CHAPTER 4:

Place-Based Biochar Production

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INTRODUCTION

Place-based biochar involves the production and application of biochar onsite. Specifically, place-based biochar is an important part of ongoing fuel reduction and vegetation management projects intended to reduce the risk of catastrophic fire and improve soil productivity. The concept is inspired by Native American management practices that shaped the forested landscapes of the American West before the arrival of European settlers. One hallmark of these practices was frequent landscape burning that cleared the forest understory, leaving biochar as a byproduct. This created outstanding wildlife habitat and a forest ecosystem that was more resistant to extreme wildfire. The goal of place-based biochar practices is to clear the accumulation of excess fuels, while converting this biomass "waste" to a valuable resource—biochar. This will ultimately allow a safe return to broader and more frequent use of prescribed fire, improving habitat and increasing the resilience of our landscapes in a changing climate.

The methodologies defined in this chapter focus on decreasing the barriers for sustainable place-based biochar production utilizing technologies with low capital and operating costs but relatively higher labor costs. Given the pandemic and ongoing economic disruptions, local and state governments are now confronted with a need for economic recovery at a time where joblessness exceeds the numbers seen during the Great Depression. Just as the Civilian Conservation Corps helped save a generation from poverty, we propose that a modern model of a carbon focused conservation corps could help our current generation recover from both economic and climate catastrophe. Place-based biochar requires a large workforce for implementation, thus the money invested goes into the pockets of citizens productively employed rather than market capitalization for biochar production and transportation. This approach offers opportunities at a range of skill levels, from machine operators and arborists to students and disadvantaged workers.

The place-based sector of the biochar industry focuses mainly on the biomass left from a range of landscape maintenance and restoration activities. Foresters, orchardists, arborists, and other professionals perform these activities to maintain urban, forest and agricultural landscapes, restore habitat, improve wildfire resistance, and provide a multitude of other benefits. Biochar produced by these practitioners is used on or near the location where it is produced, furthering the restoration and resilience objectives of the vegetation management projects by reducing hazardous fuels, sequestering carbon, and improving soil health.

The volume of urban wood waste from construction, demolition, and yard maintenance exceeds the volume of timber harvested in forest management on an annual basis (McKeever & Skog 2003). However, in urban settings, this material is often generated where open burning is not feasible. Woody material is typically loaded into dumpsters and hauled away, usually with disposal fees involved. The potential fates of the carbon in that biomass generally do not lead to long-term storage.

In forestry applications, post-treatment slash is often unevenly distributed and difficult to access. The slash left after these operations far exceeds the amount necessary for nutrient cycling, protection of seedlings and mulching soil. This excess material becomes highly flammable as it dries out, significantly increasing the mortality risk of the remaining trees, as well as impeding wildlife travel and successful natural regeneration. The current practice is to simply create slash piles by machine, or by hand on rugged ground, cover them with plastic or waxed paper until dry, then light them and burn them as completely as possible.

Because of these limitations, this biomass is viewed as a problematic waste, requiring investments in time, dollars, and energy to manage and dispose. This net-loss management frequently leads to premature release of carbon into the atmosphere, negative air quality impacts, and missed opportunities for long-term carbon storage and economic and environmental value-added benefits.

WHO ARE WE?

Place-based biochar producers fill a broad niche in the biochar production ecosystem. The writers of this chapter include biochar contractors, educators, and engineers who use transportable flame-cap kilns (typically less than 10 cu. yd. capacity) to char non-merchantable woody biomass on site. We represent a small but very broad sector of the biochar industry including:

Small woodland landowners: Family and individual forest landowners make up more than 60% of all private forest ownership in the United States according to the U.S. Department of Agriculture (USDA 2015). Biochar production can be integrated into a range of forest management objectives ranging from commercial logging to restoration or fuel treatments. Increasingly, the knowledge of ecological benefits of biochar production, integrated with economic and engineering best practices, offers an opportunity for excess biomass to be returned to the forest floor either directly by the landowner or through a hired contractor. The Natural Resource Conservation Service (NRCS) now offers a cost share program to landowners for on-site biochar production through their *Conservation Stewardship Program.*

Land management organizations and agencies: Nonprofit and governmental landowning organizations and agencies often have ecologically based missions and can incorporate biochar into their management plans if they have a clear understanding of costs and benefits. Biochar can be used for soil improvement, carbon sequestration, and remediation, for example, in abandoned mine reclamation.

Low tech (but innovative) "backyard" producers: The techniques used in place-based biochar production were mostly developed by independent "backyard" experimenters.

Permaculturists, community educators: As an extension of missions of regenerative design, restoration and education, permaculturists and community educators practice and demonstrate sustainable biochar production and use techniques. Community educators may be part of a formal organization, such as Extension Service associated with state universities, or informal groups. For example, the Umpqua Biochar Education Team is an organized group of experimenters based in Oregon that received a Conservation Innovation Grant from the NRCS specifically to develop these techniques. Any of the other practitioners listed can serve as community educators.

Small farms, vineyards, orchards, forest-to-farm: Increasingly, small farmers are learning about and adopting low tech biochar production methods, especially where they have woodlots to manage. Making biochar and using it on the farm is a way of managing woody biomass while making a valuable input for manure management, compost, and soil.

Urban foresters and arborists: Arborists are interested in adding biochar to their services as an alternative to chipping and hauling brush and tree limbs. Biochar can provide another revenue stream and it also offers a clean way to dispose of waste wood without generating the noise and diesel emissions of chippers or incurring tipping fees. City park managers are increasingly interested in making and using biochar in landscaping, tree planting and turf grass installation.

Habitat restoration contractors: A number of public agencies (e.g., NRCS, U.S. Fish and Wildlife Service, state departments of natural resources) are beginning to pay landowners to convert their woody residue to biochar, and a small but growing number of forestry contractors have begun to integrate biochar into the other services they offer their clients.

Wildland firefighters: Firefighters who are performing vegetation management in the off-fire season have the needed skill set to manage the techniques for place-based conversion of forest slash to biochar.

