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Biochar for Forest Restoration in the Western United States

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Introduction

This paper examines the value of biochar for forest restoration in the western forests of the United States, and proposes some economically viable methods for producing it. Western forests have become degraded as a result of even-aged logging and suppression of natural fire regimes. Charcoal from historic wildfires is an important component of soil that has been depleted in forests where fire has been excluded. We review some of the literature reporting on the effects of biochar in forest soils and discuss some forest restoration activities that can replace soil charcoal, thereby increasing carbon sequestration in forest soils, and improving forest health. One important forest restoration activity is removal of small diameter trees and brush that may hamper the reintroduction of natural fire regimes. This material has limited economic value, but it can make good feedstock for biochar production. Biochar produced in the forest can be retained for forest soil improvement. Some fraction of the biochar produced in the forest can be exported for sale as a forest product that can help pay for the removal and treatment of problem biomass. We compare several systems for making biochar in the forest, including new ways to approach burn piles and broadcast burning for the purpose of maximizing charcoal production for use in place to help restore forest soil carbon. Finally, we introduce a new type of pyrolysis that is well suited for mobile biochar production in forest settings -- Flame Cap Pyrolysis -- and provide details of three different biochar production systems using these technologies.

Contents

1. Historic charcoal in forest soils

Soil charcoal (or black carbon) is a product of natural and anthropogenic vegetation fires that take place globally on many scales. Biochar is a recently coined term for human-produced charcoal that is deliberately added to soil to improve soil health and sequester carbon.

Some of the most productive and resilient soils in the world contain significant quantities of soil charcoal, or "natural" biochar. Nature makes megatonnes (40-240 Mt per year) of black carbon during wildfires or prescribed fires in forests and other vegetation types (Preston & Schmidt, 2006). This kind of natural charcoal is present in large quantities in some of the most valuable agricultural soils in the world, like the carbon-rich Chernozems of the Russian steppe and the Mollisols of the US Midwestern prairie states (Skjemstad et al. 2002, Glaser & Amelung 2003).

Recent reviews are revising upward the amount of pyrogenic black carbon (char and soot) produced each year in vegetation fires. A new global estimate (Santín et al. 2015) suggests that global black carbon production could be in the range of 116–385 Mt of C per year. This equals approximately 0.2–0.6% of the annual terrestrial net primary production of plants. This type of carbon is long-lived and about 50 percent of it is likely to resist oxidation to atmospheric CO_2 for centuries.

The amount of charcoal generated by wildfire depends on fire intensity, fire return interval, vegetation type, fuel loading and fire behavior. From 10-50% of the carbon found in forest soils is charcoal (Pingree 2012). Application of biochar is expected to mimic many soil properties associated with wildfire-generated charcoal (Harvey et al. 1979).

Several studies have estimated that the conversion rate of biomass to charcoal during a forest fire event ranges from 1-10% of the biomass consumed in a fire, or 1-2% of the biomass available in the forest (DeLuca & Aplet 2008). Based on biomass inventories, DeLuca & Aplet estimated that a single fire event in a mature lodgepole pine forest might deposit 3.25 tonnes per hectare of carbon in the form of charcoal. They concluded: "Thus, wildland fire need not be viewed only as a cause of C loss to the atmosphere, demanding suppression, but rather, as a driver of long-term C sequestration."

In some forest types and under some conditions, conversion rates of woody biomass to charcoal are higher. A post fire inventory of an experimental high-intensity crown fire in a Canadian boreal forest stand found that 27.6% of the carbon in the fire zone was converted to charcoal. Extrapolated globally, the researchers speculate that charcoal production in boreal forests could be as much as 100 Mt annually, more than five times the previous estimate (Santín et al. 2015).

2. Impact of charcoal on forest soils and plants

When considering the impact of biochar on soils and plants, it is important to recognize that biochar materials are highly variable, producing different results depending on soil type and other factors. The main constituents of biochar are aromatic carbon and ash. The chemistry of aromatic carbon is highly dependent on the temperature of its formation. The proportion of ash can be higher or lower and will vary in the composition of its elements according to the biochar feedstock used. Charcoal made in a forest fire is likely to be much more variable than industrially produced biochar, containing everything from slightly burned wood to mineral ash, depending on the spatial distribution of fuels and fire intensity. Most biochar research to date has concentrated on specific kinds of biochar with consistent properties, applied to fields and crops. There is considerably less research on biochar in forests, whether applied as a soil amendment or as a result of fire (McElligot et al. 2011). Below, we review some of the published literature on the effects of biochar in forests.

