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# Biochar: Examination of an Emerging Concept to Mitigate Climate Change

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# Summary

Biochar is a charcoal produced under high temperatures using crop residues, animal manure, or any type of organic waste material. Biochar looks very similar to potting soil. The combined production and use of biochar is considered a carbon-negative process, meaning that carbon is removed from the atmosphere and will not be released into the atmosphere at a later time.

Biochar has multiple potential environmental benefits, foremost the potential to sequester carbon in the soil for hundreds to thousands of years at an estimate. Studies suggest that crop yields can increase as a result of applying biochar as a fertilizer to the soil. Some contend that biochar has value as an immediate climate change mitigation strategy. Scientific experiments suggest that greenhouse gas emissions are reduced significantly with biochar application to crop fields.

Obstacles that may stall rapid adoption of biochar production systems include technology costs, system operation and maintenance, feedstock availability, and biochar handling. Biochar research and development is in its infancy. Nevertheless, interest in biochar as a multifaceted solution to agricultural and natural resource issues is growing at a rapid pace both nationally and internationally.

Past Congresses have proposed numerous climate change bills, many of which do not directly address mitigation and adaptation technologies at developmental stages like biochar. However, biochar may equip agricultural and forestry producers with numerous revenue-generating products: carbon offsets, fertilizer, and energy. A clearly defined policy medium that supports this technology has yet to emerge (e.g., soil conservation, alternative energy, climate change).

This report briefly describes biochar, its potential advantages and disadvantages, legislative support, and research and development activities underway in the United States and abroad.

# Contents



## Figures



## Contacts

# Introduction

Biochar is a charcoal similar in appearance to potting soil. It is produced under high temperatures using crop residues, animal manure, or any type of organic waste material. Biochar is regarded by some as a product that can meet pressing environmental demands by sequestering large amounts of carbon in soil. However, little is known about how the adaptation of biochar production could successfully be implemented and what the effect would be on long-term operations in the U.S. agriculture and forestry sectors. Studies underway at federal government research institutions and in academia are focused on ensuring that biochar production systems are a practical and reliable technology for producers to adopt. The utilization of biochar is of interest to those seeking to sell or purchase carbon offsets, increase soil conservation efforts, improve crop yield, and produce alternative energy. Some contend that it will be a considerable amount of time before this technology reaches its full potential.

# Biochar

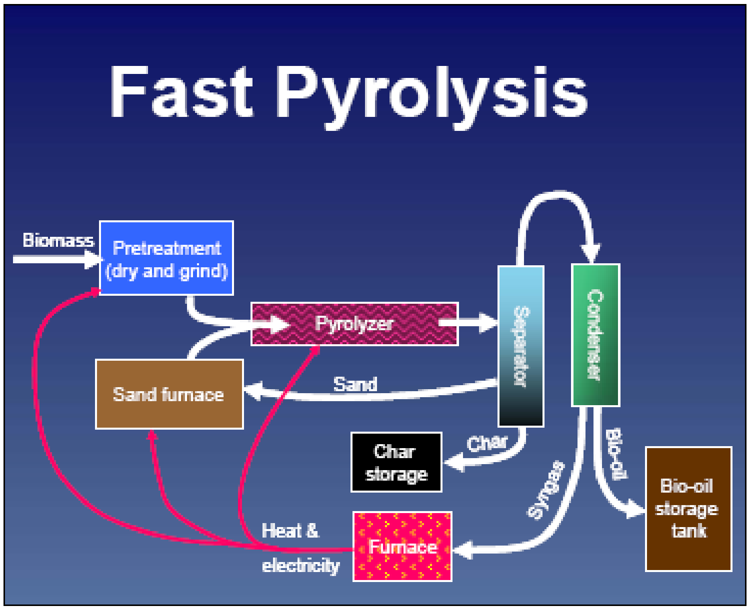
Biochar has the capability to both curtail greenhouse gas emissions and other environmental hazards in the near term and benefit agricultural producers as a soil amendment and source of alternative energy. Thus far, biochar use in the United States has been limited to small-scale applications reflective of the limited but growing number of researchers in this area over the last few years.

