



Biochar for Forest Restoration in Western States

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Introduction

Forest restoration projects in the western United States, including thinning for hazardous fuel reduction, leave behind a significant amount of wood waste or biomass, which include small-diameter logs, tree tops, and branches, as well as needles, leaves, and sometimes roots. These materials, also called forest residue or slash, are usually gathered into large piles and burned or left to decompose (Sue et al. 2016). This biomass almost always goes unused due to the wide price gap between high harvesting and transportation costs and low market values. However, a product called biochar is giving new hope for forest restoration in the West.

This factsheet introduces biochar, bio-oil, synthesis gas, pyrolysis, and torrefied wood products to the reader. We describe biochar production methods and applications for forest restoration projects in the Intermountain West.



Figure 1. Chipped (masticated) juniper | Photo credit: Patrick Rappold

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Wood

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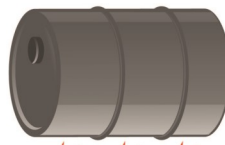
To Fuel



Woody Biomass



Woody Biomass is chipped into fine pieces, then incinerated in the pyrolysis machine, without Oxygen



Pyrolysis

A brief look into Pyrolysis

The Pyrolysis process produces Oil, Gas, and Bio-Char. Both the oil and the bio-char are highly valuable, and the machine runs off the gas it produces, making it self sustaining.



Figure 2. Production of bio-oil, bio gas and biochar by pyrolysis | Graphic credit: Darren McAvoy

If forest restoration projects could produce marketable materials, then the projects would be more affordable and more restoration could get done. Biochar is one of those materials. Pinyon-juniper (PJ) woodlands, for example, occupy about 47 million acres in the western United States (Evans 1988, Chambers et al. 1999). In many places PJ has expanded into areas formerly dominated by sagebrush and other important rangelands, which can negatively impact wildlife habitat, increase erosion, cause loss of herbaceous species, and increase fire hazard and severity. Because of biochar's various potential uses, its production may offer a way to make the restoration of these ecosystems economically feasible. This fact sheet provides an overview of what biochar is, how it is produced, and how it can be used in land reclamation and for other purposes.

What is biochar and how is it produced?

Biochar is made from biomass via pyrolysis, a thermochemical conversion of organic material under conditions of limited oxygen and

controlled high temperatures. Pyrolysis can be classified into four modes based on operating conditions and the desired products. Table 1 summarizes the main pyrolysis techniques based on temperature, heating rate, and major products. Pyrolysis produces mainly biochar



Figure 3. Five pyrolysis products plus pulp chips. Clockwise from top left: microchips from mixed conifer woody biomass, 3-inch pulp chips for reference (center), high carbon biochar resulting from pyrolysis at 1,000°C, pellets made from char, high surface area activated carbon made from char (biochar), and pellets made from wood. Photo credit: Nate Anderson, USDA Forest Service



Figure 4. Biochar pellets (left) produced using high-temperature pyrolysis compared to pellets made from torrefied wood (right)
 Photo Credit: Nate Anderson, USDA Forest Service

when conducted at a temperature of less than 400°C with a long residence time (time that the material is exposed to heat), while bio-oil is the main product when the system is conducted at an intermediate temperature of around 500°C with a short residence time (Bridgewater 2006).

Operationally, woody biomass that is going to be used for conversion to biochar and other products is typically pre-processed, usually by

chipping or mastication (Figure 1) and screened to a uniform small chip size. The moisture content of the chips is also reduced, ideally to $\leq 10\%$. Moist wood can also be processed but this slows production. Once dry chips have been produced they are fed into a high-temperature pyrolysis reactor. During pyrolysis (Figure 2) the biomass is heated, which evaporates any remaining moisture. Further heat input breaks down the major biomass components (cellulose, hemicellulose, and lignin) into pyrolytic vapors. The pyrolytic vapors consist of incondensable gases such as H_2 , CO , and CO_2 (known as light hydrocarbons), and condensable vapors which can be formed into a liquid. We call this mixture of liquid organic compounds bio-oil (Neves et al. 2011).