Nutrient cycling

Biochar can have a strong impact on soil nutrients and their availability to plants. Both biochar and ash contain some nutrients. Due to its sorption properties, biochar can bind and retain certain nutrients for short or long periods of time. Biochar, like the activated carbon used in filters, is effective at both absorbing (like a sponge) and adsorbing (through surface electrical charges) many different substances. Biochar also affects the soil biological community and its role in nutrient cycling.

Ash - The fertilizing effects of ash following fire are well known. Wildfire charcoal and most biochars contain mineral ash that is a source of soluble nutrients such as potassium, phosphorus, calcium and magnesium.

Liming, pH and CEC - Char and ash have impacts on soil pH, base saturation and cation exchange capacity (CEC). All of these properties are involved in nutrient cycling. Lime is commonly added to agricultural soils and sometimes to forest soils to raise pH and mobilize soluble nutrients by increasing the saturation of basic cations. Ash does not generally increase soil base saturation (the number of basic cations in soil) as much as adding lime. However, biochar additions can improve soil CEC by providing numerous negatively charged cation exchange sites on the biochar aromatic carbon matrix. The combination of ash and char is likely to be more effective than lime alone or ash alone in promoting soil nutrient cycling (Omil et al. 2013).

Nitrogen - Nitrogen volatilizes in a fire, but ammonium, a combustion product, is often left behind, especially in fires that burn less severely at lower temperatures. Nitrifying bacteria transform ammonium to nitrates that will soon leach into waterways with harmful effects unless they are taken up by new plant growth after the fire; one reason why it is important to establish new vegetation soon after a fire (Certini 2015). Biochar is especially effective at sorbing ammonium (Wilson 2013). Depending on conditions, char sorption of ammonium can work like a carbon-based slow-release fertilizer (Gundale & DeLuca 2006).

Nitrification - Nitrification is the biological process that converts ammonium to nitrates that are easily used by plants. Several studies have shown that biochar enhances nitrification in forest soils (Berglund et al. 2004, DeLuca et al. 2006). This effect may be especially important in forest soils where nitrogen is limited. The charcoal effect may be due to a combination of factors: sorption of phenolic compounds that inhibit nitrifier bacteria, and other properties of biochar that seem to promote the microbial community of nitrifiers. DeLuca et al. (2006) concluded that since fire is the dominant form of disturbance in western forest ecosystems, the exclusion of fire could eventually have a significant impact on forest nutrient cycles.

N immobilization – The electrochemical properties of the biochar aromatic carbon matrix seem to stimulate and support microbial activity (Chen et al. 2014). Biochar also contains some degradable carbon that is food for microbes. In some cases, increased microbial growth may thus tie up significant amounts of nitrogen, making it unavailable to plants (Omil et al. 2013).

Phosphorus - Biochar can sorb phosphorous, potentially making it temporarily less available to plants (Santalla et al. 2011).

Mycorrhizal fungi - Biochar is reported to change the abundance and species distribution of fungi, bacteria and other soil life forms (Lehmann et al. 2011). Biochar can have an especially beneficial effect on the mycorrhizal fungi that are essential for healthy forests. A pot study of charcoal used in larch tree seedlings found that biochar stimulated growth of roots and mycorrhizal fungi (Makoto et al. 2009). In this study, the fungi solubilized soil phosphorous that was otherwise unavailable to the seedlings. The phosphorous then showed up in greater concentrations in the needles of the seedlings grown in biochar-amended soil. However, in a variety of soil systems, biochar can also increase soil bacterial populations and alter the bacterial:fungi ratio (Chen et al. 2013; Farrell et al. 2013; Gomez et al. 2014).