Biochar is a soil supplement that may have the potential to help mitigate global climate change through carbon sequestration in the soil. As a charcoal containing high levels of organic matter, biochar is formed from plant and crop residues or animal manure under pyrolysis conditions (**Figure 1**). Pyrolysis is the chemical breakdown of a substance under extremely high temperatures in absence of oxygen. The quantity and quality of biochar production depends on the feedstock, pyrolysis temperature, and pyrolysis processing time. A “fast” pyrolysis (~500°C) produces biochar in a matter of seconds, while a “slow” pyrolysis produces considerably more biochar but in a matter of hours.[1]

The three main outputs of a biochar production system are syngas, bio-oil, and biochar. The biochar production system is operated using energy produced by the system. Biochar production via pyrolysis is considered a carbon-negative process because the biochar sequesters carbon while simultaneously enhancing the fertility of the soil on which the feedstock used to produce the bioenergy grows (**Figure 2**).

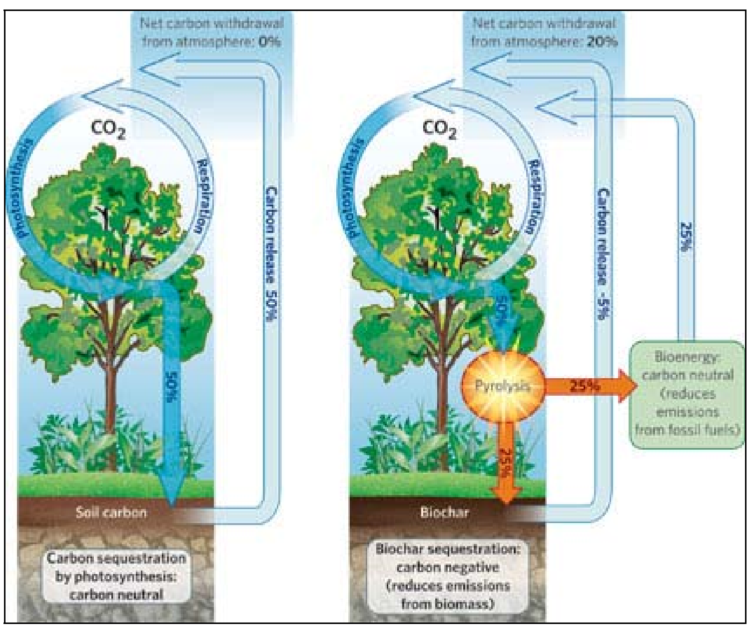
[1] Institute for Governance & Sustainable Development and IDSG/INECE Climate Briefing Note, “Significant climate mitigation is available form biochar,” December 8, 2008.

**Figure 1. Biochar Production via Pyrolysis**




**Source:** U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS), *ARS Biochar & Pyrolysis initiative*, 2009.

**Figure 2. Carbon Cycle for Soil Carbon and Biochar**




**Source:** J. Lehmann, "A Handful of Carbon," 2007. *Nature* 447, pp. 143-144.

## Potential Advantages

Whether applied to the soil as a fertilizer or burned as an energy source (e.g., for cooking and heating), biochar provides numerous potential environmental benefits, some of which are not quantifiable. The three primary potential benefits are carbon sequestration, greenhouse gas emission reduction, and soil fertility.

### Carbon Sequestration

Carbon sequestration is the capture and storage of carbon to prevent it from being released to the atmosphere. Studies suggest that biochar sequesters approximately 50% of the carbon available within the biomass feedstock being pyrolyzed, depending upon the feedstock type.[2] The remaining percentage of carbon is released during pyrolysis and may be captured for energy production. Large amounts of carbon may be sequestered in the soil for long time periods (hundreds to thousands of years at an estimate),[3] but precise estimates of carbon amounts sequestered as a result of biochar application are scarce. One scientist suggests that a 250-hectare farm could sequester 1,900 tons of $CO_2$ a year.[4]