Uneven-age forest management professionals: Forest managers who strive for multi-cohort stand structures are often unable to use broadcast burning in the way that clearcut/plantation foresters can. Biochar production offers them a safe way to dispose of logging slash in the understory without endangering the overstory trees.

OPPORTUNITIES

Integration with Forestry

Place-based biochar offers the most direct method for the forestry sector to process their biomass and utilize it as an amendment to forest soils. As fuel treatments and forest restoration activities increase to address the rising risk of wildfires across the nation, landscape biochar technologies can be adopted across the forestry sector. Place-based technologies work well over many types of terrain, providing access through machinery that is transportable with low soil compaction. Biochar has shown extensive value as a forest soil amendment with demonstrated improvements in forest soil health after biochar application (Li et al. 2017) through:

- increasing soil carbon
- increased water and nutrient retention capacity
- increased soil porosity
- increased moisture retention
- higher soil pH
- enhanced biological activity

A meta-analysis by Thomas et al. (2015) found that soil health improvements as a result of biochar addition increase tree growth responses, with an average 41% increase in biomass with pronounced results in early growth stages. Place-based biochar production also provides a ready source of biochar for improving forest soils and for managing environmental challenges created by forestry activities such as compacted soils, erosion, and re-vegetation challenges. This increase in soil health comes at a time when climate change will increasingly place our forests under greater stress. Keeping our forests healthy and resilient will be one of our greatest tools for addressing climate change, as globally forests absorb 2.4 billion tons of carbon dioxide (CO_2) each year, about a third of the CO_2 released by burning fossil fuels (Pan et al. 2011).

Potential for Broad Adoption

We examined the barriers to the wider acceptance and practice of place-based biochar production. Compared to other biochar producers discussed in this report, we are at the smallest scale in terms of daily throughput of biomass per kiln or thermochemical conversion device. The often remote and patchy distribution of our feedstock means that opportunities for scaling up the size of our equipment or the mechanization of our operations are limited. Therefore, it makes more sense to scale out this sector by fine-tuning the technology and honing operational efficiencies to develop standards and best practices for our industry. These can then be replicated by a wide range of operators, either by incorporating biochar production in their current operations or by specializing in this process.

Given that we live in a time of mass unemployment, our approach has the potential to scale widely across the landscape to treat thousands of acres and produce significant quantities of biochar while providing meaningful employment to thousands of people who need jobs. While place-based biochar methods are typically small-scale batch technologies, the collective impact of these could be very large because of the diversity of applications. Beyond forest landowners and the forest industry, the low barriers to entry make onsite biochar production an accessible option for local farms, permaculturists, gardeners, ecology organizations, and schools who can all directly engage with this technology. The low technical and financial barriers for entry mean that it can serve as a market entrance point for a broad group of practitioners with little financial risk. Some methods of production require minimal financial investment, and simply require education to alter existing practice. Place-based methods represent a democratic form of biochar production, offering open-source designs and methodologies to people interested in amending their soils with biochar. Place-based biochar also offers potential for collaboration with the organizations that provide education and outreach to the end user, including forest collaboratives, soil and water conservation districts, forestry extension services, fire districts and air districts.

Coordinated Place-Based Biochar Research, Training, and Resources

We recognize that increasing the pace and scale of biochar integration with our audience requires compiling the appropriate information and data as well as making this information accessible. There is the potential to create a centralized online and training network for information and education on place-based biochar that offers guidance in production design, education, research, permitting, and policy. The scalability of place-based biochar will depend on developing a curriculum that is science-based and accessible to both trainers and end users.

This network could also serve as an organized repository for research on the impact of biochar. This repository could utilize an open and shared database where researchers can ask questions collectively and collaboratively across disciplines. Collaborative and open data provides the opportunity to build upon existing research and generate newer and more relevant questions. As the climate changes and new questions continue to emerge, shared and collaborative data offers collective insight into both the problems and solutions.

The centralized online location can also offer assistance accessing financial resources for landowners, such as information on carbon credits or cost-share funding. These areas of assistance include projections on financial return, access to funders and assistance with applications and reporting.

Place-based biochar offers an entry point for organizations, landowners, and governments to build confidence in biochar and increase their interest in larger-scale production and application systems. Place-based biochar production and on-site use could become the common practice for reducing excess biomass and disposal of woody slash and debris for forests and farmland. These practices would be reinforced by a network of research, training, and resources that invest in the resilience of our landscapes as we continue to adapt to a changing climate.

CHALLENGES TO IMPLEMENTATION OF LANDSCAPE-BASED BIOCHAR

Place-based biochar production intersects with many other environmental and resource concerns. To be successful, it requires a trained workforce and an educated public. It can also benefit from refinement of techniques, learning from other industries, expanded markets, and supportive public policy. To understand the challenges before us, we have divided them into four categories that we will treat separately below:

- Engineering
- Economic
- Ecological
- Engagement/Education

Engineering Challenges

Background

Over the past decade, many individuals worldwide have invented and developed small-scale flame-carbonizing devices. These have been deployed most widely with smallholders in developing countries who mostly pyrolyze crop waste, and with forest managers everywhere who use them as alternatives to burn pile incineration for waste disposal. These technologies are passive devices with no moving parts. Inventors have made many advances in design that improve efficiencies and reduce emissions of pollutants.

Flame-cap kilns are the primary pyrolysis technology currently used for place-based biochar. Flame-cap kilns are a type of gasifier that produces biochar in an open flame (Figure 4.1). In some cases, specially constructed and managed open burn piles are also used to make biochar. The use of unprocessed biomass residues is a key defining feature of landscape-based biochar production.