Soil water holding capacity

One of the most important effects of biochar is its impact on soil water holding capacity and hydraulic conductivity. Because biochar is porous, it can absorb water like a sponge. Water is held in biochar pore spaces and voids, and in the spaces between particles in the soil. Biochar interacts with other soil constituents to form aggregates, and over time, it stimulates the formation of humus, which also retains water in soil (Masiello et al. 2014). The impact of biochar on soil water holding capacity has a lot to do with soil texture. A series of experiments in the 1940s looked at the impact of charcoal on three different forest soil types based on sand, clay and loam. Using different percentages of charcoal addition, different types of charcoal (hardwood and softwood) and different particle sizes, the results showed that, overall, charcoal greatly increased the water holding capacity of sand, slightly increased the capacity of loam, and reduced the water holding capacity of clay soil (Tyron, 1948). It is important to keep in mind that fresh, un-wetted biochar is hydrophobic. Therefore, the practical application of biochar may depend on overcoming this hydrophobicity before substantial gains in water holding capacity can be seen (Page-Dumroese et al. 2015).

Impacts on tree growth

Most biochar plant growth studies have been performed on field and horticultural crops, however, there are a growing number of studies on biochar and forest species. Many of these have been pot studies of forest tree seedlings. A meta-analysis has summarized a number of these studies on responses of woody plants to biochar (Thomas & Gale 2015). The analysis found a significant tree growth response to biochar, with an average 41% increase in biomass. This is a highly significant result, but it is important to understand that since many of the studies were of tree saplings in early growth stages, it is unlikely that this kind of response would apply to older trees with much slower growth rates. However, if biochar improves the early growth of tree seedlings, it would support the idea that biochar is a valuable tool for reforestation. The effects were less pronounced in temperate forests than in tropical or boreal forests. The authors of the study speculate that this could be due to a greater amount of nitrogen limitation in temperate forest soils than in other forest types. One reason for some of the positive effects of biochar in forest soils may be that biochar adsorbs salts, heavy metals and organic compounds like phenols that can inhibit plant germination and growth (Thomas, 2013). However, adding biochar to regular nursery potting media seemed to have little effect, either positive or negative (Matt 2015).

3. Impact of management on forest soil charcoal

Given the widespread presence and many functions of charcoal in fire-adapted forest soils, it is important to examine the impact of fire exclusion on forest soil charcoal and consider management changes that could restore it.

Management that reduces forest soil charcoal

A few studies have attempted to correlate soil charcoal with the history of fire suppression in order to estimate the charcoal deficit in forest soils. Looking at different site histories in ponderosa pine/Douglas-fir forests of the inland northwest, Brimmer (2006) found that sites that experienced multiple fires during the past 79–130 years contained about three times more charcoal than forests where fire was excluded.

Post-fire salvage logging is another management activity that can impact soil charcoal levels. Removing burned trees removes a lot of char that would otherwise fall to the ground and become incorporated into soil over time. Trees that tip over and fall will turn over soil as their root masses lift out of the soil. This is one of the ways that charcoal can get incorporated into soil. Charcoal that gets incorporated below the litter layer is more biologically active and also less vulnerable to incineration in the next fire (DeLuca & Aplet, 2008).

Management that can increase forest soil charcoal

Changes in the fire regime could potentially restore natural biochar to forest soils, however there are many site-specific considerations and unknowns. One of the goals of forest restoration in western North America is to return the natural fire return interval through a combination of biomass removal and controlled burning, eventually allowing fires to burn more naturally across larger landscapes.

Hart & Luckai (2014) concluded that active management to produce soil charcoal may be needed. They found that North American boreal forests had soil charcoal levels that were 2–3 times higher than in Eurasian boreal ecosystems, where fires are less intensive. Stand-replacing fires in North America produced larger amounts of charcoal. Because charcoal becomes less reactive in soil over time and less able to absorb phenolic compounds that inhibit seedling growth (after about 100 years), these researchers said: "In the absence of fire, management of boreal charcoal stocks may be required to maintain ecosystem function and C balance."

It would be useful to have management options to optimize charcoal production through natural fire processes; thereby restoring historic charcoal levels. A research program to understand the available options would evaluate variables such as fire return interval, fuel loading, fuel moisture, and other factors that are more site-specific such as forest species, climate and topography. An examination of soil charcoal in a forested landscape in the Pacific Northwest found that soil charcoal was correlated with site microclimate conditions such as temperature and moisture (Jauss et al. 2015). Warm-dry sites produced less charcoal than cool-wet sites and less intense fires may produce more charcoal (Knicker 2006). On the other hand, frequent fires can potentially incinerate char that remains in the litter layer, reducing the accumulation of charcoal, but that is not always the case (Santín et al. 2013). A modeling exercise that compared different fire return intervals in a 100-year old ponderosa pine forest found that more frequent fire is likely to promote the accumulation of char in mineral soil and slightly more soil charcoal overall, while less frequent, more severe fire left more charcoal in the soil organic horizon (DeLuca & Aplet 2008).

