Biochar and Sustainable Agriculture

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Biochar has the potential to produce farm-based renewable energy in a climate-friendly manner and provide a valuable soil amendment to enhance crop productivity. If carbon offset markets develop, biochar can provide income for farmers and ranchers who use it to sequester carbon in soil. This publication will review the current research and issues surrounding the production and use of this emerging biomass energy technology and explore how biochar can contribute to sustainable agriculture. Biochar is the product of turning biomass into gas or oil with the intention of adding it to crop and forest production systems as a soil amendment.

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Biochar from various feedstocks. Photo courtesy of **Nature.**

Introduction

Biochar was initially linked to the exploration and archeological study of early human settlement and soils. These early studies of soils being enriched from what appears to be the deliberate mixing of burned biomass in soils around human settlements helped spark more recent interest in biochar. These deposits of enriched soils, known as *terra preta* in the Amazon region of South America, have a fascinating history of scientific study of their own (Lehmann et al, 2004).

More current studies of biochar are focused on its role in a growing demand for biomass-based energy sources that can mitigate greenhouse gas emissions and slow climate change. For more information about bioenergy, see the ATTRA publication *An Introduction to Bioenergy: Feedstocks, Processes and Products.* In addition, biochar has the potential to enhance soil quality and soil carbon sequestration. For more information about carbon sequestration, see the ATTRA publication *Agriculture, Climate Change and Carbon Sequestration.* A secondary source of interest in biochar comes from the growing need to develop low-cost and healthier biomass-fueled stove technology.

What is biochar?

The definition of biochar is more about its creation and intended application rather than what it is composed of. Both charcoal and biochar are produced through an energy conversion process called *pyrolysis,* which is essentially the heating of biomass in the complete or near absence of oxygen. Pyrolysis of biomass produces char, oils and gases. The amount of these materials produced depends on processing conditions. What makes biochar different from charcoal is that the biochar product is created for use as a soil amendment. Biochar can be produced from a variety of biomass feedstocks, but is generally designated as *biochar* only if it produces a useable co-product for soil

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Healthier stoves

In rural areas, an estimated 3 billion people still cook with biomass fuels such as wood, dung and leaves. The many inefficient stoves in use have resulted in severe respiratory illness and death. Over 1.6 million children die annually in the developing world from the consequences of exposure to biomass fuel (Edelstein et al., 2008). The International Biochar Initiative (IBI) has assisted in several projects that are improving cookstove efficiency while producing biochar for use as a soil amendment. These projects are part of a broad movement to end this serious world health issue. See the **Further resources** section at the end of this publication for more information about IBI.

Making a biochar stove in Kenya. Photo courtesy of Dorisel Torres, Cornell University.

Related ATTRA Publications

Agriculture, Climate Change and Carbon Sequestration

An Introduction to Bioenergy: Feedstocks, Processes and Products

Biodiesel: The Sustainability Dimensions

Renewable Energy Opportunities on the Farm

improvement. The oils and gases from pyrolysis can be used for energy production. The biochar and energy created can provide a carbon-negative energy source and a useable co-product for soil improvement. Carbon-negative renewable fuels are discussed later in this publication. However, not all biochars are created equal. The efficiency and effectiveness of the process of its creation and use can vary and the specific biomass sources used can affect the characterization and usability of the biochar (McLaughlin et al., 2009).

Complex ongoing research is striving for a more uniform and standard biochar that will limit potential environmental problems associated with biochar production and application to soils. Creating a standardization of biochars may make it possible for people who buy biochar to depend on uniform attributes. Issues such as what should be the ideal moisture and ash content of standard biochar are relatively easy to measure and standardize, but tests for metals and alkalinity are not. Some of the attributes that might be expected from biochars can go beyond just physical characteristics to issues of whether the feedstock used in its creation was from a renewable feedstock, whether its production reduced greenhouse gas emissions and whether the biochar can improve soil quality in a reliable way (IBI, 2009).

