes, roads and TP soils are now being described. This story was covered in a BBC Horizon documentary—**The Secret of El Dorado**[13.]

There are similar histories of soil-charcoal modification throughout the world... probably including Malaysia but currently still untold. Tanah hitam (black soil) seems to be a common term in Malaysia and Indonesia but I've failed to turn up any historic local research.

Biochar in Agriculture

Biochar has physical and chemical properties that form the basis to benefits for its application in agriculture. Physically, it is extremely porous, retaining the micro-structure of the original biomass as seen in the following **image**[14]. This porosity is important for a number of reasons. Biochar behaves like sponge in the soil, retaining moisture, improving drought tolerance and reducing erosion risk. It provides a much expanded habitat for soil biological life. Some biochars can match activated carbons for surface area, providing a rich range of chemical bonding **sites**[15] for nutrients and minerals. This can mean that less nutrients (mineral or organic) are lost to leaching or chemical and biological transformations.

Biochar can also bind in metals, pesticides and chemicals so a lot of research is being focused on soil remediation. These environmental services may be further enhanced by biochar's affinity to soil biology. Soil microbes and fungi are important contributors to soil remediation processes. Soil gas emission profiles are also linked to soil biology so soil-biochar greenhouse gas emissions are being studied.

Biochar can modify the **soil pH**[16], generally raising the pH thus providing a liming effect. This may be helpful in typically acidic tropical soils. Biochar can also have positive effects on soil tilth, improving aeration, water and root penetration.

Epigenetics is the study of how genes are activated or deactivated in response to changing conditions. Plant responses to biochar and other naturally occurring fire-related compounds are thought to include epigenetic links. Further studies may help explain some of these mechanisms for biochar related crop enhancement. Studies have also shown that plants grown in biochar as a soil medium tend to have a higher resistance to pests and diseases (i.e., systemic resistance) at concentrations as low as 1 - 5% of the total soil mixture.

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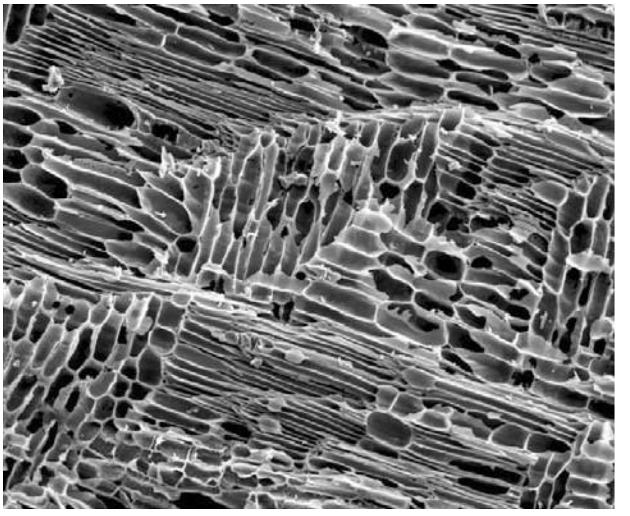
13 The Secret of El Dorado: <<link to online viewing of the BBC Horizon 2002 documentary.

14 SEM image of rubber wood biochar, Co/ http://www.geos.ed.ac.uk/facilities/sem/Biochar.html

15 CEC / AEC: Cation and Anion Exchange Capacity—light electrical bonds, useful for nutrient management and enhanced with biochar amendments to soil.

16 Soil pH: is a measure of the acidity or alkalinity in soils. Important for plant nutrient uptake.

This short introduction to biochar in agriculture can not adequately describe all of the possible soil and environmental applications that are being applied and researched around the world. An interesting summary has been put together by Hans-Peter Schmidt and can be viewed from his website at the **Ithaka Institute**[17] as "**55 uses of biochar**[18]". Some of these don't have any direct relationship with agriculture but could be considered as cascading carbon utilisation... providing multiple services or pathways to final soil carbon sequestration.



SEM of rubber wood biochar

Climate Change—the Cool Black Knight Returns?