All of these site condition factors should be considered along with burning methods when determining fire prescriptions for optimizing soil charcoal formation. For instance, during a prescribed fire in north-central Florida, researchers tested char formation under two different fire-spread patterns: a head fire (with the wind) and a backing fire (against the wind). They found that backing fires formed more than twice as much charcoal as head fires due to differences in oxygen availability and residence time (Carvalho et al. 2011). This site-specific result would likely only be attained in similar wet, flat land forests, but this is also an example of the kind of investigations that could be conducted in western forests. Such an investigation should also consider the opportunistic use of managed wildfires to achieve restoration objectives (Ingalsbee & Raja 2015), including the restoration of soil charcoal. The interaction of prescribed fire with other fuel load reduction techniques like mastication could also be optimized for maximum charcoal production (Brewer et al. 2015).

4. Forest restoration goals and biochar

The most extensive forest management challenges in western forests today revolve around fire and watersheds. Large-scale logging and fire suppression have resulted in overstocked stands of small diameter trees that are vulnerable to extreme fire (Noss et al. 2006). As a result of climate change, rainfall and mountain snow packs are in decline and there is a longer summer drought period, which increases fire risk and lowers forest and soil resilience. Active management to remove excess biomass is being prescribed for the Wildland Urban Interface

(WUI) and other areas where it is ecologically warranted. The acreage of forestland that should be treated is extensive and disposal of the waste wood (tops, limbs, cull sections and unmerchantable round wood) from thinning or other harvest operations can be expensive. However, these residues are potentially available for bioenergy and biochar production.

Paying for restoration

Treatments to remove biomass from forests include various combinations of mechanical thinning, chipping or mastication, and prescribed fire. With thousands of acres needing treatment, managers are looking for ways to help pay for logging and residue disposal costs. Some sites can be commercially thinned which often pays for residue removal (slash pile or broadcast burning), however, many sites do not have commercial-sized timber or removal of large trees is not warranted for watershed health and restoration of late-seral conditions (old growth forest). Small-diameter residues or trees can be used for bioenergy, but economic constraints of transportation costs do not often support this use. Combining low energy prices and high costs for collecting and transporting biomass to facilities is the main barrier. One alternative may be a transportation subsidy, but this is not available at this time (Rapp 2010).

In-woods pyrolysis

The Forest Service has been evaluating the potential to reduce the cost of restoration treatments and biochar production through mobile, in-woods pyrolysis systems, obtaining biochar as a co-product of mobile bio-oil production systems using forest biomass. Since the production facility is located in the woods, there are no transportation costs for returning the biochar to the forest. Revenues from the energy production could pay for the biochar co-product and for applying it to forest soils (Page-Dumroese et al. 2009).

However, the challenges of implementing mobile plants that produce both bio-oil and biochar are significant. Aside from technical challenges, the economic performance of mobile pyrolysis is not promising, to date. In a thesis paper comparing the economics of mobile vs. stationary fast pyrolysis using forest biomass, Sorenson (2010) found that despite the mobile platform's advantage of a shorter biomass hauling distance, a stationary energy facility was three times more profitable, and both kinds of facilities were only marginally profitable under specific conditions. A sensitivity analysis pinned economic performance most strongly on capital costs, labor and feedstock costs, and projected bio-oil and biochar prices. However, methods to optimize harvesting, transportation, and centrally located pyrolysis equipment are now being developed (Harrill and Han 2014). This change in how forests are harvested and residues are treated may help make future efforts at in-woods processing more cost-effective. More favorable economic conditions would also include both higher energy prices and a tax or other mechanism to put a price on carbon emissions that would pay for carbon sequestration (and soil improvement) in the form of biochar.