### Greenhouse Gas Emission Reduction

Primary greenhouse gases associated with the agriculture sector are nitrous oxide ($N_2O$) and methane ($CH_4$). Cropland soils and grazing lands are an agricultural source of nitrous oxide emissions. Livestock manure management and enteric fermentation are leading agricultural sources of methane emissions. When applied to the soil, biochar can lower greenhouse gas emissions by substantially reducing nitrous oxide emissions.[5] Emissions of nitrous oxide, a greenhouse gas that is approximately 300 times stronger than carbon dioxide in terms of global warming potential, were reduced by 40 percent in one report.[6] Laboratory studies suggest that nitrous oxide emissions reduction from biochar-treated soil are dependent on soil moisture and soil aeration.[7] Greenhouse gas emission reductions may be 12%-84% greater if biochar is land-applied instead of combusted for energy purposes.[8]

### Soil Fertility

Biochar retains nutrients for plant uptake and soil fertility. The infiltration of harmful quantities of nutrients and pesticides into ground water and soil erosion runoff into surface waters can be

[2] Johannes Lehmann, John Gaunt, and Marco Rondon, "Bio-char Sequestration in Terrestrial Ecosystems—A Review," *Mitigation and Adaptation Strategies for Global Change*, vol. 11 (2006), pp. 403-427.

[3] Bruno Glaser, Johannes Lehmann, and Wolfgang Zech, "Ameliorating Physical and Chemical Properties of Highly Weathered Soils in the Tropics with Charcoal—A Review," *Biology and Fertility of Soils*, vol. 35 (2002), pp. 219-230.

[4] Emma Marris, "Black Is the New Green," *Nature*, vol. 442, no. 10 (August 2006), pp. 624-626.

[5] Johannes Lehmann, "Bio-energy in the Black," *Frontiers in Ecology and the Environment*, vol. 5, no. 7 (2007), pp. 381-387.

[6] Tyler Hamilton, "The Case for Burying Charcoal," *Technology Review*, April 26, 2007.

[7] Yosuke Yanai, Koki Toyota, and Masanori Okazaki, "Effects of Charcoal Addition on $N_2O$ Emissions from Soil Resulting from Rewetting Air-Dried Soil in Short-Term Laboratory Experiments," *Japanese Society of Soil Science and Plant Nutrition*, vol. 53 (2007), pp. 181-188.

[8] Johannes Lehmann, "A Handful of Carbon," *Nature*, vol. 447 (May 10, 2007), pp. 143-144.

limited with the use of biochar.[9] If used for soil fertility, biochar may have a positive impact on those in developing countries. Impoverished tropical and subtropical locales with abundant plant material feedstock, inexpensive cooking fuel needs, and agricultural soil replenishment needs could see an increase in crop yields.[10]

## Potential Disadvantages

Recognizing that biochar technology is in its early stages of development, there are many concerns about the applicability of the technology in the United States. Three issues paramount to technology adoption are feedstock availability, biochar handling, and biochar system deployment. Successful implementation of biochar technology is rooted in the ability of the agricultural community to afford and operate a system that is complementary to current farming practices.

### Feedstock Availability

The availability of a plentiful feed supply for biochar production is an area for further study. To date, feedstock for biochar has consisted of mostly plant and crop residues, a primary domain of the agricultural community. There may be a role for the forestry community to be involved as woody biomass is deemed a cost-effective, readily available, feasible feedstock. Little is known about the advantages of using manure as a biomass feedstock. Some researchers have stated that manure-based biochar "has advantages over typically used plant-derived material because it is a by-product of another industry and in some regions is considered a waste material with little or no value. It can therefore provide a lower cost base and alleviate sustainability concerns related to using purpose-grown biomass for the process."[11]

### Biochar Handling

The spreading of biochar onto soil as a fertilizer is ripe for further exploration. Specifically, the ideal time to apply biochar and ensure that it remains in place once applied and does not cause a risk to human health or degrade air quality are concerns.[12] Particulate matter, in the form of dust that is hard for the human body to filter, may be distributed in abnormal quantities if the biochar is mishandled. Additionally, there are potential public safety concerns for the handling of biochar as it is a flammable substance.

### Biochar System Deployment

Biochar systems are designed based on the feedstock to be decomposed and the energy needs of an operation. It would be ambitious to expect a "one size fits all" standard biochar system. According to proponents, a series of mass-produced biochar systems designed for the needs of a

[9] Johannes Lehmann, "Bio-energy in the Black," *Frontiers in Ecology and the Environment*, vol. 5, no. 7 (2007), pp. 381-387.