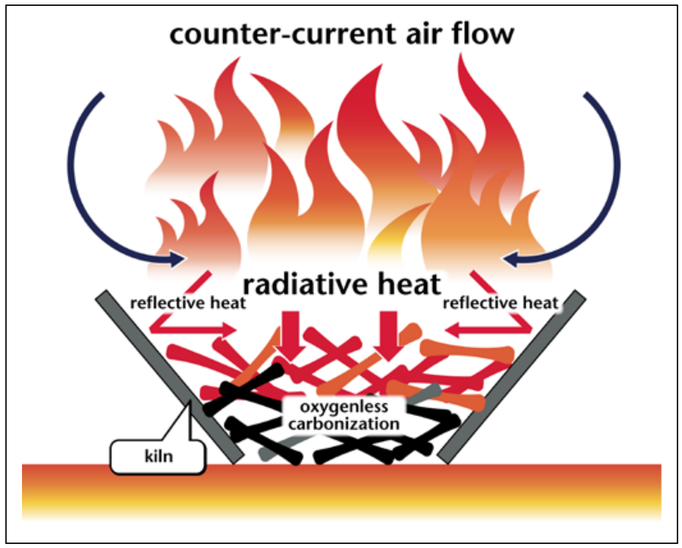

Figure 4.1. *Schematic showing basic operation of a flame-cap kiln. (Source: WilsonBiochar.com)*

A flame-cap kiln is a simple container that can be made from an earthen pit, bricks or ceramics, or metal. Only the metal kilns are portable. Kilns can have any shape, including cylinders, cones, troughs, pyramids, rectangles, or polygons. They should have an aspect ratio of height to width that is 1:1 or less. A kiln that is too tall will have trouble getting enough air to maintain combustion. The basic principle of operation is that of counterflow combustion. All combustion air comes from above. The air feeds a flame that is always maintained. The flame heats the feedstock below by radiation, which emits gasses that are burned in the flame. The flame consumes all the available air, so that no air is available to burn the char that forms beneath the flame. The counterflow combustion air keeps the flame low and prevents emission of embers or sparks. The flame also further combusts organic compounds in the smoke, reducing emissions of harmful compounds. Periodically, new feedstock is loaded into the kiln. This temporarily interrupts the flame-cap which is quickly reformed. When the kiln is full of char, it is quenched either with water or by snuffing with a lid.

With properly prepared and dry feedstocks, the biochar conversion efficiency of a flame cap kiln can rival that of industrial pyrolysis kilns. If well-managed, a flame cap kiln can convert biomass to biochar with an efficiency of up to 22% by weight (Cornelissen et al. 2016). It is important to recognize that this is accomplished with no other energy inputs for heating.

On very remote and steep sites, the best option may be to use newly developed open pile burning techniques for char production. This "Conservation Burn Pile" technique begins with constructing a clean pile that is loose enough to allow air flow and does not contain large amounts of dirt or rock. The pile must be lit on the top and allowed to burn down to the glowing coal stage. Then the fire is extinguished using water or a shovel before the char burns to ash. Top-lighting ensures that most of the smoke is burned, reducing emissions. Quenching before complete incineration preserves the char and protects forest soils from incineration and destruction of the organic soil horizon.

While there are further improvements to be made in flame carbonization methods and equipment, in forestry settings, the primary technical challenges are in feedstock handling and preparation. Widely distributed forest residues need to be gathered and transported to areas where kilns can be set up and where water is available for quenching. Some combination of hand work supplemented by machinery for moving feedstocks is appropriate for most landscapes. However, terrain, feedstock distribution, and access vary widely.

The biggest need at present is to develop protocols for different situations, along with costs, so that biochar jobs can be specified and implemented in a consistent fashion. Below we discuss the priority engineering challenges that should be addressed, categorized as kiln design, kiln emissions, feedstock preparation, feedstock comminution and handling, kiln loading, biochar quenching and handling, and landscape tiers for project design.

Scope of Engineering Challenges

Kiln Design

Kiln design should be based on two primary factors: feedstock and size. For instance, if feedstock is mostly forest slash less than 4 inches in diameter and less than 25% moisture, a kiln that is 5 to 6 feet across will generate enough heat to pyrolyze the feedstock. A larger kiln can also handle longer branches and boles, with less need for cutting to length. Kilns that are too large are more difficult to move, especially if used off-road. Larger kilns also generate more heat, which can be a concern for exposing workers to heat stress. Adding a heat shield surrounding the kiln body reduces heat loss, improves biochar conversion efficiency, and reduces emissions, but adds to the cost and complexity of kilns. More work is needed to optimize kiln designs for specific feedstocks and feedstock moisture levels. To date, this engineering development work has been done by individual entrepreneurs with little outside help. A small amount of investment in an organized program to compare and compile results could produce and disseminate more optimal designs.

Kiln Emissions

There is a great need for emissions measurements of different flame-cap kiln designs using different feedstocks, especially feedstocks with different moisture levels, including freshly harvested green material. The small amount of data we have indicates that flame-cap kilns are significantly cleaner than open burn piles. Visual assessment of emission opacity confirms that flame-cap kilns (Figure 4.2) emit very little particulates as compared to standard open burn piles. A robust set of emissions measurements for flame-cap kilns can help to assess kiln design modifications and lead to guidelines for feedstock specifications and loading rate practices. Information on U.S. Environmental Protection Agency criteria pollutants and hazardous air pollutants will help regulators understand how and when to permit flame-cap kilns. Greenhouse gas measurements will allow for accurate carbon accounting and life cycle assessment.

Figure 4.2. *Backyard biochar production using the Ring of Fire flame-cap kiln in April 2020 in Cave Junction, Oregon. Counterflow combustion keeps the flame length low and holds heat in the kiln for greater efficiency. Most of the smoke generated is burned in the kiln. (Photo: WilsonBiochar.com)*

Feedstock Preparation
Preparing forest slash materials for biochar production is similar to preparing those materials for burn pile incineration. The main difference is that branches and boles may need to be cut to a shorter length to fit inside a kiln. This would imply slightly more chainsaw cuts if for instance a 6-foot length requirement was changed to a 4-foot length requirement. Feedstock diameter limits are also key to biochar production efficiency in a flame-cap kiln and are shown in Table 4.1. Material that is greater than 6 inches in diameter is more difficult to convert to char, as the heat needs to penetrate to the center of the log in order to pyrolyze it. When working on the landscape, this thicker diameter material is best left on site where it has multiple ecological functions. From a vegetation management point of view, this larger diameter material is not a fire danger and does not need to be incinerated for disposal. However, where leaving more of the larger size material on the ground interferes with other management objectives, land managers may need to identify alternative treatments.