Importance to farmers and ranchers

Increased fertility

Farmers and ranchers may have an interest in biochar as a soil amendment that can enhance fertility and reduce the need for more expensive fertilizers. However, practical issues of how much to apply, cost, availability and possible risks with application are yet to be fully explored even though research is expanding rapidly. The book *Biochar: Environmental Management,* by edited by IBI board members Johannes Lehmann and Stephen Joseph, has some of the best current information available.

Scientists still don't have a specific understanding of how biochar provides fertility for crops, but the following provides a good summary of what research has suggested to date.

- Biochar has little plant nutrient content itself but acts more as a soil conditioner by making nutrients more available to plants and improving soil structure.
- The high surface area and pore structure of biochar likely provides a habitat for soil microorganisms, which in turn may aid in making some nutrients available to crops.

- With respect to if biochar can provide improved nitrogen and phosphorus availability to crops, the research is not definitive but is suggestive of a positive effect.
- Biochar may provide an indirect nutrient effect by reducing leaching of nutrients that otherwise would not be made available to crops.
- The quality of the biochar applied, the process of application and the over-application of biochar may have negative impacts on air and water quality.

Moisture retention

A few studies of biochar application on crops suggest that biochar may enhance soil moisture retention. This attribute of biochar may lessen the effects of drought on crop productivity in drought-prone areas. As noted above, this moisture retention capacity is largely related to the high surface area and porosity of biochar. However, there is some controversy because the moisture retention capacity is related to the feedstock that was used to produce the biochar, as well as the exact process of the biochar's production. These two factors can affect the pore and surface structure of the biochar. However, if climate change leads to even drier conditions in many agricultural production areas of the world, biochar as a soil amendment from various feedstock sources may still have some positive effect on retaining soil moisture even if it is variable (Lehmann and Joseph, 2009).

Soil pH balancing

For soils that require liming, there is growing evidence that biochar may provide similar benefits of improving soil pH balance (Collins, 2008). However, the quantity of biochar that needs to be applied relative to liming may be high. Also, the substitution of biochar for lime can likely provide for net carbon benefit compared to standard liming.

On-farm and community-based bioenergy production

The process of making biochar has the potential to be scaled to a level that allows biochar and bioenergy to be produced on the farm or as a rural community economic development project. Farms and ranches have the advantage of being close to several sources of biomass that would be appropriate for biochar production and use. A few demonstration and research projects in the United States are just beginning to examine biochar production but have so far been largely limited to forestry-based biochar and bioenergy production. There are also a few fairly new companies developing biochar production equipment and even selling biochar as a soil amendment. See the **Further resources** section at the end of this publication for a short list of these projects and companies.