Other than chipping for biomass energy, the main alternative for biomass disposal is the current practice of incinerating it in onsite burn piles, which is costly, can alter soil productivity, increase CO_2 emissions, and produce particulates. Slash pile burning may alter soil microbial populations, destroy seeds, and result in bare soil, which is vulnerable to colonization by invasive species (Korb et al. 2004). Smoke and particulate production from slash pile burning limits the burning window especially in air-quality limited watersheds, making it more difficult to accomplish the work.

Mitigating biomass removal with biochar

There is concern that large-scale removal of biomass from forests will export nutrients and carbon that is needed to replenish soils, especially where whole trees are harvested. However, not all sites display a noticeable decline in nutrients or carbon after one-time harvest operations (Jang et al. 2015). On sites that are particularly susceptible to nutrient export, climatic changes, or insect and disease stress, biochar could help return nutrients and carbon, and increase water-holding capacity of soils as part of forest health restoration strategies.

Researchers at the US Forest Service have been investigating biochar applications for protecting soil quality, function, and site productivity following biomass removals for fuel load reduction and forest health, and have established both field research sites and pot studies to assess impacts of biochar addition. The US Forest Service is conducting multiple investigations of biochar as tool for improving soil water-holding capacity, reducing bulk density of compacted soils and old roads, restoring range soils and mine sites, filtering sediment to improve water quality, and as an amendment in container media for native plant nurseries (Page-Dumroese et al. 2011, Page-Dumroese & Anderson 2012).

5. Flame Cap Pyrolysis for mobile biochar production

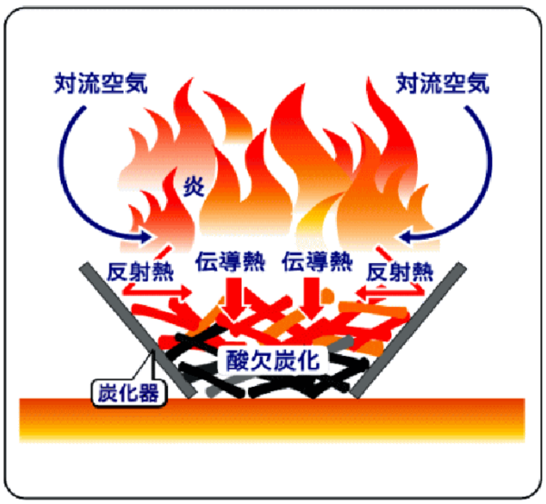
Wilson Biochar Associates (WBA) proposes an alternative for mobile pyrolysis of waste forest biomass that could be profitable under current conditions. In this section, we describe a suite of three low cost methods for biochar production at remote forest sites. These methods are based on Flame Cap Pyrolysis, a pyrolysis method that uses a curtain or cap of flame to exclude oxygen from the pyrolyzed biomass.

These technologies are characterized by low to extremely low capital cost and by the use of bulk woody debris as feedstock with no requirement for chipping and transport of raw biomass, similar to the current practice of pile and burn. We expect the overall economics of in-woods Flame Cap Pyrolysis to be competitive with current pile and burn methods for debris disposal.

Flame Cap Pyrolysis technologies do not produce an energy co-product, which could be seen as a lost opportunity. However, they do produce biochar which can be sold to help pay for the cost of fuels treatment. Some of the biochar produced can also be retained on site to help meet restoration objectives. Looking ahead to future conditions where oil prices begin to rise again, and biofuels production from woody waste may become economically profitable, it would be wise to invest now in the productivity of forest soils to meet future needs. In-woods Flame Cap Pyrolysis methods can help improve the health and resiliency of forest soils now, while also providing some biochar products to improve organic waste management (biochar is a valuable compost accelerator – see Ma et al, 2013) with benefits to agricultural soils.

Inspiration for the Flame Cap Pyrolysis technologies

The technologies discussed below were inspired by the Japanese Cone Kiln, also called the "Smokeless Kiln" (see illustration, below). The Japanese Cone Kiln makes high quality, well-carbonized biochar with reported biomass to char conversion efficiencies of around 15% (Inoue et al. 2011). We have found that other shapes like pyramids, tubes, metal boxes, trenches and pits work just as well as the cone shape. Collectively, these are known as "Flame Cap Kilns." To start the kiln, make a fire in the bottom and add new wood, slowly, in layers. Each new layer bursts into flame, excluding air from the layer below, and allowing pyrolysis to take place. Because there is always a flame present on top, most of the smoke burns in the flame. When the kiln is full of char, quench it and cool the char for use or sale.