Table 4.1. *Three types of flame-cap kilns. (Source: Wilson Biochar)*

	Small Bin Kilns	Large Bin Kilns	Panel Bin Kilns
Mobility	ATC, Hand Crew	Road-based	Hand Crew
Feedstock diameter	Up to 4"	Up to 8"	Up to 4"
Feeding	Hand fed	Machine or hand fed	Hand fed
Quenching*	Flood	Flood	Spray and Rake


Oregon Kiln


Big Box Kiln


Ring of Fire Kiln™

** All kilns can also be snuffed with a lid.*

Feedstock Drying, Collection, and Handling
Once the material is cut, it needs to be moved. In standard burn pile treatments, material is immediately stacked into carefully constructed "jackpot" piles and covered with polyethylene sheets to protect them from winter rains. In biochar treatment areas, material may be left in place to be gathered later and loaded into a kiln, or loosely windrowed and covered with polyethylene. In some cases, small diameter material can be cut green and immediately charred in a kiln with very little loss in conversion efficiency. If material is left in place uncovered, it should be processed in a kiln in late fall before winter rains have started in earnest.

There are many possible methods for feedstock collection, including whole-tree yarding[1] to a roadside. Off road vehicles can be useful for moving piles of feedstock closer to kilns, reducing the need for workers to walk. These options need to be explored and documented for different scenarios depending on road access and terrain. Most importantly, the costs of various options need to be evaluated, as described in the Economics section below, to support job planning and logistics.

Kiln Loading
Biochar kilns are loaded by hand. Workers require training to do this with the greatest efficiency and lowest emissions. If kilns are loaded too fast, the flame front moves upward and the radiant heat from the flame is not able to char all of the fuel. Unburned fuel will remain in the kiln. If the kiln is loaded too slowly, more of the material may burn to ash, reducing efficiency. Workers must be aware of feedstock species, size and moisture level and must be able to adjust loading rates and practices accordingly. Worker training and safety protocols are crucial to the success of landscape-based biochar. Given the number of workers needed, training programs will need to be well-organized and widely available.

Biochar Quenching and Handling
There are several options for recovering biochar and using it on site. Where water is available, biochar is easily quenched. One cubic yard of biochar can be quenched in a kiln with less than 50 gallons of water. For example, a 500-gallon fire truck parked on a road and utilizing a one inch line can be used to quench ten kilns up to a quarter mile away. Biochar can be quenched with little to no water just by spreading it thinly over the ground so that it loses heat (Figure 4.3). Five gallons of water in a backpack pump, combined with raking, can quench a cubic yard of biochar. Using a lid to snuff a kiln is also an option (Figure 4.4). We need further analysis of the time and costs for each of these options in the field.

Landscapes Tiers for Project Design
Current systems for fuels reduction and disposal on site are well-established with set costs per acre based partly on fuel density and partly on terrain and access. Contracting agencies may divide jobs into tiers based on these factors and provide differential pay rates for different tiers. Planning a fuels reduction project specifically for recovery of biochar from slash will change how fuels are cut, piled, and processed. Biochar kilns and quench-

1 *Yarding is the practice of, after felling, using a cable to pull an entire tree to a centralized location or roadside. There limbs and branches are removed and the tree bole cut to transportable lengths. This removes the need for brush piling and concentrates all slash in accessible locations.*

ing water need to be mobilized and put in place. There is a need for a systematic approach to pilot projects to learn what works best under different conditions.

Figure 4.3. *Numerous small conservation burn piles at the Big Chico Creek Ecological Reserve in Chico, California. The piles are extinguished by flinging the hot coals out onto the wet grass in wintertime. This also distributes and applies the biochar across the landscape. (Photo: WilsonBiochar.com)*

Figure 4.4. *Using a lid to snuff quench a flame-cap kiln. (Photo: WilsonBiochar.com)*

Summary of Engineering Challenges and Recommendations

1. We need to launch an effort to measure emissions from different kinds of kilns and conservation burn piles for several purposes: to demonstrate improvements compared to open burning to regulators; to aid in engineering cleaner and more efficient kiln designs; and to determine best practices for kiln operators and worker training.

2. We need to work with forestry professionals to develop better systems for kiln mobilization and deployment at scale across landscapes. Many different types of logging equipment and techniques can be adapted to the needs of on-site biochar production, whether it takes place in the woods or on a roadside or landing. We need access to knowledge and experience of forestry operators to help us design systems for different terrains and conditions.

3. We need to work with land managers to make sure that the techniques that we propose for processing slash materials into biochar are consistent with other economic and ecological management objectives. Where they are not, we need to go back to the drawing board and engineer more workable systems.

4. Ultimately, to expand biochar production to the landscape scale, we will need specifications and guidelines for the work that will allow managers to plan and offer contracts. These guidelines will also need to include workforce training objectives and safety protocols.

Economic Challenges

Background

The economies of indigenous cultures in the western hemisphere were to a large extent built on the expert use of landscape fires to manage resources in the absence of metal implements and draft animals (Pyne 1982). Large-scale landscape fires were used by Native Americans in western North America (and beyond) to maintain forage for the animals they hunted (Douglas 1914) as well as to promote the growth of staple crops such as camas, tarweed, biscuit root, huckleberries, and myriad other edible and medicinal plants (Riddle 1953; Anderson 1993).

Depending on their agro-ecological objectives, Native Americans burned habitats on one to five-year intervals (LaLande & Pullen 1999). This included the whole landscape—grasslands, shrublands and forest understories (Carloni 2005). These frequent, low intensity fires not only tipped the balance toward preferred plant and animal species, but also added regular pulses of char to the soil. With the extirpation of Indian management practices and the advent of effective fire suppression in the mid-20th century, this source of char input into our soils has dramatically decreased. Site-based biochar production can reverse this trend.

Every year in the forested areas of our nation, modern equipment and practices produce an enormous amount of small diameter, non-merchantable woody biomass during forest thinning and restoration activities. This highly flammable slash increases fire risk and restricts management options. The current practice in our region for disposing of this unmarketable woody material in areas where under-burning is not feasible is to build burn piles by hand and/or by machine, wait for them to dry, light them and walk away. While this may be the cheapest way to dispose of slash, open burn piles damage soils, produce significant amounts of smoke and greenhouse gases, and increase the risk of igniting wildfires downwind.