Potential income offsets, fuel and soil amendments

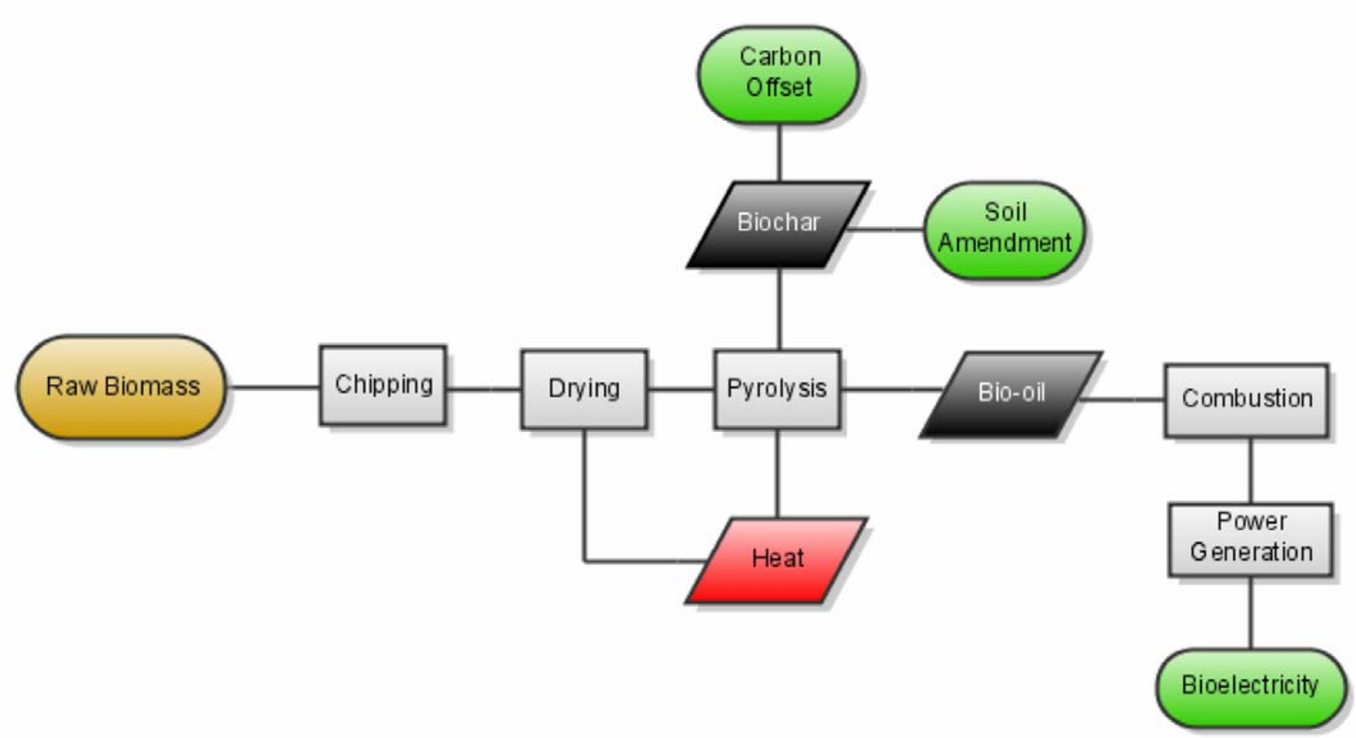
The economic potential of biochar for farmers and ranchers can come from three sources: as a soil amendment that could partially replace fertilizer; as a source of heat, bio-oil and gases for farm and ranch use; and as potential income as a carbon offset in a future cap-and-trade market For example, it is conceivable that a farm or ranch with significant renewable biomass sources available for harvest could covert that biomass to heat and liquid or gas fuel for machinery operation and return the biochar back to the fields to enhance fertility and collect a carbon offset payment. See **Figure 1** for an illustration of possible income sources from biochar production. However, several economic, institutional and regulatory questions need to be answered before such a project could be fully optimized.

Farms and ranches have the advantage of being close to several sources of biomass that would be appropriate for biochar production and use.

First, what are the costs and values of on-farm biochar production? The answer to this question is still very much an open research issue. A recent study published by Washington State University provides estimates for non-farm, ranch-based biochar production costs as well as an excellent review of limited additional research studies (Granatstein et al., 2009). The result of this study, which is based on biomass from sustainable forest thinning, offers a wide range of costs for biochar and bio-oil production. As noted earlier, the creation of biochar results in not only char but also oils (bio-oil) and gases

Figure 1. Potential income sources from biochar production

(Figure courtesy of Re:char, *www.re-char.com/technology/mobile-pyrolysis*)



that have potential economic value. Depending on the scale of production, which ranges from mobile to stationary, the WSU study suggests a range in total costs of production of biochar of between $194 and $424 for each ton of feedstock (Granatstein et al., 2009).

