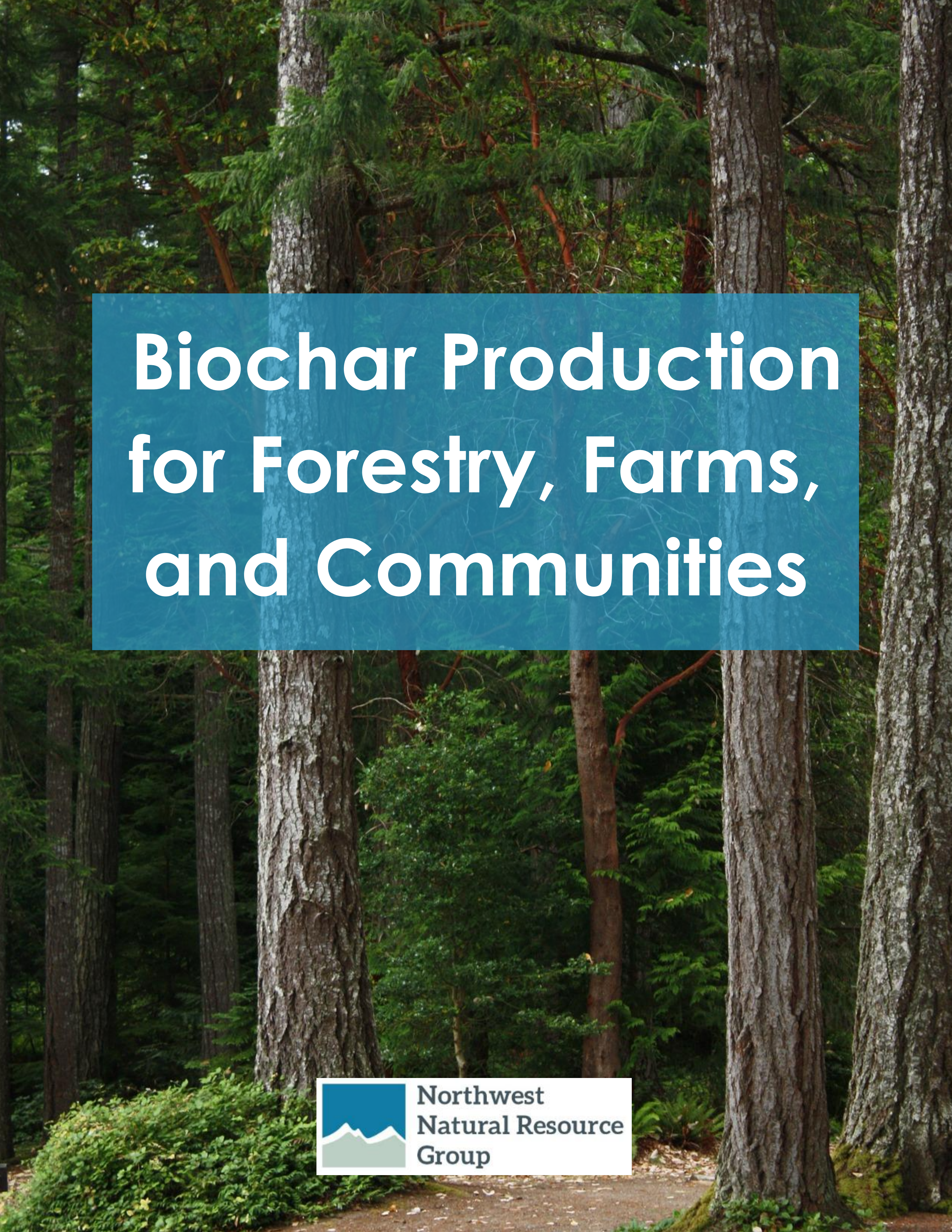

Biochar Production for Forestry, Farms, and Communities

Northwest Natural Resource Group

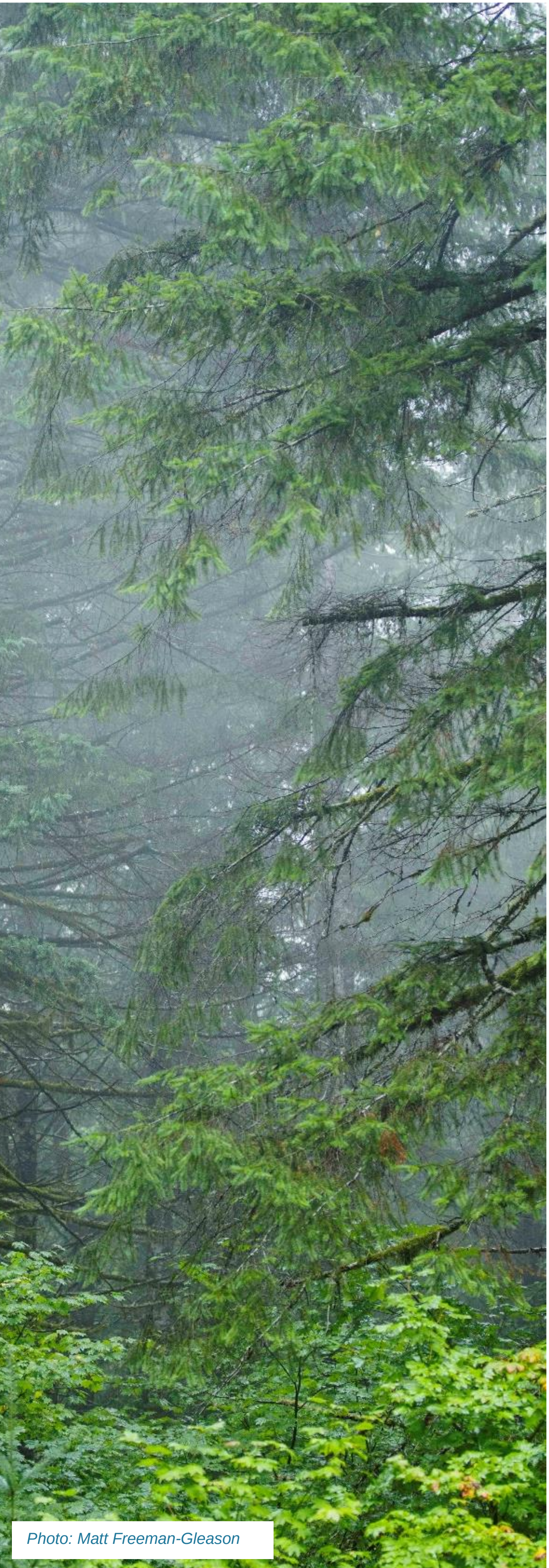

Photo: Matt Freeman-Gleason

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CONTENTS

CREDITS 2
CONTENTS 3
SUMMARY 4
INTRODUCTION: THE POTENTIAL OF BIOCHAR 4
Farms 5
Forests 6
Summary of Biochar Production Methods 7
PHYSICAL AND CHEMICAL PARAMETERS OF BIOCHAR PRODUCTION 8
Pyrolysis 8
Key Feedstock Variables 8
Processing and Organizing Woody Biomass 10
Greenhouse Gas Emissions Reductions 10
Safety 11
BIOCHAR PRODUCTION TECHNIQUES 12
Conservation Burns 12
Flame Cap Kilns 14
Pit Burns 17
Air Curtain Burners 19
Bioenergy 20
COMMUNITY PRODUCTION CASE STUDY: WALDRON ISLAND 21
Lessons learned 21
CONCLUSION 23

SUMMARY

This paper describes the potential for biochar to address the twin problems of agricultural soil fertility and greenhouse gas accumulation in the atmosphere. After surveying the chemical parameters underlying biochar production, the paper describes five methods of producing biochar at a variety of scales, from DIY techniques for small farms and forests, to large-scale opportunities for community implementation. The paper concludes with a case study of a medium-scale community project converting forest thinnings for fire hazard reduction into useable biochar for application in gardens.

Photo by Forage Media

INTRODUCTION: THE POTENTIAL OF BIOCHAR

Carbon dioxide, a gas that traps heat from the sun within Earth's atmosphere to create a greenhouse effect, makes up more than three-quarters of the greenhouse gas emissions in the world.[1] Atmospheric carbon dioxide volume has increased by more than 40% since the Industrial Revolution and — along with other greenhouse gases — is considered by the scientific community an "extremely likely" cause of more than half of the warming of the planet observed since 1950.[2]

Strategies to sequester carbon and prevent its atmospheric release have never been more important. Charcoal is a stable form of carbon that has been a part of natural soil ecosystems for as long as natural fires have existed. Historians have also found many ways that indigenous farmers throughout the Americas, Europe, and Asia incorporated charcoal in their soil

[1] IPCC. 2014. Climate Change 2014: Mitigation of Climate Change.