***Left: Muentankaki (charcoal kiln)**. Diagram of the Japanese Cone Kiln shows how heat transfers from the flame on top to the biomass below for carbonization (http://xn--w8jwca1ob4719g78a.net/muentankaki/).*

***Right: Tube Kiln from Biochar Industries**. This 6-ft diameter tube can make about 5 cubic yards of biochar in one batch (http://biocharproject.org/tag/biochar-industries/*

Japanese Cone Kiln in a forest. *Japanese "Smokeless Kiln" makes charcoal in a bamboo forest. (from: http://aoiuminokai.junglekouen.com/d2011-01.html)*

Another inspiration is the "rick" method of making biochar, used by the Jack Daniels Distillery to make charcoal for filtering their whisky. The "rick" is an open pile of criss-crossed lumber that maintains air voids within the pile. The rick pile is lit from the top. The open rick structure allows flame to envelope each stick, burning the outside and charring the inside. When all the sticks are charred through, the pile collapses and it is quenched with water.

Jack Daniels Rick Method*. Making charcoal for the Jack Daniels Distillery using open ricks (photo: Wikipedia).*

Three Flame Cap Technologies

Wilson Biochar Associates has conducted preliminary analysis of three Flame Cap pyrolysis technologies. We also built prototypes and field-tested the first two of these:

1. Rick Pile Burns
2. Forestry Flame Cap Kiln
3. Air Curtain Burners operating in pyrolysis mode

#1 Rick Pile Burns

The least capital-intensive of the Flame Cap Pyrolysis methods is the Rick Pile Burn, which is simply a different way of constructing a burn pile in the woods, inspired by the "rick" method used by the Jack Daniels Distillery, as shown above. In November 2013, WBA sponsored a rick burning demonstration at an oak meadow restoration project in southwest Oregon being completed by Lomakatsi Restoration Project. A group of volunteers spent three days experimenting with different methods of piling and burning to achieve reduced smoke emissions and increased char production (Wilson 2014). The photos below illustrate some results of the successful demonstration.

Open Rick Burn in a forest: *a rick made of fir and pine from an oak meadow restoration project in Oregon. As the outside of each log burns, the inside chars. When fully charred, the rick collapses and can be quenched with water or dirt to save the char. (Photos copyright Kelpie Wilson, 2015.)*

In addition to making biochar, the Rick Pile Burn has other advantages:

- The Rick Pile maintains a flame on the top that burns most of the smoke produced, significantly reducing particulate emissions.
- Rick Piles are elevated off the forest floor, which reduces heating of the organic soil horizon for less severe impacts on soil life forms.
- Rick Piles could require less labor to construct than standard, compact piles. This needs to be tested in the field under different conditions including terrain and type of debris.
- Rick Piles can be quenched by spreading them out to cool and adding some dirt to exclude air. This activity serves to apply and incorporate the char into the soil where it can become biologically active. Incorporation also reduces the potential for loss of char from incineration in the next fire event.

Disadvantages of the Rick Pile Burn may include:

- Rick Pile Burns require labor to tend and quench the piles, however, under the right conditions of moisture and precipitation, quenching may not be needed.
- Rick piles could require more labor to construct than standard, compact piles. This needs to be tested in the field under different conditions of terrain and type of debris.
- Rick piles may have higher flame lengths than compact piles. However, it is possible to construct rick piles that are shorter with wider bases. Shorter piles would produce shorter flame lengths to overcome this problem.

#2 Forestry Flame Cap Kiln

The Forestry Flame Cap Kiln is a very simple, low cost device based on the Japanese Cone Kiln described above. WBA designed this version of the Flame Cap Kiln to be optimized for low cost manufacturing and for efficient logistical deployment and use along forest roads as an alternative to pile burning or chipping. Basically, it is a method of improving the efficiency and char recovery of the Rick Pile Burn by placing it inside a container.