Second, there are only a few private carbon offset markets available and none have institutionalized a market for carbon offsets related to biochar. While the U.S. House of Representatives has passed legislation (HR 2454) that could lead to the establishment of a carbon offset market, as of the date of this publication (February 2010) the Senate has yet to consider fully its version of similar legislation. An amendment to the Senate bill does mention biochar as a potential for carbon offset projects. Finally, in October of 2009 two bills were introduced in Congress (HR 3748, SB 1713) that would provide for loan guarantee programs to support demonstration projects for biochar production from biomass collected on public lands. Several studies have estimated what level of carbon offsets income may be generated from biochar production, but these are based on estimates of life-cycle greenhouse gas emissions and price expectations of future unknown carbon prices. One of the distinct advantages of biochar is that it provides a relatively easy measurement for soil carbon sequestration compared to other ways of increasing soil carbon sequestration that are not as easily measured.

Finally, the production of biochar has several potential regulatory issues to overcome before a biochar industry can develop. Major issues include:

- Applications and potential carbon dust air pollution. Biochar is very light and easily broken into small particles that can become airborne.
- Air emission standards from biochar production have not been fully examined and may vary depending on the design of the pyrolysis equipment.
- Water quality issues related to applied biochar on potentially erodible fields.

- Potential heavy metal content of biochar (depending on the biomass feedstock) and its effect on human and animal health.

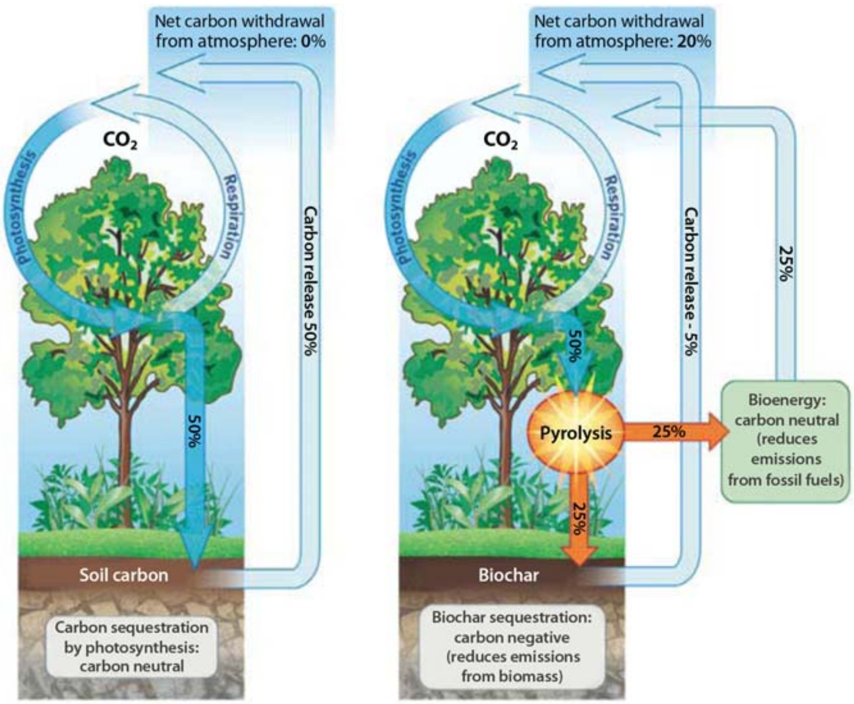
While these issues are not beyond solution, they will all have to be investigated and will likely add costs to the production and use of biochar as a soil amendment.

Relationship to climate change and soil carbon sequestration

As noted above, one of the most promising aspects of biochar with bioenergy production is that it could be an important renewable energy source with the potential to significantly mitigate greenhouse gas emissions and slow climate change. **Figure 2** provides an illustration of this capacity of biochar. The percentages are estimates of potential atmospheric carbon offsets but are not yet fully documented and are used here as an illustration of the process only.