[2] NASA. Climate Change: Causes. https://climate.nasa.gov/causes *Climate Change 2014: Synthesis Report,* IPCC, pp. 44 and 48. http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf

amendment practices. Today, the scientific community is researching beneficial applications for charcoal produced from agricultural crop waste and forestry residue, called biochar.

This research suggests that biochar provides two key benefits: it stores carbon from the live biomass that is burned to create the char, and it stabilizes the soil carbon cycle when applied as a soil amendment. Biochar represents an opportunity for communities to enhance forests and agriculture for ecosystem health, food security, and climate resilience.

Farms

Global agriculture is experiencing a carbon crisis. Tillage has off-gassed 50-70% of carbon in farm soils into the atmosphere.[3] Carbon, known as the building block of life, is the single most essential element in soil fertility. It aids in soil structure development, water and nutrient retention, and biological processes. Decreases in soil fertility resulting from carbon loss exacerbate the already formidable challenges facing the world's farmers in the era of changing climate. The Intergovernmental Panel on Climate Change estimates that crop failures prompted by increased weather variation could reduce global food production by up to 17% by the year 2100.[4] These stresses will only grow as the world's population is expected to increase to 11.2 billion people by the same year.[5]

[3] Judith Schwartz. 2014. Soil as Carbon Storehouse: New Weapon in Climate Fight? Yale Environment 360. http://e360.yale.edu/features/soil_as_carbon_storehouse_new_weapon_in_climate_fight

[4] IPCC. 2014. Chapter 7: Food Security and Food Production Systems. Fifth Assessment Report - Impacts, Adaptation, and Vulnerability. https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/drafts/fd/WGIIAR5-Chap7_FGDall.pdf

[5] UN Department of Economic and Social Affairs. 2017. World Population Prospects: The 2017 Revision. https://www.un.org/sustainabledevelopment/blog/2017/06/world-population-projected-to-reach-9-8-billion-in-2050-and-11-2-billion-in-2100-says-un/

Biochar can enhance *regenerative agriculture* by increasing carbon sequestration from composting, animal rotations, cover crops, and no-till farming methods. Biochar applied to agricultural soils has been found to decrease carbon off-gassing by up to 68.8%.[6] Increasing carbon retention in agricultural soils can improve crop endurance, and biochar's potency as a soil amendment could be a critical step toward climate resilience.

Forests

Due to past management, many forests in the Pacific Northwest are densely crowded with suppressed trees. These stressed trees are vulnerable to many threats including fire, pests, and climate change.

Thinning out excess woody biomass from these overcrowded stands has myriad benefits. It provides forest owners with modest revenue from timber sales. It restores the structural complexity that makes for ideal wildlife habitat. And it gives retained trees the light and space they need to thrive and sequester carbon to their maximum potential.

A common concern regarding forest thinning is the carbon that is released from the removed woody biomass in the form of limbs, tops, and unmerchantable trees. Biomass left to decompose releases carbon back into the atmosphere. The carbon-stabilization functions of biochar can help reduce carbon emissions and make thinning even more productive. Char can also reinvigorate poor forest soils to further inspire tree and understory growth. More and more research is being published highlighting the different ways biochar can be a valuable part of making our forest ecosystems sequester more carbon and stay resilient in the face of climate change.

[6] Hongguang Cheng et al. 2017. Biochar stimulates the decomposition of simple organic matter and suppresses the decomposition of complex organic matter in a sandy loam soil. Bioenergy. 9(6): 1110-1121. DOI: 10.1111/gcbb.12402

Summary of Biochar Production Methods

Five biochar production methods are described in detail:

- Conservation burns (Page 12)
  Conservation burns offer the simplest method for producing biochar because they don't require a kiln. Branches and small diameter wood are stacked in a precise method that maximizes the conversion of biomass to charcoal. The fire is then extinguished with a significant amount of water. Conservation burns are usually short in duration, often lasting less than 20 minutes, and require wood that is at least moderately dry.
- Flame cap kilns (Page 14)
  Based on the Japanese *Kon Tiki* kilns, flame cap kilns are typically an open-topped metal cylinder or box that is capped at the end of the burn to extinguish the fire. Flame cap kilns allow for continual loading of material throughout the burn process.
- Pit burns (Page 17)
  Pit burns use a sunken pit in the ground instead of a metal kiln. Pit burns typically retain more internal heat than flame cap kilns, which increases the amount of carbon in biomass that is converted to biochar. Pit burns may impact soil biology and tree roots depending on their proximity and require digging either by hand or with an excavator. They allow for continual loading of material and are capped to extinguish the burn.
- Air curtain burners (Page 19)
  Air curtain burners are designed to minimize air pollution – the burner uses a series of air blowers to generate a "curtain" of air that drives volatile gases back into the burner to be consumed as fuel in the fire. Mobile models are being engineered to integrate with logging and other forestry operations.
- Bioenergy (Page 20)
  Larger, energy-producing biochar technologies are emerging that can process up to eight tons (7.2 metric tons) of waste biomass and produce up to 100 kW of electricity. By converting biomass from farms, forests, and other sources into both energy and biochar, bioenergy can integrate with solar, wind, and other renewable energy models to power communities.