The Forestry Flame Cap Kiln. *Designed by Wilson Biochar Associates for use in forestry to convert burn piles to biochar. Newer model will have fork pockets for lifting and unloading.*

Forestry Flame Cap Kiln design specifications:

- Shape: inverted truncated pyramid
- Bottom base: 4 ft square
- Top base: 5 ft square
- Height: 2 ft
- Capacity: 40 cf (when the chunky char is shredded, it will yield about 1 cy per kiln.
- Additional features: drain for quenching water, fork pockets for lifting, hinge and lock for dumping

Operational logistics are keyed to typical shaded fuel break treatments that thin 150' on either side of forest roads. Material is yarded to the roadside as for chipping, but instead of a chipper, a number of pyramid kilns are placed along the road. Material needs to be cut to 4-5' lengths.

Hand crews will begin by constructing and lighting a rick in each kiln and then continue to feed the material into the kilns until they are full of char. A water tank truck will dispense quenching water into the kilns. If limited water is available, a smaller amount (40 gallons) of water can be used with a loose fitting metal cover that will complete the quenching step. The cover will exclude air while the char cools overnight.

If water is abundant, kilns can be quickly quenched with 100 or more gallons of water. Once the water is drained, workers can immediately load the biochar into cubic yard size tote bags for transport to market.

Below is a detailed description of the operational steps needed with some projected numbers for production volumes and labor requirements:

Operational Plan for Roadside Biochar Production with Forestry Kilns

- Goal: Approximately 1/4 mile of roadside treatment per day
- Crew: 12 people in teams of 2
- Kilns: 48 kilns delivered on a truck or trailer and dropped off one every 50' along each side of the road. Each crew of 2 is responsible for 8 kilns
- Ancillary Equipment: 2000 gal water tender, loader, flatbed and totes for removing biochar
- Total daily production volume: 48 cy of biochar (4.8 tons if biochar is 200 lb/cy)
- Daily production per worker: 800 lbs
- Total value of daily production at $150/cy: $7,200

Description of operation steps:

1. Team builds a rick inside kiln about 4' tall and lights it
2. Move to next kiln and build another rick
3. Light that rick and move on until all kilns are ablaze
4. Return to first kiln which should have collapsed into hot coals
5. Build another rick on top of glowing coals - rick will self-ignite

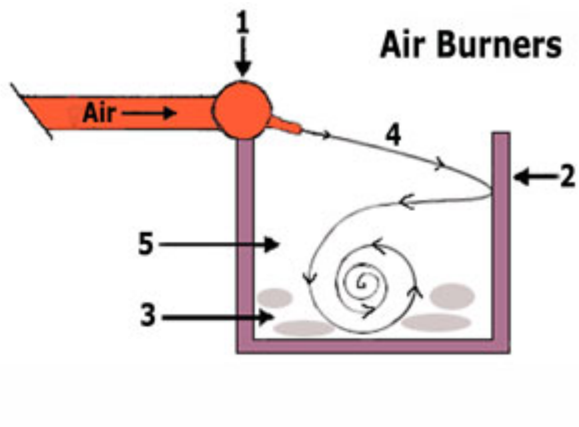
6. Return and build more ricks in each kiln until kiln is full
7. Bring 2000 gal water tender to first kiln that is finished
8. Each kiln gets 40 gal of water
9. Place thin sheet steel lid on kiln and leave overnight
10. Return to site next morning and unload biochar into totes
11. Pick up kilns and move to next site

There are several significant operational and economic advantages of the Forestry Kiln over mechanized mobile pyrolysis systems:

- **Low Capital Cost** - The Forestry Kiln has low capital cost. In our scenario, a full complement of 48 kilns capable of producing 48 cy of biochar a day would cost no more than $50,000 - far less than any mechanized system with similar capacity.
- **Always Ready** - Mechanized pyrolysis kilns and gasifiers are subject to equipment downtime and maintenance needs. The Forestry Kiln is always ready for work.
- **Highly Mobile** - The Forestry Kiln can be placed on a roadside berm or in the woods near a road or skid trail.
- **Scalable** - Adding or deleting capacity is simple and cheap.
- **Potentially Cheaper than Pile & Burn** - The Forestry Kiln system uses a large amount of labor and labor will be the most significant cost by far. However, it may not use a great deal more labor than current labor-intensive pile and burn methods that do not produce a useful product to offset costs.
- **Work Force Training** - Working with fire to produce biochar would be valuable training for the thousands of young people who are recruited to fight wildland fires every year. Doing this work in the winter keeps fire crews in shape and prepares them for summer firefighting.