Figure 2. Biochar can be a carbon-negative renewable fuel source

Source: International Biochar Initiative. Available at *www.biochar-international.org/biochar/carbon*



The first illustration shows the carbon sequestration process. This represents the natural carbon cycle. As plants pull carbon dioxide (CO_2) from the atmosphere, part of that carbon is built into the plants' structures through the process of photosynthesis. When plants die, they sequester that embodied carbon into the soil, but most of the carbon is rather quickly released back into the atmosphere as CO_2 through plant respiration and soil microbiological activity. The relative amounts of CO_2 are more or less balanced and hence the process is said to be carbon neutral. Carbon neutral means that there is no net carbon added to the atmosphere other than what naturally occurs. Climate change is caused by net additions of carbon (carbon positive) to the atmosphere. These additions are primarily due to humans burning carbon-based fossil fuel stocks at an increasing rate over the past 500 years. Carbon negative refers to the actual net reduction of carbon in the atmosphere.

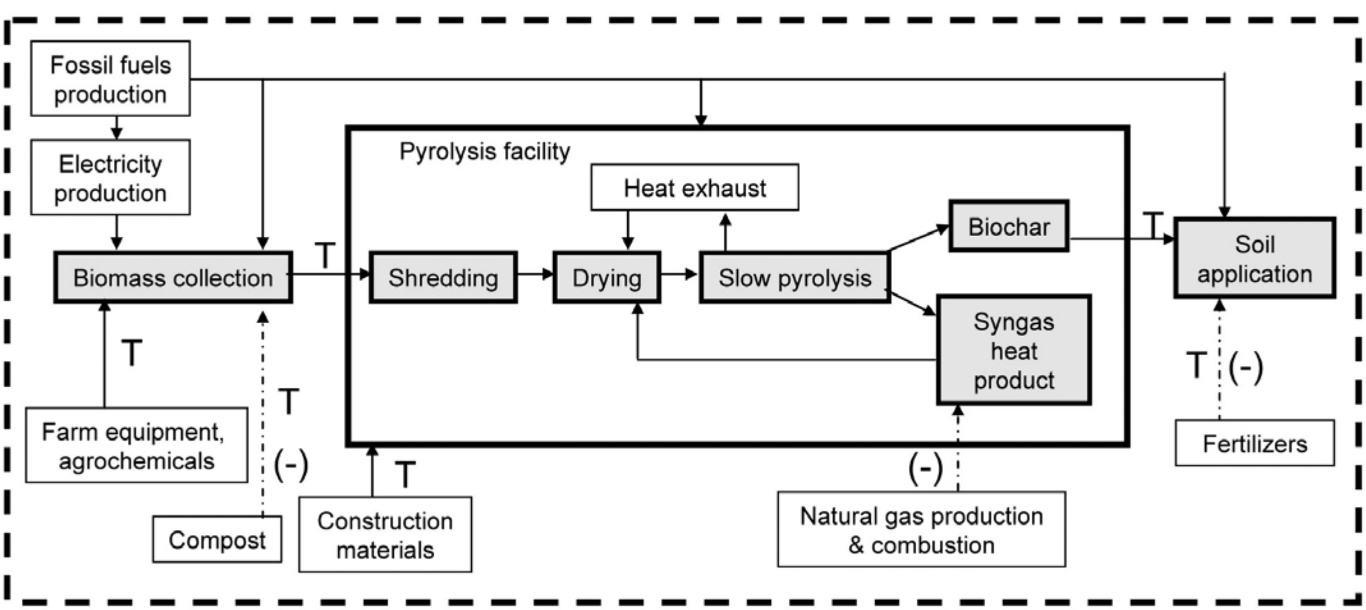
In the case of biochar in **Figure 2**, the natural process is interrupted by capturing part of the biomass before it reaches the soil directly and using part (25 percent in the example above) for the production of bioenergy and part for the production of biochar. The illustration shows that the biomass that is converted to energy (potentially in the forms of heat, gas or liquid fuels) releases part of the carbon in the form of CO_2 back into the atmosphere in an assumed carbon-neutral process. The other part of the biomass is converted into biochar and because of its stability sequesters all but 5 percent of the carbon (in this illustration) in the soil and hence has the ability to provide a carbon-negative source of energy.