[10] Stephan M. Haefele, "Black Soil, Green Rice," *Rice Today*, April-June 2007, p. 27.

[11] K. Y. Chan, L. Van Zwieteb, and I. Meszaros et al., "Using Poultry Litter Biochars as Soil Amendments," *Australian Journal of Soil Research*, vol. 46 (2008), pp. 437-444.

[12] David A. Laird, "The Charcoal Vision: A Win-Win-Win Scenario for Simultaneously Producing Bioenergy, Permanently Sequestering Carbon, While Improving Soil and Water Quality," *Agronomy Journal*, vol. 100, no. 1 (2008), pp. 178-181.

segment of the agriculture or forestry communities might prove to be feasible (e.g., forestry community in the southeastern region, corn grower community in the midwestern region, poultry producer community in the mid-Atlantic region). Extensive deployment of biochar systems would be dependent upon system costs, operation time, collaboration with utility providers for the sale of bio-oil, and availability of information about technology reliability.

# Policy Context

## Climate Change Debate

The 110th Congress deliberated over a large number of bills to address and organize climate-change mitigation efforts, including legislation for carbon offsets.[13] A carbon offset is defined as "a measurable avoidance, reduction, or sequestration of carbon dioxide ($CO_2$) or other greenhouse gas (GHG) emissions."[14] In the 111th Congress, carbon offsets could play a prominent role in the climate change debate. Carbon sequestration projects are one type of carbon offset. In addition to direct carbon capture and sequestration activities, the 111th Congress may consider the role of biological (indirect) sequestration, such as projects that can be implemented by agricultural producers at the field level.[15]

Congress may examine the use of biochar as an indirect carbon sequestration technology that could be used to offset carbon emissions from major emitters. In 2006, 6% of total U.S. greenhouse gas emissions were attributed to the agricultural sector.[16] While not as large as the amounts produced by some other sectors, agricultural emissions come from a large number of decentralized sources, leading many to conclude that controlling such emissions would be difficult. On the other hand, some argue that soil carbon sequestered as a result of biochar application is easily quantifiable and transparent, which may be ideal for carbon trading requirements. Others contend that ancillary benefits could include additional revenue earned by agricultural producers through the sale of carbon credits earned from biochar application or the sale of biochar as a fertilizer. Energy costs for a producer's operation may be reduced by using the alternative energy generated from the biochar production system. Additionally, some assert that the use of biochar results in higher crop yields. This could be a criterion to consider within the larger land use debate.

[13] CRS Report RL34067, *Climate Change Legislation in the 110th Congress*, by Jonathan L. Ramseur and Brent D. Yacobucci.

[14] CRS Report RL34241, *Voluntary Carbon Offsets: Overview and Assessment*, by Jonathan L. Ramseur.

[15] CRS Report RL33801, *Carbon Capture and Sequestration (CCS)*, by Peter Folger; CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector*, by Renée Johnson; CRS Report RL34560, *Forest Carbon Markets: Potential and Drawbacks*, by Ross W. Gorte and Jonathan L. Ramseur.

[16] U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*, 430-R-08-005, April 2008, http://www.epa.gov/climatechange/emissions/usinventoryreport.html. Unlike the U.S. Environmental Protection Agency Greenhouse Gas Inventory Report that covers all U.S. greenhouse gas emission sources and sinks, USDA only reports for the agriculture and forestry sectors. The *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005*, Technical Bulletin No. 1921, issued by the U.S. Department of Agriculture in 2008, reports the agricultural sector as having contributed approximately 481 teragrams (Tg) of carbon to the atmosphere in 2005. With the addition of forest carbon sequestration (approximately 787 Tg), the agriculture and forestry sectors combined contributed a net *sink* of approximately 306 Tg of carbon in 2005. One teragram (TG) equals one million metric tons (MMTE).