Thus, pyrolysis breaks down the organic portion of the biomass into three products (Figures 3 & 4), a carbon-rich solid (biochar), a liquid (bio-oil), and a synthesis gas (syngas) (Sensoz et al. 2000, Babu 2008, Briens et al. 2008, Vamvuka 2011).

Table 1. Modes of pyrolysis and major products (RT = reactor temperature, HR = heating rate; adapted from Bridgewater, 2006)

Mode	Conditions	Liquid (%)	Solid or char (%)	Gas (%)
Fast	RT (500°C) Very high HR (> 1000°C/sec) Short hot vapor residence time ~ 1 sec	75	12	13
Intermediate	RT (400-500°C) HR range (1-1000°C /sec) Hot vapor residence time ~10-30 sec	50	25	25
Slow-Torrifaction	RT (~290 °C) HR (1°C /sec) Solids residence time (~30 min)	0-5	77	23
Slow-Carbonization	Low temperature (~400-500°C) HR (1°C /sec) very long residence time (days)	30	35	35



Figure 5. The Tucker RNG thermal conversion system uses forest biomass and other woody material as its fuel source
Photo credit: Nate Anderson, USDA Forest Service

Biochar, therefore, is a refined charcoal (sometimes called bio-coal) left behind after pyrolysis. Bio-oil is similar to crude oil and can be refined to make heating oil or a variety of other biochemical products. Bio-oil can be further refined to create very high value products such as adhesives and plastics that have the potential to produce significant revenues. The syngas is similar to propane and can be used to dry the biomass or to operate the machinery, so the process can be self-sustaining to a large extent.

Numerous laboratory and pilot-scale studies of pyrolysis and gasification of woody biomass to produce biochar and other products have been done (Mohan et al. 2006, Kumar et al. 2009, Van der Stelt et al. 2011) and several systems are available commercially. For example, the Tucker Renewable Natural Gas System (Tucker RNG System) is a core conversion technology that produces a methane-rich syngas and a high carbon char output from a wide range of woody biomass feedstocks (Figure 5).

However, the associated support systems (e.g. feedstock storage, handling and drying, gas scrubbers, gas compression and storage, and fuel storage) makes it impractical to be used for most restoration projects. They are very costly to tear down and reassemble at a field site. The Tucker RNG System also requires high temperatures (1,000°C) and they are not designed for a daily warm up, cool down cycle, but rather for continuous operation.

Several companies, such as Western Renewable Technologies in Linden, Utah, are developing and marketing commercial equipment for biomass conversion that can be



Figure 6. The Amaron Energy Rotary Pyrolysis Reactor in a field setting | Photo credit: Darren McAvoy

deployed near the biomass source to avoid long haul transportation and associated costs of bulky woody biomass. Amaron Energy, a Utah-based company, has developed a mobile (field deployable) pyrolysis reactor capable of producing varying levels of biochar, biogas, and bio-oil (Figure 6). Amaron is currently working with PacifiCorp on using torrefied wood pellets, which release fewer volatile organic compounds and heavy metals than coal, as partial replacement for coal in its coal-fired power plants.

What are the uses for biochar?

Biochar has a number of unique chemical and physical properties that make it very useful and potentially valuable. Its most important property is its ability to absorb elements and hold them, especially in the soil. Karhua et al. (2011) Uzoma, et al. (2011) Absorbing and holding water and nutrients makes them more available to plants. Biochar is a fairly stable source of carbon when it is incorporated in the soil as well. It breaks down slowly so that humic acid and soil nitrogen is available to plant roots over time. Absorbing and holding hazardous or toxic elements can keep them from translocating through soil and into groundwater and can give microbes time and a favorable environment to them break down.