We have been developing an alternative practice to turn this liability into an asset by converting slash into biochar in the field. Fine fuels are used as feedstock for low-cost, transportable flame-cap kilns (see above) to heat the wood to high temperatures (450-550 °C) with little oxygen. This converts the slash to a form of carbonized biomass that when added to forest soils will remain sequestered there for centuries to millennia (Spokas 2010).

Biochar also increases soil water and nutrient storage capacity and promotes resilient soil ecosystems. Increased soil productivity promotes faster plant growth and the conversion of greenhouse gasses in the atmosphere into long-lasting biomass. Increased forest productivity also maintains and enhances biodiversity by accelerating the formation of old growth forest structure in appropriately configured stands.

Given the need to scale this technology out to reduce fire hazard, sequester carbon, and increase ecosystem productivity and resilience across the landscape, *on-site char production must become more competitive with current fuel treatments*.

Scope of Economic Challenges

While the extensive production and integration of biochar into local soils will have large-scale macroeconomic impacts (e.g., mitigating climate change, improving regional crop and timber yields, minimizing soil erosion and nutrient leaching, etc.), this discussion focuses on the microeconomic barriers to the wider acceptance of site-produced biochar as a mainstream practice. These challenges can be overcome in two ways: 1) by reducing the cost of producing biochar on site, and 2) by developing new markets for site-produced biochar.

Reducing the Cost of Biochar Production Compared to Open Pile Burning

The fewer times a piece of feedstock is handled, the less expensive it is to process. The first stage of producing biochar on site employs the same technologies, skills, and workforce as building burn piles, so there are well-trained local labor pools in regions where large amounts of woody biomass need to be treated. Feedstock handling for biochar production varies considerably with terrain and equipment, but typically requires more labor than simply piling and burning.

Current practice is to allow cut slash to dry in the field over the summer for fall charring. The piling necessary to dry the feedstock, and the subsequent dismantling of those piles before kiln loading, adds considerably to labor costs compared to simple hand piling and burning. If some of the extra touches could be eliminated by charring green feedstock, the cost of producing biochar in the field would come closer to the cost of hand piling and open burning treatments.

In order to test the efficacy of producing biochar directly from green feedstock, a project to compare logistics and biochar quality using green vs. dry feedstock was conducted on 12 acres at the Yew Creek Land Alliance property in southwest Oregon. Six acres of slash from an NRCS-funded oak habitat restoration project were dried in piles for the summer and were charred in the fall. On another six acres in the same project area, materials went directly from stump to kiln with feedstock four inches in diameter and below. Low-flammability woody residue over four inches was left on site as an ecosystem resource.

No quantitative measurements were made, but the consensus of the crew was that char recovery was at least as good with green feedstock as with dried feedstock, and with careful kiln loading, the increase in smoke was minimal (and presumably much of that was water vapor).

In a related pilot study, we found that 30% to 40% of the carbon contained in three green tons of feedstock charred in an insulated flame-cap kiln remained in the biochar. These results rival the highest recovery rates found in the literature. (See sidebar: *"Calculating Carbon Capture in Flame-Cap Kilns" on page 67*.)

Although we have demonstrated that streamlining the process by using green feedstock yielded robust biochar production, the potential for green biomass to produce potent greenhouse gases (GHGs) has yet to be rigorously measured. Given the amount of carbon trapped in the char, it is highly unlikely that GHG output of flame cap kilns approaches that of an open burn pile. Nonetheless, the types and amounts of emissions from both green and dry fuels need to be quantified to settle on best practices for future projects.

Another reason to collect quantitative data on kiln emissions is to demonstrate that flame-cap kilns produce significantly less smoke than open burning. This is visually obvious in practice, and empirically evident by observing how little char remains from open burn piles compared to slow pyrolysis in flame-cap kilns. Quantifying this smoke reduction may allow on site biochar producers to obtain burn permits when open burning is prohibited due to air quality considerations.

Incremental efficiencies can also be gained by looking into both new and old technologies for getting "stranded"[2] feedstock to the kilns and/or vice versa. This is particularly problematic in steep terrain in remote areas away from established road systems. A systematic evaluation of traditional and emerging technologies to augment human labor should be researched and compared to continue to improve best practices. For example, small tree yarding systems such as monocable ("zig-zag") systems developed in the 1970s and 1980s can be repurposed for on-site biochar production.

Developing New Markets for On-Site Biochar

Our sector of the industry integrates the production and use of biochar in the same location—biochar made on-site to be used on-site. The biochar we produce is rarely processed, marketed, transported, and sold. Rather, the value accrues to the landowner in the form of reduced fire danger, improved site productivity, reduced smoke production, and sequestered carbon. But because our char does not change hands, there is no monetary value attached to it. If integrated on-site biochar production is to become a significant practice, the "intangible" values of the char must be established to offset the extra production costs compared to open burning.

Two barriers exist to quantifying the value of biochar that has been returned to the soil: 1) quantitative data to determine the carbon sequestration efficiency and negative emissions of flame-cap kilns has been very limited with only one life cycle analysis study (Puettman et al. 2020), and 2) few if any studies have been done to establish the economic value of the ecosystem services provided by on-site biochar production.

While the value of standing biomass carbon in terms of CO_2 equivalents is well established for carbon offset markets, to date there have been no controlled studies of flame-cap kilns to determine feedstock C to biochar C efficiency ratios. Nor are there studies of avoided emissions relative to other methods of woody residue disposal. Until these parameters are established based on current equipment and practices, on-site biochar producers have no ability to capture the monetary value of their char. Once data on carbon sequestration rates and avoided emissions are gathered, a life cycle analysis of the alternate fates of a project's feedstock carbon can be used to generate the algorithms to quantify the ton of CO_2 equivalents stored in long-lasting biochar.

Although the value of the ecosystem services provided by integrated on-site biochar production is well-known, there is currently no system established to monetize these benefits in ways that generate income for the producer/landowner. Mechanisms

2 *Biomass that is currently unavailable due to access issues or the expense of harvest and transport.*

Calculating Carbon Capture in Flame-Cap Kilns

How much feedstock carbon becomes sequestered in biochar?