PHYSICAL AND CHEMICAL PARAMETERS OF BIOCHAR PRODUCTION

Pyrolysis

Pyrolysis is the process of decomposing plant or animal residue through the application of heat in a low-oxygen environment. During pyrolysis, organic material is broken down into smaller compounds and converted into gases. As some of the organic gases condense, a mass of carbon, ash, and oil is formed.[7] The majority of trace minerals and metals contained in the original biomass remain in the charcoal and ash produced.

Open burns, such as flame cap or pit burns, use oxygen at the top of the fire to generate heat that volatilizes the organic materials in the biomass *below* the fire. As new biomass is added from the top, the fire rises to combust this material and in so doing pulls oxygen up, leaving behind the low oxygen environment needed for pyrolysis to create charcoal. When a burn is conducted correctly, the bottom of the kiln should be cool enough after it has filled with biochar that you can put your hand on it, as the lack of oxygen at this depth effectively inhibits combustion.

Key Feedstock Variables

The wood material used to create biochar is called feedstock. While various wood types and sizes can be combined in any open burn, using feedstock that is approximately equal in size and moisture content and of the same wood species will allow for the most efficient burn. A homogeneous feedstock will convert biomass to charcoal at a consistent rate, which makes it easier to manage the burn and extinguish it when the time is right. When a highly variable feedstock is mixed together during the burn process, less dense or smaller-diameter materials will turn to ash, while the denser materials or those with larger diameters will remain partially charred. However, if you already have a pile of mixed materials, the work of separating and organizing the material may outweigh any gains in efficiency. As long as you remove anything that is larger than 24” in diameter, a mix of woody biomass materials can be converted to charcoal. The key feedstock variables that influence the qualities and benefits of biochar are size, moisture content, temperature, and feedstock type and pH, discussed in more detail below.

[7] Encyclopaedia Britannica. 2018. Pyrolysis. https://www.britannica.com/science/pyrolysis

Size

The diameter of woody biomass will dictate the amount of time the material is actively burning, and when the next batch of feedstock should be added. Organizing woody biomass into 1" – 2" diameter classes, then feeding common size classes into the fire is the best way to ensure an even burn.

Moisture content

Moisture affects the length of time wood actively burns before the organic materials have volatilized, as well as the temperature of the overall fire. This can be mitigated to a certain degree with larger and hotter burns. However, drier material is more efficient and effective for small-scale production systems where the pile or kiln is less than five feet in diameter. A general best practice is to let material dry through one summer before burning during the following rainy season.

Temperature

Higher burn temperatures (above 750° F) result in biochar that has more surface area and therefore greater capacity to both retain moisture and persist longer in the soil. Higher burn temperatures also emit fewer greenhouse gases. Lower temperatures (below 750° F) decrease biochar's longevity in the soil, increase biochar's ability to retain nutrients, and convert more biomass to biochar. Cooler burns tend to release more damaging greenhouse gases like methane. Therefore, burns that occur at variable temperatures may optimize the range of soil enhancements provided by the resulting biochar while mitigating emissions.[8] The key characteristics that influence the burn temperature are the BTU (British Thermal Unit) rating or heat content of the feedstock, the size of the fire, moisture content, and whether or not air curtains (blowers) are used.

Photo: Oregon State University

Feedstock type and pH

Biochar with higher pH (8.1 - 9) is more stable in the soil, and promotes enhanced biological activity compared to biochar with lower pH.[9] Due to their naturally higher pH, deciduous trees will produce biochar with a higher immediate value in the soil. However, given that common deciduous trees in the Northwest

[8] Hongguang Cheng et al. 2017. Influence of biochar produced from different pyrolysis temperature on nutrient retention and leaching. Archives of Agronomy and Soil Science. DOI: 10.1080/03650340.2017.1384545

[9] Shuwei Liu et al. 2016. Response of soil carbon dioxide fluxes, soil organic carbon and microbial biomass carbon to biochar amendment: a meta-analysis. Bioenergy 8(2): 392-406. DOI: 10.1111/gcbb.12265

tend to have a lower BTU rating than coniferous trees, it is harder to reach the 750° F temperature necessary to create biochar that has optimal soil longevity.[10] Therefore, using burn systems that result in the hottest burn, combined with hardwood feedstock, will likely produce the highest quality charcoal for the Pacific Northwest.