However, the ability of biochar with bioenergy production to offer carbon-negative renewable fuel through its energy co-products is limited to critical points in the process of its production and use. First, it is important that biochar applied as a soil amendment remains sequestered for a very long time. In climate change jargon, this refers to the issue of permanence. In other words, it would be hard to claim a permanent sequestration of carbon if the biochar carbon that was applied as a soil amendment was immediately released back into the atmosphere through possible soil decomposition processes. However, most research to date clearly demonstrates that biochar applied to soil releases carbon back into the environment at a very slow rate that is in excess of several hundreds if not thousands of years (Lehmann and Joseph, 2009). Whether hundreds or thousands of yearsmeans a permanent sequestration, it is a much slower release compared with the soil carbon sequestration that occurs when agricultural practices such as conservation tillage are adopted as a means to mitigate climate change. It also offers safer and likely less expensive carbon sequestration than methods related to the storage of carbon dioxide in underground geologic formations known as carbon-capture and sequestration technologies.

Second, the carbon-negative potential of biochar is either enhanced or limited by the efficiency of energy production and the ability of the overall production process to limit carbon dioxide and other greenhouse gas emissions. In part, this is because of controversy over the scientific methodologies for measurement of biomass-based energy production (UNEP, 2009). Nonetheless, to properly understand these potentials for biochar, a life-cycle analysis of biochar needs to be examined to fully account for energy efficiency and greenhouse gas emissions. Life-cycle analysis is a method used to evaluate the environmental burdens associated with a product, process or activity throughout its full life by quantifying energy, resources and emissions and assessing their effect on the global environment. Only a few researchers have undertaken this type of analysis, but to date their work supports the conclusion that biochar results in a net reduction in greenhouse gas emissions (carbon-negative) and is an energetically efficient use of biomass (Guant and Lehmann, 2008; Lehmann and Joseph, 2009; and Roberts et al., 2010).

More specifically, one study estimated that the production of biochar was from 2 to 5 times more likely to reduce greenhouse gas emissions than if the biomass was used just for the production of energy alone (Gaunt and Lehman, 2008). Significantly, the energy produced per unit of energy input (known as the energy ratio) was estimated to be in the range of from 2 to 7, which means that output energy of biochar production is between 2 and 7 times greater than the energy input for its production. This estimated energy ratio for biochar is potentially more energetically efficient than energy production for other biofuels like corn ethanol or even new technologies such as cellulosic ethanol. **Figure 3** provides an example of the details of the life-cycle analysis of biochar led by Kelli Roberts of Cornell University.

Figure 3. Life-cycle analysis of biochar. Source: Roberts et al., 2010. T= Transportation energy



Finally, these early positive results of life-cycle estimates need further verification and more careful study before anyone can say with great certainty that biochar has the potential to provide carbon-negative renewable energy. This caution is advised for two important reasons.

First, the life-cycle analyses to date are based on research that has yet to clearly demonstrate that biochar applied to all soils can both reduce nitrous oxide ($N2_O$) emissions from soil and enhance fertility. Nitrous oxide emissions from soils represent the single greatest source of greenhouse gas emissions from agriculture production and are related to the use of synthetic fertilizers. If biochar can reduce nitrous oxide emissions because it can offset the use of synthetic fertilizers and lower nitrous oxide emissions generally, then biochar production can play an important role in climate change mitigation. Research shows that the majority of emission reductions come from the stable carbon in the biochar and that the reduced nitrous oxide emissions and synthetic fertilizer reductions contribute only a small amount to the life-cycle greenhouse emissions reductions (Roberts et al., 2010). However, other studies that point to both the fertility effect and reduction of other greenhouse gas emissions from the use of biochar as a soil amendment are still limited in number and will require greater research effort to further substantiate results.