Preliminary results using green woody feedstock indicate that 30% to 40% of the carbon remains in the resulting char.

METHODS: We used an excavator to load a truck parked on a wireless scale *(top left/right)* to measure the green mass of our feedstock. A moisture meter was used to determine the mean moisture content of each species, and estimates were made of the percentages of each species in the feedstock.

Two burns *(bottom left)* were conducted on successive days—the first with approximately 1 ton of biomass, and the other with approximately 2 tons. The kilns were then snuffed for about 1 hour before being quenched with water to stop pyrolysis.

Three samples from each kiln were sent to a lab and analyzed for percent moisture, bulk density and percent carbon. We calculated biochar mass by measuring the char volume *(bottom right)* and multiplying by its bulk density.

RESULTS: Our preliminary results indicated that the first trial with approximately 1 ton of feedstock yielded 40% biochar carbon, and the second trial with approximately 2 tons yielded 30% biochar carbon.

CONCLUSIONS: Green feedstock can be successfully used to produce high-quality biochar with high conversion efficiency. ■

to generate income to the producer/landowner for these critical ecosystem services need to be developed. In addition to facilitating access to carbon markets, quantifying the value of on-site biochar production will also help to promote its use by landowners and land management agencies whose goals include outcomes beyond simple financial gain.

Once values are quantified for carbon sequestration, decreased emissions, and ecosystem services, standards can be developed and consulting foresters/ecologists/agronomists can be trained to certify the amount and quality of the biochar carbon stored on the site.

Summary of Economic Challenges

Current economic barriers to scaling out place-based biochar production include (but are not limited to):

1. Lack of comprehensive studies on traditional and emerging technologies to increase the efficiency of accessing stranded biomass and streamlining its conversion to biochar in the field.
2. Lack of rigorous measurements of green and dry feedstock to biochar carbon sequestration rates and avoided emissions compared to other fates for that biomass, allowing monetary value to be ascribed to these services.
3. Lack of data-based algorithms to access existing carbon markets.
4. Lack of studies to assign dollar values to the ecosystem services provided by in situ biochar production.

Ecological Challenges

Background

Ecological barriers include the lack of organized and easily available data about biochar's influence in forest ecosystems. This research is necessary to quantify the benefits of biochar and biochar production in comparison to other fuel reduction strategies. Addressing this barrier requires comprehensive and coordinated engagement with both forestry programs at regional universities as well as conservation and ecology organizations to create a comprehensive repository of research results on biochar's influence on forest ecology. Establishing this network of organized data will drive best practices in active forest management.

Understanding this influence requires both an understanding of biochar forestry research and challenges in modern forestry as the climate changes. One of the most significant challenges is wildfire, which is projected to increase with greater variation in weather patterns (Fried et al. 2004). These fires diminish the carbon capture capabilities of forests, while also contributing 4% to 6% of our nation's yearly GHG emissions. As increased public and private investment seeks to mitigate the risk of wildfires, quantifying the role of biochar in improving a forest's fire resilience offers an opportunity for scaled adoption at multiple scales.

The development of best practices for biochar re-application on the landscape should also be developed in coordination with Native American communities continuing their history of active fire management. As Native Americans have a long and rich tradition with prescribed burns, their knowledge can help shape best practices, and identify areas for further research. In this area of potential ecology collaboration, we seek to uplift voices not currently influencing modern forestry.

Scope of Ecological Challenges

Quantifying Reduction of Ecological Risk

Forests are expected to face an increasing number of environmental stressors in a changing climate, specifically issues of drought, flooding, soil erosion and nutrient depletion in topsoil, and pest damage. These factors combine to increase tree mortality, resulting in the increasing flammability of our woodlands. A combination of research and meta-analysis can help paint a picture of biochar's influence on these challenges, and quantify the reduction of these ecological risk factors.

Impact on Tree Growth Rate, Soil Health, and Forestry Economics

Quantifying the impact of biochar on tree growth requires a localized approach to research. Thomas & Gale (2015) found biochar amended forest soils to have varied effects on growth rates regionally and by tree species, with an average increase of 41%. Providing accurate and localized data that allows a landowner or logging company the ability to project the financial return can economically incentivize adoption. This research also needs to generate information on appropriate biochar application rates for different tree species, as well as the influence of soil health at different application rates.

Quantifying Impact on Fire Recovery

One key factor that could drive adoption is biochar's effects on resilience after fire. Quantifying the influence of biochar on forest ecosystem recovery, including plant and soil response, as well as post-fire challenges such as erosion, could help drive implementation. One study found that a biochar mulch reduced soil erosion by 50% to 64% compared to burned plots (Jien et al. 2013).

Carbon and Ecosystem Comparisons to Biomass Processing Alternatives
Comparing apples-to-apples data for on-site biochar production in comparison to other biomass processing alternatives gives research-based information to inform decision making. The factors guiding decision making should include impacts on ecological risk, but also carbon emissions and soil properties. For example, quantifying the biological health of soil after biochar production in comparison to soil sterilization from pile burning, and the subsequent vulnerability to invasive weeds, offers land managers a way to make informed decisions on their management practices.

On-Site Biochar Application Guidance
Organizations and landowners focused on returning biomass to the forest floor require clear guidance on the appropriate volume, size and distribution of biomass needed to provide the desired soil health, carbon sequestration and biological value, based on forest and soil types.

Biochar Integration with Prescribed Burning
As an increasing number of organizations look to integrate prescribed burning into forest management and fire risk reduction practices, there is potential for integrating biochar production. Several studies have estimated that the conversion rate of biomass to charcoal during a forest fire event ranges from 1% to 10% of the biomass consumed in a fire, or 1% to 2% of the biomass available in the forest (DeLuca & Aplet 2008). Some experimental burning practices have resulted in higher rates of biochar production, such as an experimental high-intensity crown fire in a Canadian boreal forest stand that captured 27.6% of the carbon in the fire zone in the form of charcoal. Aggregating the diverse number of metrics involved for biochar-based prescribed burns will likely require an open-source database, built collaboratively.