Processing and Organizing Woody Biomass

Conveniently, trees naturally organize their own feedstock: the diameters of limbs and trunks decrease moving up the tree. During thinning, you can organize woody biomass into piles of common sizes while limbing and bucking. You'll thank yourself when it's time to burn. The use of machinery makes feedstock aggregation more efficient. Tractors with forks and mini-excavators are ideal tools for collecting woody biomass into larger piles, and both can be used for moving biomass to the burn site and loading feedstock into the burn.

Manually moving woody biomass from where its left after thinning to the burn site is often labor intensive. You have the choice of either combining smaller piles of like material and transporting them to the burn site or conducting a series of smaller burns nearer where the biomass was generated.

Greenhouse Gas Emissions Reductions

While fire is often associated with air pollution, converting woody biomass to biochar emits fewer greenhouse gases than many other common methods for disposing of excess woody biomass. Conventional pile burning can release nearly 100% of the carbon contained in the feedstock; for every 100 pounds of woody slash burned in a

[10] For average BTU ratings of Pacific Northwest wood types please visit the following web pages for deciduous and coniferous trees.
Coniferous: http://northwestforestproducts.com/wp-content/uploads/2012/01/firewood-btu-ratings.jpg
Hardwood: http://northwestforestproducts.com/wp-content/uploads/2012/01/firewood-btu-chart.jpg

conventional pile, approximately 150 pounds of carbon is released.[11] Similarly, chipped woody material will off-gas most of its carbon through decomposition within three to six years of chipping. Carefully managing the process of pyrolysis through the biochar burn methods outlined in this guidebook generates more stable carbon bonds that produce charcoal rather than emitting carbon dioxide.

The amount of carbon biomass converted to biochar varies depending on the production method. For example, a field project in Nepal recently demonstrated the following production differences:

- Pit burn: 43% carbon sequestered
- Flame cap kilns: 36.8% carbon sequestered
- Steel shield in pit: 56% carbon sequestered

This research also revealed that, compared to traditional open pile biochar burns, which are most like conventional slash pile burns, flame cap kilns "significantly lower[ed] emissions of CO (carbon monoxide) and NOx (nitrogen oxides)" by consuming these volatile gases in the area of active flame. Compared to open pile burns, flame cap kilns reduced emissions of carbon monoxide by 650% (54 ± 35 g/kg compared to 351 ± 141 g/kg) and nitrogen oxide by 37,000% (0.4 ± 0.3 g/kg compared to 148 ± 64 g/kg).[12]

Safety

Always consult your local fire department before conducting a burn. A permit may be required, and outdoor burning may be limited or prohibited during the driest times of the year.

Fire poses many risks to you and your community. A familiarity with fire management and fire safety are requirements before conducting a biochar burn. Ideally, burns are conducted during the wet season when surrounding vegetation is the least flammable. A steady source of water, such as a pressurized hose, should be available, as well as a heavy rake or hoe to manage the ground immediately adjacent to the burn as it heats up.

There are a few major risks to consider when planning a biochar burn:

Wildfires

The risk of causing a wildfire is elevated at the transition points between spring and summer and summer and fall. Early fall rains often do not saturate the sub-soil, even though the forest floor may appear moist, leaving a dry sub-soil that can transfer fire via dry roots and other wood biomass underground. Similarly, middle to late spring can appear lush, yet the duff

[11] https://ir.library.oregonstate.edu/concern/graduate_projects/gx41mn92n

[12] Gerard Cornelissen et al. 2016. Emissions and Char Quality of Flame-Curtain "Kon Tiki" Kilns for Farmer-Scale Charcoal/Biochar Production. PLoS ONE. 11(5): e0154617. DOI: 10.1371/journal.pone.0154617

(organic material) layer can be dry enough that fire can travel along the ground. Make sure to clear organic matter from the ground at least five feet around a burn site. The safest practice is to scrape down to mineral soil, removing all duff material with a shovel, tractor, or excavator blade. This material can be replaced after the burn.

Personal injury

Fire burns: Biochar burns can cause permanent scarring to skin and even death if a person falls into the fire box. Wearing long sleeves and gloves is a good way to protect your skin. It is especially important with pit burns to watch your step so that you do not fall toward the fire. Be sure to keep a first-aid kit with burn supplies on hand.