Second, the energetic analyses of cropping systems, which determine how much energy goes into the production of biomass energy crops, are also limited. Thus, it is difficult to know which biomass cropping systems can reduce fossil fuel use. With improved work on these two issues, future life-cycle studies can better measure the carbon-negative fuel capability of the biochar production process.

Limits of biochar and climate change: The fuel-versus-food debate

Biochar is both a potential renewable biomass energy source and a means to expand the sequestration of soil carbon and mitigate climate change. However, this depends on the sustainable use and production of biomass sources. One major issue that looms for all biomass-based energy – including biochar development – is what is commonly referred to as the fuel-versus-food debate. Another characterization of this debate is what has been called the *trilemma* of the food, energy and environment implications of beneficial biofuels (Tilman et al., 2009).

This trilemma is related to the general issue of sustainability and how to maximize multiple objectives simultaneously. In the case of beneficial bioenergy, the trilemma is posed as follows:

> "Biofuels done right can be produced in substantial quantities. However, they must be derived from feedstocks produced with much lower life-cycle greenhouse gas emissions than traditional fossil fuels and with little or no competition with food production." (Tilman et al., 2009)

One major issue that looms for all biomass-based energy – including biochar development – is what is commonly referred to as the fuel-versus-food debate.

Broadly, how can biofuels be produced in a way that does not over time destroy our natural environment and also does not reduce our ability to maintain and improve food security for all people? The authors who posed this question provide a list of beneficial feedstocks for bioenergy that can address this trilemma (Tilman et al., 2009):

- Perennial plants grown on degraded lands abandoned from agricultural use.
- Part of crop residues from agricultural production provided that a significant portion is returned to land to enhance future soil fertility and health.
- Sustainably harvested wood and forest residues.
- Double crops and mixed cropping systems that integrate food and dedicated fuel crops.
- Municipal and industrial wastes.

However, the authors also point out that the full development of these biomass stocks needs to be done in a way that does not indirectly result in significant land use changes that can lead to even greater releases of greenhouse gas emissions. For example, if parts of the crop residues produced in food production are not returned to soils to maintain soil fertility and health, that loss may be made up with increased synthetic fertilizer use. That causes greater use of greenhouse gas-emitting fossil fuels through fertilizer production and ultimate nitrous oxide emissions from its use. Furthermore, if food-producing acres are substituted for dedicated energy crops, this may cause the destruction of forests and grasslands in other parts of the world to make up for the lost production of food on those acres. This can lead to an even greater release of greenhouse gas emissions. This last problem is often referred to as the indirect land-use issue and is the source of considerable debate in assessing the sustainability of various biofuel production systems. For more information, see the article *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Land Use Changes* by Timothy Searchinger. More information is available in the **Further resources** section.

There seems to be great attention focused on these issues and even international attempts to produce principles of sustainability to use in the identification of biomass sources for ultimate biochar conversion. At the first North American Biochar Conference in August of 2009, there was extensive discussion about creating sustainability standards for biochar production (IBI, 2009). Finally, because biochar efforts are largely directed toward the production of renewable carbon-negative bioenergy (versus simply carbon-neutral fuels) there seems to be an inherent understanding of these issues among biochar advocates.

Summary: The future of biochar for sustainable agriculture

Biochar has very promising potential for the further development of sustainable agriculture production systems. Also, biochar production provides a great potential for worldwide climate change mitigation that goes beyond its uses in agricultural production alone. The research on the many complex issues related to biochar production systems is growing very quickly and will be needed to more fully understand the implications for food systems, the environment and bioenergy production. Finally, biochar could play an important basis for rural economic development because its production can be scaled down for smaller communities closer to biomass sources.

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Further resources

Demonstration projects:

EcoTechnologies Group
Through 2008 and 2009, EcoTechnologies developed numerous relationships and targeted domestic and international projects for waste reduction, biochar and biocoal production and energy creation.
www.ecotechnologies.com/projects.html

North Carolina Farm Center for Innovation and Sustainability
This is a forestry-based project that uses a demonstration model of a biochar production unit manufactured by Biochar Systems. Contact Richard Perritt at *rperritt@ncfarmcenter.org* or by phone at (910) 630-6232 for more information.