Summary of Ecological Challenges

1. Organized research on the benefits of place-based biochar in forest soils must center on the most pressing issues in modern forestry such as increasing resilience to wildfire, post-fire recovery, and increasing plant health in a changing climate.
2. Ecology research must quantify the carbon sequestration value of place-based biochar.
3. Potential exists to integrate place-based biochar with modern prescribed burning, requiring further research and outreach to practitioners.

Engagement/Education Challenges

Background

Biochar awareness, although growing, has not penetrated deeply into small-scale agriculture and forestry practices. In the past decade there has been noteworthy progress in the number and geographic distribution of workshops, demonstrations, and educational presentations increasing the general understanding about biochar efficacy, production and uses. But awareness has not yet converted learners to producers and consumers on the scale desired. The actual use of biochar in small agricultural and landscape-based forestry applications is still considered somewhat novel.

We find the highest acceptance and use levels among gardeners and niche farmers. Despite successes and enthusiasm amongst users in cannabis gardens, vineyards, orchards, and organic farms, markets remain small.

Forest managers who are looking for ways to improve operational efficacy, reduce carbon emissions, and improve forest health, are focusing more strongly than ever on the benefits of biochar (Figure 4.5 - 4.7). Taking their cue from nature and from indigenous traditional ecological knowledge and practices, forest managers understand that returning carbon to the soil in the form of charcoal provides a plethora of ecosystem values as well as socio-economic opportunities.

Figure 4.5. *Small private forest landowners attending a Family Forests stewardship presentation. Colville, Washington. 2018. (Photo: Gloria Flora)*

Figure 4.6. *Northeast Washington Forest Coalition and Colville National Forest personnel discuss forest health, 2018, Colville, Washington. (Photo: Gloria Flora)*

Figure 4.7. *The Tualatin Soil and Water Conservation District sponsored a two-day biochar workshop in 2019 at goat dairy that has an excess of waste woody biomass and a need for biochar to use in the goat barn. (Photo: WilsonBiochar.com)*

Scope of Engagement/ Education Challenges

Adoption Insights—Encouraging Change

Forestry operations and market farmers, because of ingrained practices and tight profit margins, are hesitant to change without being thoroughly convinced that that change will improve productivity and profit. Sustainable crop productivity improvement, soils remediation, drought protection, carbon sequestration and thus, improved long-term profit—some of biochar's outstanding benefits—are harder to see in immediate bottom lines.

Both forestry and agricultural practices generate biomass suitable for conversion to biochar. That includes surplus biomass which requires time and energy to manage. This provides an opportunity for on-site production and reduces cost-per-acre applications. However, suitable transportable equipment, basic skills for safe equipment operation, and user-friendly air quality permitting (should your operation be large or continuous enough to merit one) still require investment of time and money to get started.

Coordinating Education through Networks and Shared Resources

Fortunately, there is incredible depth of expertise, research, and applied science by biochar professionals around the globe. What is needed is a comprehensive, coordinated approach that provides easy access to that research, integrating it into diverse learning opportunities, workforce training, and technology transfer.

There are many high-quality biochar education programs and courses, but there is also a lack of consistency and language among them, even, for example, in defining, quantifying, and verifying the benefits of biochar. Coordination of these educational resources would increase efficacy, consistency, and availability of information for educators and presenters. Likewise, coordinated train-the-trainer programs would dramatically expand reach and could include opportunities for continuing education credits and other incentives.

Formal/semi-formal networks of practitioners are essential to provide training/leadership – as well as mutual assistance. Networking could likewise facilitate essential collaboration with organizations and agencies sharing a similar spectrum of objectives.

Target Audiences for Education

Increasing improved understanding of benefits and confidence in outcomes, in both the production and the use of biochar, requires increased coordination and a comprehensive approach to biochar education and outreach. Likewise, intelligent techniques that rely on integrating and improving current practices through minor modifications in biochar production processes, rather than adding work and expense, need to be fully explained, demonstrated, and proven in the field.

Key target audiences include agency leaders and large forest landowners who either make or influence decisions about forest management on specific landscapes. These entities would hire others to accomplish the work or train their own workforce in biomass handling for producing biochar. Other important groups are agencies and organizations with the mission to incentivize proper stewardship and educate the current and emerging generations of agricultural and small forest landowners (Figure 4.8). These landowners would most likely be doing the work themselves or with the assistance of small-scale contractors or individuals knowledgeable in the production of biochar. Forest and agricultural workers are yet another target audience, whether they are individual contractors or small companies providing services.

Figure 4.8. *Permaculturists and farmers learning biochar production and use at TerraFlora Permaculture Learning Center, 2019. Colville, Washington. (Photo: Gloria Flora)*

The final but very important audience are students: K-12, technical schools, through graduate school. Informal youth education organizations are also smart targets (e.g., 4-H, YMCA/YWCA, Future Farmers of America). Engaging the younger generation is one of the most significant ways to ensure that biochar and its benefits continue to be tested, refined, and replicated across landscapes.

Collaborating for Success

There are organizations at the international, national, regional, and local levels eager to participate in expanding biochar education and outreach. With the funding of key individuals, organizations, and initiatives in the four focus areas of engineering, economic, ecological and engagement/education, we believe significant strides can be made in increasing biochar education and outreach to grass-roots level audiences.

Because of the significant interest across educational venues, the opportunities for collaboration are high. Some tools are already developed, and contact lists from various agencies and organizations provide outreach avenues. Educational organizations are hungry for fresh opportunities and the latest techniques that provide integrated, natural solutions to address a range of issues.

Collaboration varies by location but is already occurring among the following groups since their mission and objectives overlap with the mission and objectives of biochar leaders:

- Agricultural commodity boards
- Community college vocational training programs
- Community gardens
- Economic development organizations
- Environmental NGOs
- Farmers
- Farmers' markets
- Federal agencies under U.S. Departments of Agriculture and the Interior
- Fire districts
- Professional society training programs
- Soil and water conservation districts
- State agencies (Departments of Natural Resources, Labor and Commerce)
- State firefighting services
- State park services
- Sustainable agriculture and permaculture NGOs
- Tribes
- University extension services
- Watershed councils

Summary of Engagement/ Education Challenges

We seek to provide comprehensive, consistent, and coordinated information disseminated through decentralized, yet broadly accessible, venues. These educational resources will cover small-scale, sustainable landscape-based production and use of biochar and will emphasize garden, farm, and forestry applications.