#3 Air Curtain Burners operating in pyrolysis mode

The most capital intensive and least labor intensive of the Flame Cap Pyrolysis methods is the air curtain burner. An air curtain burner is a large, refractory-lined box equipped with a powerful blower that is used to incinerate biomass to ash. However, by changing some of the operating parameters, these units can be used to produce biochar. Several manufacturers make these units, but we focused our investigation on the units produced by Air Burners, Inc. The company website explains the principle of operation: "The purpose of the air curtain is to stall or slow down the smoke particles on their way out of the FireBox. In doing this, the particles are subjected to the highest temperatures in the FireBox. Stalling the smoke particles in this region just under the air curtain causes them to re-burn, further reducing their size to an acceptable limit."



Left: Air Burner principle of operation. Right: Air Burner S-327 unit in operation. (Photos from http://www.airburners.com)

The US Forest Service San Dimas Technology and Development Center (SDTDC) investigated Air Curtain Burners and recommended their use for incinerating forest waste with low emissions (Schapiro 2002). An in-depth analysis of air curtain burner emissions came to similar conclusions but also found that in some cases the air curtain burners produced very low particulate emissions even when the blower was turned off (Miller & Lemieux 2007). The authors noted: "It is very likely that even poorly operated systems will exhibit significantly lower PM emission levels when they are able to increase the high-temperature residence time of the pyrolyzed organics that form most of the fine PM." This has implications for our proposed modified use of the units to produce biochar.

WBA has proposed that the refractory lined box itself, either without the blower or with the blower operating at a lower speed, will be capable of producing biochar instead of full incineration to ash. It will operate like other Flame Cap Kilns, but more effectively since the refractory lining will create higher temperatures than can be achieved in a simple steel container. WBA contacted Air Burners, Inc. about using the units to produce biochar and was referred to Rick Whybra of PurFire (http://www.purfire.net/) who owns a small trailer-mounted Air Burner unit with a 4'x 4'x12' fire box called the Burn Boss. Mr. Whybra reported that he had inadvertently made char on several occasions with the unit when he had to shut it down early. In discussions with Mr. Whybra, we estimated that the unit could make about 4 cubic yards of biochar per batch.

The largest unit that Air Burners, Inc. sells is the S-327, with firebox dimensions of 12'x12'x37'. This would give it a capacity of about 165 cubic yards. Air Burners, Inc. has a large rake attachment for a skid steer that can scrape the char out of the unit after opening the end gate of the box. Then the char can be quenched with water and left to cool. The 165 cubic yards of char would bring in $24,750 if sold for $150/cubic yard.

Conclusion

Biochar has value both as a forest product and as an amendment to forest soils. It can be made on site from excess biomass removed from the forest as part of forest management, using simple, economically viable methods. Given the ecological value of charcoal in forest soils, forest managers may determine that a percentage of biochar produced in the forest should be left behind to replenish soil charcoal stocks. Biochar production in the woods (especially at remote sites) is best viewed as a temporary project that will help prepare forests for the return of natural fire regimes. Biochar markets thus provide part of the financial support for biomass removal. Once fire is returned to the system, charcoal will begin to accumulate in soil once again, restoring its ecological function. In addition, managers may want to explore landscape level fire management tools for controlled or managed burning that could increase char production in order to accelerate forest soil charcoal development for forest health and/or carbon sequestration.

About SURCP

SURCP is a community-based 501(c)(3) non-profit dedicated to restoration ecology and sustainable stewardship in the South Umpqua river basin. We are very active in constructive collaborative restoration projects with many partners. These multifaceted projects and initiatives are supported by SURCP Directors and community members through our organizational committees and the collaborative process. The goal of our service is that ecological, environmental, social and economic stability is established in our region.

About WBA

Wilson Biochar Associates is a consultancy owned by Kelpie Wilson. Wilson is a mechanical engineer, project developer and writer. She has worked in the biochar field since 2008. Her contracts and clients have included work for the International Biochar Initiative, Washington Department of Ecology and many biochar companies. Wilson also has an extensive background in forestry and biodiversity protection resulting from her twelve years (five as executive director) with the Siskiyou Regional Education Project, an Oregon forest advocacy group.

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