## Farm Bill

The 110th Congress promoted biochar development through the 2008 farm bill (P.L. 110-246), which listed it under grants for High Priority Research and Extension Areas. Noted research areas include biochar production and use, co-production with bioenergy, soil enhancements, and soil carbon sequestration. Listing biochar development as a high-priority research area in the 2008 farm bill did not authorize a specific appropriations amount. Funding for biochar development research would be determined in future appropriation bills and by the U.S. Department of Agriculture. Farm managers facing soil fertility, residue and manure management, energy efficiency, and additional revenue generation needs may benefit from a policy that further supports biochar production and use (e.g., technology practice standard, cost-share).

## Long-Term Prospects

Biochar's fate as a viable component of the long-term solution to mitigate climate change by way of carbon sequestration depends upon further development by the scientific and technology transfer communities; in particular, biochar's practical application at various locations and scales using multiple feedstocks throughout the United States is an area for additional study. A policy vehicle to communicate the status of biochar technology to decision-makers and interested communities has not been identified. Natural resources conservation policy, alternative energy policy, or climate change policy are a few examples of possible policy areas. Policy that encourages academia and other institutions to conduct in-depth research and development could quicken the pace of technology deployment.

## International Recognition

A series of presentations delivered at the United Nations Climate Change Conference in December 2008 has elevated interest in biochar as an immediate action response to mitigate climate change through its carbon sequestration ability.[17] Biochar's success rate as a potential clean development mechanism (CDM) mitigation technology may provide insight on its use for U.S. carbon trading purposes.[18] A CDM, monitored by the United Nations Framework Convention on Climate Change (UNFCCC), allows developed countries to invest in and receive credit for activities that reduce greenhouse gas emissions in developing countries. A formal discussion by the UNFCCC to include biochar as a CDM mitigation technology is expected to take place in 2009.

# U.S. Department of Agriculture Activities

According to a U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) official, an estimated $1.1 million was allocated in 2008 toward in-house biochar research by ARS. ARS has over a dozen projects underway to analyze the utilization of fast pyrolysis to

[17] "Dangerous Sea Level Rise Imminent without Large Reductions of Black Carbon and Implementation of Other Fast-Action Mitigation Strategies," *Environmental Research Web*, December 12, 2008.

[18] CRS Report RL34150, *Climate Change and the EU Emissions Trading Scheme (ETS): Kyoto and Beyond*, by Larry Parker.

convert biomass into biochar and bio-oil at various labs nationwide. ARS estimates that the United States could use biochar to sequester 139 Tg of carbon on an annual basis if it were to harvest and pyrolyze 1.3 billion tons of biomass.[19]

# Select U.S. Manufacturers

While some consider biochar research to be in its infancy, a limited number of U.S. manufacturers are selling biochar production technology to the public. CRS was not able to obtain the level of private investment in biochar technology and promotion.

## Eprida, Inc.

Located in Georgia, this technology development company sells biochar production equipment. The company advocates use of both the biochar and the bio-oil produced from its patented system. Officials at Eprida, Inc., believe their technology brings value to three markets: energy, fertilizer, and carbon credit.[20]

## Carbon Char Group, LLC

Agricultural grade value-added biochar is available for purchase from this New Jersey company.[21] In 2008, the company received approximately $50,000 from the USDA New Jersey Conservation Innovation Grants program (CIG) to use biochar to enhance the soil condition in sunflower fields. The CIG is a program administered by the USDA Natural Resources Conservation Service (NRCS) to encourage the development and adoption of innovative conservation technologies that work in conjunction with agricultural production.

# International Activities

The International Biochar Initiative (IBI) is a nonprofit organization consisting of individuals that support a sustainable biochar production system that would remove carbon from the atmosphere and would enhance the earth's soils. IBI currently has nine developing country projects in progress to analyze cost-effective alternatives for the introduction and adoption of biochar. In Vietnam, scientists are conducting an environmental, economic, and social assessment of introducing biochar technology at the household level. The University of Tarapacá in Chile is working on a project to promote the use of biochar to stabilize and buffer soil salinity and increase water retention. Researchers in Kenya are developing a sustainable pyrolysis cook-stove and biochar system for rural agricultural households. More information concerning these projects in Africa, Asia and South America is available at http://www.biochar-international.org.

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[19] E-mail from Robert Fireovid, USDA ARS National Program Leader, January 8, 2008.

[20] http://www.eprida.com, 2009.

[21] http://www.carbonchar.com, 2009.

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