Let us take a closer look at some of the claims around biochar related to carbon sequestration. There is no doubt in my mind that climate change is the most important planetary issue on the horizon and that it will affect every one of us... soon. Its too big a subject to discuss here in detail but why is biochar in the discussion?

The diagram below provides an indication of the carbon cycle on our planet. It is interesting to note that the thin layer of surface soil on the earth stores more carbon than the atmosphere and all surface life combined. Wikipedia claims a much higher figure for **soil carbon**[19]: 2,200-2,700Gt but nevertheless, this store of carbon has been increasingly lost to the atmosphere since humans starting farming—oxidised away by ploughing, lost to soil erosion and lost with the decline in soil biology via the 'green **revolution**[20]'. Carbon is also released to the atmosphere from land-use change, forest destruction, fire and desertification but with the major culprit being our demand for fossil fuels, it is not surprising that we have a serious climate problem.

New technologies may help us migrate away from fossil fuel relatively quickly but that may

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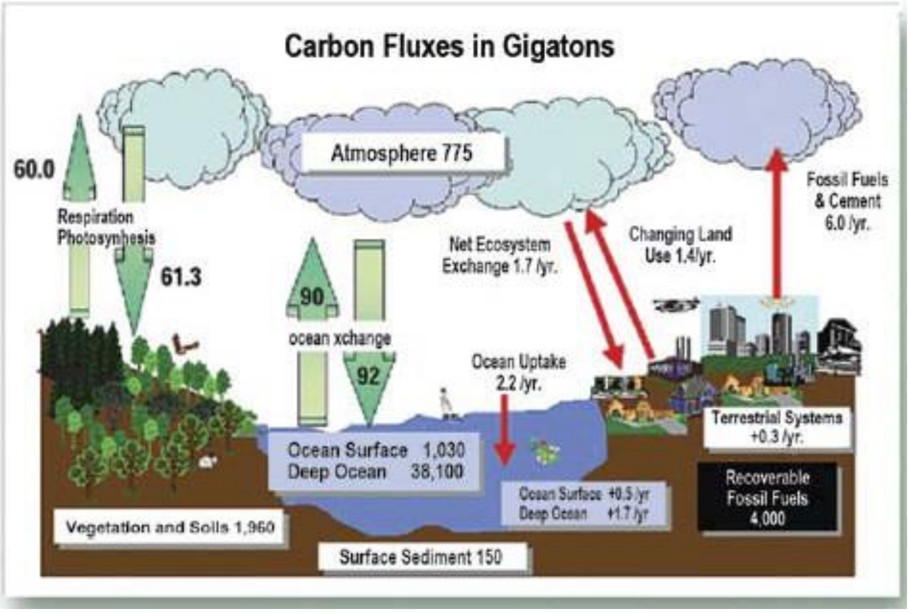
17 Ithaka Institute: "The Ithaka Institute is an international open source network for carbon intelligence.."

18 55 uses of biochar: "Biochar is much too valuable for it to be just tilled into soil without having used it at least once for more beneficial purposes " http://www.ithaka-journal.net/55-anwendungen-von-pflanzenkohle?lang=en

19 Soil carbon: "the generic name for carbon held within the soil, primarily in association with its organic content. Soil carbon is the largest terrestrial pool of carbon... well above the combined total of atmosphere (780 Gt) or biomass (575 Gt), most of which is wood."

20 Green revolution: *"refers to a series of research, and development, and technology transfer initiatives, occurring between the 1940s and the late 1960s, that increased agricultural production worldwide, particularly in the developing world, beginning most markedly in the late 1960s."*



not be enough to avoid dangerous **tipping points**[21], with damaging climate temperature feedback loops. We may need to remove some of the CO2 buildup in the atmosphere... and quickly. A bunch of scientists and engineers have been focusing on this issue and have been proposing some radical solutions around '**climate engineering**[22]'. The proposed solutions fall into two camps: solar radiation management (SRM) or carbon dioxide removal (CDR). A lot of SRM looks like science fiction (expensive and risky) but CDR seems to have some more realistic options. Many of these are around trying to reverse the flow of carbon back to its soil and **terrestrial**[23] home via photosynthesis. Simplistically, this could be described as growing more trees, improve marginal land, greening the deserts, moving to more sustainable agriculture practices... all directed toward sequestering carbon. Biochar could play an important role in all of these activities due to the soil and agriculture attributes described above but principally, due to its stability.