Biochar's various properties give it a potential economic value if markets can be developed for it. This can make forest restoration projects financially viable by providing a valuable product made from woody biomass (Anderson et al. 2013). Its economic value can enhance rural economic development, and can make renewable energy generation possible, enhancing national energy security (Groot et al. 2016). Moller (2013), Page-Dumroese (2013), Anderson et al. (2013), and Chalker-Scott (2014) identify six primary markets or uses for



Figure 7. USU Extension crew applying biochar at a commercial organic vegetable farm near Kaysville, Utah
Photo credit: Darren McAvoy

biochar that include (1) large-scale agriculture, (2) forest and rangeland management (e.g. through post-fire vegetation responses), (3) mine reclamation, (4) urban forests and golf courses, (5) horticulture, forest nursery, gardening, and vegetable production, and (6) industrial applications (e.g. activated carbon).

The Utah Biomass Resources Group currently is conducting field trials of biochar as a soil amendment under both agricultural and reclamation conditions. One study is amending the soil of several production vegetable farms located along the Wasatch Front near Salt Lake City, Utah. It seeks to determine the relative productivity of these amended soils to enhance tomato and melon growth and to protect against the common root disease phytophthora (Figure 7). Final results for this study are not yet complete but appear to be promising. Go to [http://
utahbiomassresources.org/html/biochar/biochar-research-utah/biochar-amendment-for-productivity/](http://utahbiomassresources.org/html/biochar/biochar-research-utah/biochar-amendment-for-productivity/)

Another study being conducted in the Uinta Basin near Vernal, Utah looks at using biochar as a soil amendment on an abandoned oil/gas drilling pad now overrun with noxious weeds. Reclamation of the site using standard techniques had failed. Soil moisture, plant growth and a variety of other parameters are being monitored to examine the effects of a variety of biochars and application rates. The project goals include reducing cost and length of time for contractors to achieve bond release, increase seedling establishment success, especially for native plant species, improve soil growing conditions, and others. For complete details on this ongoing study see <http://utahbiomassresources.org/biochar/biochar-research-utah/land-reclamation-study>.

Conclusions

Biochar has value both as a forest product and as an amendment for restoration projects in the West. The main barrier to biochar gaining more market share, in the soil amendment market, is capacity limitations of current biochar production technologies. Research to identify processing techniques that will increase biochar yield from woody biomass is ongoing. Biochar manufacture for fuels reduction provides a potential avenue toward a market-based solution for implementing forest and grassland restoration projects in the western United States. Implementing new technologies, such as biochar production, can shrink the gap between harvesting/transportation costs and true market value. Further developing this industry is a key part of the restoration-economics puzzle. For landowners and agencies in western states seeking market based solutions for implementing grassland restoration projects and hazardous fuels reduction projects, biochar is a promising product. Numerous research studies illustrate the ability of biochar to increase water retention

in arid soils and increase plant productivity. While there are several methods of producing biochar, the underlying catalyst is exposure of woody biomass to either high heat for short time intervals or moderate heat levels over a sustained time period. Research to identify processing techniques that will increase biochar yield from woody biomass is ongoing at public and private laboratories. The drivers for the research initiatives is to conserve water and forest resources in the face of uncertain climatic changes.

Key terms

Pyrolysis – a process of heating organic materials (e.g. woody biomass) in the absence of oxygen to yield a series of bioproducts, bio-char, bio-oil, and syngas.

Biochar – a refined charcoal (sometimes called bio-coal) left behind after heating biomass in a closed system under limited supply of oxygen.

Bio-oil – generally considered a crude oil (sometimes called liquid pyrolysis oil) and can be further refined to create heating oil or a variety of other biochemical products

Synthesis gas – similar to propane (sometimes called syngas) and can be used to dry the biomass or to heat the pyrolysis unit for continued production.

Torrified wood – a densified wood product that is cooked at lower temperatures than biochar

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