Steam burns: Extinguishing the fire with water generates a significant amount of hot steam, which can cause serious burns. Apply water to the burn from a safe distance, and never place exposed skin over the surface of a steaming kiln or pit while extinguishing it.

Equipment damage

If you use heavy equipment to load kilns, it is important to consider the potential influence of the fire's heat on the hydraulic hoses of tractors and excavators. The pressure of these hoses usually ranges from 2,000-3,000 PSI, and a line bursting due to heat can cause risks to your health, your vehicle, and the environment. Machine loading is possible and recommended for commercial producers, but make sure to move the loading apparatus in and out of the fire's heat as quickly as possible.

BIOCHAR PRODUCTION TECHNIQUES

Before starting a burn, make sure you have these basic tools on hand:

- Water
- Shovel
- Gloves
- Rake (ideally a fire rake)
- Chainsaw
- Pitchfork (helpful for hand-loading branches)

Conservation Burns

Conservation burns are the simplest and most accessible way to produce biochar – all they require is an organized stack of approximately uniform wood. The theory behind conservation burns is that most of the feedstock heats uniformly to reach the temperature where organics are volatilized and the biomass converts to charcoal. As soon as charcoal is produced, the fire is extinguished with water before the burn process further converts the charcoal to ash.

Photo: Wines and Vines: https://www.winesandvines.com/news/article/185902/Burning-Vineyard-Waste-for-Biochar

Extinguishing a conservation burn requires a significant amount of water to be applied at a rapid rate in order to sequester the maximum amount of carbon and prevent ash formation. Therefore, pressurized water hoses are a necessity.

Conservation burns are lit from the top. As the fire moves down to consume material lower in the pile, it leaves a low-oxygen environment in its wake that converts biomass to charcoal. Flames consume oxygen that would otherwise cause the charcoal to continue to burn to ash. Unlike flame cap kilns, which raise the fire zone in order to eliminate oxygen supply to charcoal, conservation burns create one large fire zone that needs to be extinguished at the point when additional woody biomass would otherwise be added to a kiln.

Method

The success of conservation burns depends on how the pile is constructed. Successful burns use a feedstock with relatively consistent diameters that are less than 4 inches. Length can vary, but material in the range of 1-4 feet is easier to manage and will improve the rate of biochar production.

Using dry material is extremely important for conservation burns. Higher moisture content in the feedstock will result in slower fire development, resulting in the top material turning to ash before the lower layers convert to charcoal.

Pile feedstock in a cone, with the largest diameter material placed in the center of the pile and smaller material placed both on the bottom and the top. Because temperatures are hottest at the center of the fire, the larger diameter material will convert to char at the same rate as the smaller diameter material surrounding it.

Once the pile is constructed, start the fire at the top. If there is wind, the pile should be lit on the downwind side 2/3 of the way towards the bottom. The goal of conservation burns is to have the pile burn quickly, with the fire moving from the top of the pile to the bottom in under 20 minutes, depending on the size of the pile.

Extinguishing the fire

Extinguish the burn after the fire has reached the bottom of the pile and a slight coating of ash can be seen on all the material from top to bottom. Spray the fire with pressurized water (from a garden hose, for example). It is important to make sure that the pile is fully saturated before leaving the pile. Often the pile can look extinguished and still have live coals that can dry out the surrounding charcoal and reignite the pile. Turning the char with a pitchfork or shovel is a good strategy for ensuring that all layers have been extinguished.

Flame Cap Kilns

Flame cap kilns use a metal cylinder or box with either an open or closed bottom. Old metal drums are commonly converted to flame cap kilns by either cutting out their circular end or cutting them in half lengthwise.

Kilns can vary in diameter and height. Kilns with larger diameters and shorter heights result in cooler burns that are less efficient at converting biomass to biochar. Taller and narrower kilns result in cooler, more efficient burns. A general guideline for an ideal kiln is a 1.5:1 ratio of height to diameter.

CREATING YOUR OWN KILN

If you are cutting a metal cylinder or box to create a kiln, it is important to discover if the container has previously stored any flammable products. If so, fill the container with water before cutting, as a spark can ignite residual gases in the container, creating the potential for an explosion.

One of the significant advantages of flame cap kilns is feedstock material can be loaded continuously throughout the burn process. The burn ends when the kiln is full of biochar.