Biochar production equipment and systems:

International Biochar Initiative
Provides a general overview of biochar
www.biochar-international.org/technology/production

Alterna Biocarbon, Inc
This is a company focused on the manufacturing of biocarbon from products such as wood, municipal and agricultural waste and tires. Biocarbon, also called biochar or charcoal, is a renewable replacement for coal manufactured for industrial markets. *www.alternaenergy.ca*

BEST Pyrolysis, Inc.
This company works to develop clean energy solutions. It has developed proprietary pyrolysis and gasification technologies to use renewable bio-based resources while providing clean energy from rich local sources of biomass.
www.bestenergies.com/companies/bestpyrolysis.html

Biochar Systems
This company works to bring together the business, science and technology of biochar. *www.biocharsystems.com*

Ecoera
This bioenergy innovation company provides technologies enabling energy-efficient agriculture and carbon capture and is focused on the second-generation biomass heating fuel, including agropellets from hemp, agro-residues and energy grasses. Ecoera also offers carbon sequestration and soil enhancement through the use of biochar for carbon capture. *www.ecoera.se/index.html*

EcoTechnologies Group
This whole-systems company partners private, public and nonprofit organizations with emerging ecologically and economically sustainable technologies.
www.ecotechnologies.com/index.html

Eprida
This company offers a revolutionary new sustainable energy technology that removes carbon dioxide from the air by putting carbon into the topsoil where it is needed. The process creates hydrogen-rich biofuels and a restorative high-carbon fertilizer from biomass alone, or a combination of coal and biomass, while removing net carbon dioxide from the atmosphere.
www.eprida.com/home/explanation.php4

Evergreen Fuel Technologies
This renewable energy company converts agricultural and forest byproducts into clean electrical energy. Its energy centers are designed to convert agricultural waste (plant byproducts) and forest refuse into clean renewable electricity and biochar. *www.evergreenfueltech.com*

Re:char
This company is a developer of innovative mobile pyrolysis technologies. It produces biochar and renewable biocrude from waste. *www.re-char.com*

VenEarth Group, LLC
This group and its portfolio companies have assembled an international team of scientists, engineers and business leaders to develop earth-friendly technologies and businesses. *www.venearth.com*

Other Web sites

The International Biochar Initiative
This site is a source for biochar information from around the world. *www.biochar-international.org*

AirTerra
AirTerra is a nonprofit organization committed to poverty reduction. *www.airterra.ca*

BioChar Central
This site is a user-driven information hub and strives to provide a community where new ideas, old practices, events and news can be discussed. *www.biocharcentral.com*

Biochar Farms
This Web site was established to provide practical, accessible and objective information about biochar production and its application to soils. *www.biocharfarms.org*

Biochar Ontario
This group promotes biochar as a vehicle to reduce greenhouse gas emissions, improve soil fertility and enhance food security by advocating research, development and commercialization of biochar. *www.meetup.com/biocharontario*

Biomass Energy Foundation (BEF)
This nonprofit foundation is devoted to biomass energy and specializes in gasification. *www.woodgas.com*

Carbon Zero Foundation
This foundation supports public and private initiatives to reduce global warming caused by the accumulation of greenhouse gases in the atmosphere. *www.biochar.info/biochar.biochar.info.cfml*

Seachar
This is the Web site for the Seattle Biochar Working Group, an organization that promotes the use of biochar as an important part of Seattle's response to the challenge of global climate change. Through a campaign of education and community involvement, the group intends to research and implement a local pilot program to produce biochar from clean green waste. *www.seachar.org*

Sustainable Obtainable Solutions
This nonprofit was created to increase the understanding of sustainability and the interrelationships of people and nature, especially on public lands. It has several links to biochar information. *www.s-o-solutions.org/biochar.html*

Books and reports

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Notes

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