1. **A lack of well-developed biochar outreach and education networks.** Establishing networks and information clearinghouses for trainers to coordinate programs would increase consistency in information and techniques, and facilitate coordination with collaborators and partners. Training courses and educational materials should be widely accessible and broadened to reach to target audiences, particularly focused on on-line programs (entry, advanced, business, youth).

2. **Limited workforce training programs.** Labor-intensive forest management would have the local skill pool to implement wildfire risk, reduction, and restoration management projects which would in turn benefit small businesses, local economies, and individuals in collaboration with economic development organizations/agencies. Training programs would provide a missing link in public land forest management to biochar internships, potentially creating jobs and develop an emerging workforce in rural communities.
3. **Lack of business planning templates and cost estimation tools for contractors.** Accessible tools essential for small business should be developed in collaboration with Departments of Commerce and Secretaries of State, in addition to creating uniform sustainability guidelines for labor, carbon, and ecosystem services. Consistent permitting regulations and standardized cost ranges by forest habitat type, agricultural applications, etc. would facilitate communication between customer and provider, leading to greater interest in and implementation of biochar.
4. **No central database of research or clearinghouse for biochar-related information.** There is a need for comprehensive research syntheses and meta-analyses on biochar, collated by subject matter, geographic relevance, and application. This database would increase accessibility and usefulness of the myriad research while also differentiating between applied and theoretical studies. Not only would the database draw from and present academic papers, but traditional knowledge derived from historical practitioners would be included as well. The database would be used to curate and develop citizen science guides to be disseminated for individual projects or regional considerations. This distillation of complex data into accessible materials would benefit all biochar users.

RECOMMENDATIONS FOR IMPLEMENTING PLACE-BASED BIOCHAR

Our recommendations for implementation identify needs that are cross-cutting with impacts on each of the disciplines within our approach: Engineering, Economics, Ecology and Engagement. Investment in the following areas will have positive ripple-effects and impacts on other aspects of biochar production and use. Note that the numbering here does not indicate higher or lower priorities—all recommendations are interdependent and equally urgent.

1. **Fund research to quantify flame cap kiln biomass to biochar conversion efficiencies.** This will provide data to determine comparative design efficiencies and to quantify carbon sequestration rates for access to carbon markets.
2. **Fund research to quantify avoided emissions compared to conventional open burning.** This will provide data to access carbon markets, reduce health impacts, improve kiln effectiveness, and respond to air quality permitting concerns.
3. **Fund field research to compare different production systems for accessing stranded biomass in varying terrains.** Conduct a systematic study of traditional and emerging technologies to decrease feedstock handling and increase efficient kiln deployment in the field. This will establish best practices for maximizing biochar output and for providing economic metrics for contractors bidding on jobs.
4. **Evaluate carbon market potential.** Use kiln emissions, biochar conversion efficiency, and field production data to complete a life cycle analysis of the fates of feedstock carbon compared to current slash disposal methods. Establishing the market value of sequestered carbon and avoided emissions will allow contractors to offset the cost of creating biochar compared to open pile burning.
5. **Fund the development of business planning templates and cost estimation tools for contractors.** This will help practitioners doing projects at varying landscape scales to convert forest or agricultural residue into biochar. Include guidelines for labor, best production practices, and carbon and ecosystem benefits of biochar production. Determine contracting costs for greatest efficiency by collecting data on all contracting costs associated with on-site biochar production for comparison to other slash disposal pathways. Collaborate with departments of commerce and economic development agencies.
6. **Develop workforce training programs.** The Conservation Corps model offers an opportunity to address unemployment and underemployment while reconnecting people with their landscapes through collaboration with economic development organizations and community colleges. This work addresses fuels mitigation on public lands that is currently a missing link in wildfire risk reduction. These "Carbon Conservation Corps"

could offer the potential for certificate programs in landscape biochar technologies as a pathway to enter the natural resources, forestry, or arborist/urban landscaping sectors.

7. **Ascribe monetary value to the social and ecosystem services provided by place-based biochar production including:**
   - Smoke reduction and effects on human health,
   - Increase in forest resilience metrics to forest fires, drought and other risk factors in a changing climate, and
   - Impact on tree growth rates and forest soil health.
8. **Develop outreach and education networks.** These networks would enable place-based biochar practitioners to improve the quality and consistency of information, education, curricula and communication, including train-the-trainer and resource sharing programs. Targeted groups would include forest organizations, landowners, contractors, youth programs and indigenous practitioners of prescribed fire.
9. **Create an open access research and information clearinghouse for biochar producers at all scales.** A centralized online location for technical, ecological, and economic publications on biochar production, use, and influence on forests and farmland will allow researchers and organizations to merge data to collectively understand emerging opportunities from all sectors of the biochar industry.

CONCLUSIONS

Place-based biochar has the potential to solve many different problems centered on the diverse areas of forest health and management, climate change mitigation, and job creation. There are a legion of benefits resulting from increasing the health of our forests. Not only do forests provide products, they also provide clean air and water, wildlife habitat, and improved quality of life for residents who depend on these landscapes. Yet a warming climate threatens the ecological benefits of forests and increases the quantity and intensity of wildfires, endangering homes, businesses, and lives of individuals living in proximity to forests.

Converting forest slash from necessary vegetation management projects into biochar and leaving it on site to enrich forest soils should help forests become more resilient to the environmental stresses of climate change. The climate impact of place-based biochar is not limited to the soil carbon sequestration achieved by adding biochar. If biochar can be returned to forest soils at a large enough scale to improve soil and plant resiliency, it could be the difference between forests sequestering carbon or contributing carbon to the atmosphere through forest fires.

Solving climate change requires society-wide mobilization and focus. Place-based biochar provides a rare opportunity to achieve many additional social and economic benefits—healthy forests, fire protection and jobs—as we work to strengthen forest landscapes through the application of biochar.

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