Flame cap kilns prevent oxygen from entering the fire from the side of the burn. Instead, the area of active flame rises as new woody material is added to the top, consuming the oxygen that would otherwise continue to burn the charcoal forming in lower layers. Research on flame cap kilns found an average conversion rate of total biomass to biochar of 21%.[13]

Method

To optimize your burn, separate woody biomass into piles of similar species, size, and moisture. Add each pile separately to the fire to ensure an even burn. If you have a pile of larger diameter

[13] Gerard Cornelissen et al. 2016. Emissions and Char Quality of Flame-Curtain “Kon Tiki” Kilns for Farmer-Scale Charcoal/Biochar Production. PLoS ONE. 11(5): e0154617. DOI: 10.1371/journal.pone.0154617

material, reserve this pile for the middle third of the kiln as the fire is constructed, as that area will sustain the highest heat for the longest period.

Starting the fire

Make a hot fire in the base of the kiln using kindling and small sticks. If the kiln has an open bottom, initially allow air to enter the kiln from the bottom to encourage the fire. You can improve ventilation by shoveling out several small access points around the perimeter of the kiln. When the fire is burning well (usually 10-20 minutes after starting the burn) seal the bottom perimeter of the kiln with soil so no air can enter. If air can enter the bottom of the kiln, the low-oxygen environment needed for charcoal to form will not become established.

Photo: Forage Media

Adding material

Watch the surface of the woody material as it burns in the kiln. When ash begins to form on the top surface, add more material to the top. The active fire zone will rise to consume this new material, drawing oxygen from lower layers up to feed the fire. In the oxygen-starved lower layers, combustion slows and biomass converts to charcoal instead of ash.

Continue adding fuel until the kiln is full of charcoal or you run out of fuel or time. As the level of charred wood rises in the cylinder, carefully feel the temperature of the outside of the kiln's bottom. The kiln should be significantly cooler than the area of active burning, indicating that little to no oxygen is entering the kiln from below.

Analyzing the fire

The color of the smoke coming from the kiln is a good indicator of the temperature of the fire and the cleanness of the burn. Use these visual clues to guide your burn:

- No smoke or minimal smoke with heat waves is ideal.
- White smoke, primarily comprised of steam as moisture in the wood vaporizes, is not a significant air quality concern.
- Blue smoke indicates that some volatile gases are escaping before they burn. The fire is too cool – stop adding fuel or begin adding drier fuel to increase the fire's temperature.
- Yellow and greenish smoke (see image to right) indicates that methane, a harmful greenhouse gas, and other volatile gases are being emitted. This happens when the fire is too cool and the gases are not being consumed by the fire. It is critical at this point to stop adding fuel and let the burn heat up to the point where methane and other gases and organic materials are more completely combusted.

Photo: Forage Media

Extinguishing the fire

There are two different methods for extinguishing flame cap kilns: 1) using a lid to suffocate the fire, or 2) using water. The lid method is a good option if water conservation is a concern.

Lid method: Create a lid 1-2 inches smaller than the diameter of the kiln so the lid can easily fit inside. A lightweight lid can be constructed of metal roofing material that has been screwed together and cut to the right circular dimension. When the burn is ready to be extinguished, apply 10-15 gallons of water evenly around the top of fire, dousing all flames, then place the lid inside the kiln. Seal the gap between the lid and the edge of the cylinder with soil. Steam leaks will indicate the need for a better seal. The cylinder will take at least two days to cool completely. Once the cylinder has cooled, tip it over to unload the biochar. Be very careful with fresh char, as it can hold heat for a surprisingly long time. If a live coal is exposed to air, it will burn. Make sure there is no heat in the char before transporting.

Photo: Forage Media

Water method: The water method requires a significant volume of water that will vary depending on the size of the kiln, but usually at least 80-100 gallons. This method works best with kilns that have closed bottoms, as the water will fill the container and submerge the coals. If the kiln has an open bottom, thoroughly soak the charcoal in the kiln until little to no steam is released, then tip the kiln over and allow the charcoal to spill out.

Spray the charcoal with water while raking it around and periodically pulling more from the kiln. Continue stirring and wetting the charcoal while looking for hot spots that continue to produce steam. Any steam issuing from the pile after 30 minutes of applying water indicates that the fire is not out. After an hour or two, return to the pile and spray and rake it again. It is highly recommended that the charcoal be inspected several times more before assuming that the fire is out and the char is safe to handle and transport.