Biochar's inherent stability in the soil is evidenced by Terra Preta and described extensively in science literature. Other forms of soil carbon (living and dead flora and fauna, humus, compost) are recycled to CO2 (or other greenhouse gases) via biological, chemical and physical processes. These carbon turnover rates vary depending on environmental conditions with tropical turnover much higher than in temperate regions. Biochar may also provide positive feedback loops in these processes, adding to the stored carbon pool, by stimulating plant growth and biology above and below ground.

[21] Tipping point: *"A **climate tipping** point is a somewhat ill-defined concept of a point when global climate changes from one stable state to another stable state..."*

[22] Climate engineering: *"also referred to as geoengineering, is the deliberate and large-scale intervention in the Earth's climatic system with the aim of reducing global warming."*

[23] Terrestrial: of the land.

The open burning of crop residues is a serious contributor to greenhouse gases and environmental pollution around the world. Slash and burn agriculture is the main culprit in the annual **SEA haze problem**[24] afflicting Indonesia, Malaysia and Singapore. Imagine a scenario where the carbon in the 'waste' biomass was valued as a soil amendment. A new rural industry could evolve, supplying biochar to the plantation companies and farmers. Simple, mobile, low cost and clean biochar production technologies have been developed and are easily deployable. Unfortunately, there is currently little awareness within regional governments, industry or NGO's on biochar applications or efficacy. Field trials and research projects are still thin on the ground.

Biochar Production Technologies, Bioenergy Co-Production and Application Economics

Biochar implementation projects offer multi-scale opportunities for enhancing bioenergy utilisation. The opportunities for co-production of bioenergy with biochar are closely linked to the chosen production method and could be grouped based on technology scale:

1. Micro-scale: biomass cooking stoves have been designed to cleanly and efficiently use crop wastes, forest litter / trash, wood chips, fuel pellets and briquettes. These **TLUD**[25] stoves produce small regular quantities of biochar, improve indoor air quality and have many other social and environmental benefits.

2. Small-scale: farm and community scale biochar pyrolysis technologies are developing that offer heat / energy co-production opportunities. These technologies are currently the least well developed for bioenergy, commonly flaring pyrolysis gases and heat. Surplus 200L drums are commonly employed as part of retort batch systems or large TLUD's. **Cone kilns**[26] are becoming popular and even controlled open burning can and has been employed to enhance char production where circumstances dictate.

3. Medium scale: small industrial scale biomass pyrolysis and gasification systems are available and/or under development that offer co-production of biochar and bioenergy. They can be located intimately with agriculture processing facilities to utilise available biomass wastes while providing heat and energy opportunities for the adjoining facility and local community. Energy recovery technology would generally describe a continuous production system (as opposed to batch system).

[24] SEA haze problem: is there a potential biochar solution?... http://sea-biochar.blogspot.com/2013/07/haze-slash-and-palm-oil-plantations-in.html

[25] TLUD: Top Lit Updraft gasifier stoves... http://www.biochar-international.org/technology/stoves

[26] Cone kiln: Backyard Biochar website has a nice coverage... http://backyardbiochar.net/

4. Large scale: biomass can provide the fuel for large scale combustion and gasification technologies for energy production. These type of projects try to optimise energy production and minimize unoxidised char co-products. Future large scale pyrolysis systems are competing for this biomass and offer a range of products including electricity, transport fuels, chemicals, fertilizers and biochar.

There many interesting stories to tell about the nascent biochar industry at all production scales and too many to be accommodated within this article. The economics around biochar production and application are also of critical interest to the future uptake of the technology but again, the scope is too broad to describe adequately here... for a future article.

FOR MORE INFORMATION

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