Pit Burns

Pit burns operate on the same principles as flame cap kilns using a hole dug in the ground to provide the same function as an above-ground kiln. Pit kilns can be dug with a shovel or an excavator and can range in diameter from 3 to 10+ feet and be dug to any depth that is practical to manage. Pit kilns use the insulation value of the soil to reflect heat back into the fire, generating cleaner and hotter burns than metal kilns. Heat can be further concentrated by shaping the bottom of the pit into the form of an inverted cone.

Photo: Forage Media

Research on pit burns found an average conversion rate of total biomass to biochar of 23.3%, and steel-lined pit burns of 29.3%.[14]

Compared to flame cap kilns, pit kilns have the following advantages and disadvantages:

Advantages

- There is no need to purchase or move large metal kilns
- Higher temperatures result in cleaner burns and more efficient conversion of biomass to charcoal
- Feed stock can be easily pushed into the fire without the need for lifting

Disadvantages

- Digging a pit can be laborious and/or challenging depending on soil types. In rocky or excessively sandy soils, digging a pit may not be viable
- The pit will need to be filled after the burn
- Removing charcoal from a pit is more difficult than tipping over a kiln
- High temperatures can destroy soil biota close to the pit
- Increased waiting time before biochar can be removed

Method

Loading and extinguishing a pit burn follows exactly the same procedure as the flame cap kiln method described above using the lid method. Make sure to have a lid of appropriate size for the pit ready before the burn. In sandy soil, extra soil should be added around the edges of the pit to exclude oxygen after the lid has been placed, as air can move through sand. Additionally, extra cooling time (4-5 days) should be allowed for pits constructed in sandier soils before the lid is removed.

Fire safety with pit burns

Dig pits far from trees to avoid damaging roots. Once dug, the interior of the pit should be examined for tree roots or buried organic debris that could smolder and cause fire to travel underground. Pit burns should also be conducted during the wet season, when surrounding vegetation and the surface of the ground is sufficiently wet to prevent the fire from escaping.

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[14] Gerard Cornelissen et al. 2016. Emissions and Char Quality of Flame-Curtain “Kon Tiki” Kilns for Farmer-Scale Charcoal/Biochar Production. PLoS ONE. 11(5): e0154617. DOI: 10.1371/journal.pone.0154617

Air Curtain Burners

Air curtain burners tend to be large-scale, commercial-grade systems that convert woody biomass into biochar using highly efficient and low-emissions technology. There are at least two companies currently producing air curtain burners: Ragnar Original Innovation (https://roi-equipment.com/) and Air Burners (https://airburners.com/). A series of blowers push air across the top of the fire box to create an air curtain, funneling emissions of wood particulate and organic gases back into the fire for secondary combustion. The result is a very clean burn, with emissions well under 10% opacity (per EPA Method 9 test). Open burns typically generate emissions that are 80-100% opaque.[15] Both companies have created a series of kilns on trailers or tracks to increase ease of transport.

Photo: Wilson Biochar Associates

While air curtain burners were originally designed for mitigating wood waste, they have recently been used for biochar production. Wilson Biochar Associates — a research collaborative in Oregon — has piloted a burner that eliminates the air intake at the bottom of their Air Burner model, thus converting it to a large-scale flame cap kiln. The group found that this modification created a counter-flow of air, which increased the temperature of the fire box, generating clean burns even with large, wet, and dirt-caked woody biomass.[16] Plus, the size of the kilns makes loading long logs with an excavator easy. Because of their size and price, Wilson Biochar Associates concluded that while their air curtain technology and enhanced insulation value provided benefits, these kilns were appropriate for large-scale production but not necessary for effective manufacture of biochar.

The marketplace for biochar is still in its infancy, so the price of air curtain burners ($53,000-$82,000 for Air Burners) may be beyond the investment point for small-scale forestry businesses. The more practical model would be for a non-profit or conservation district to purchase an Air Burner that could be rented by farmers and foresters.

[15] AirBurners. Technology Principle. https://airburners.com/technology/principle/

[16] Wilson Biochar Associates. Kiln Design Gallery. http://greenyourhead.typepad.com/wilson_biochar_associates/kiln-design-gallery.html

Bioenergy

Air curtain burners have also been converted to energy generators by processing the heat produced from burning wood waste into electricity. The burner directs heat to a heat exchanger that produces hot water, which in turn supplies a thermal generating unit. This thermal energy is converted to electricity that can be used on site or fed directly into the electrical grid in a "net metering" arrangement similar to rooftop solar.[17]

This process requires an onsite cooling source, which can be sourced from river, lake, or ocean water. The water returns to the source unchanged except for a small temperature rise.

A current commercial grade Air Curtain Energy Generator is produced by Air Burners: the PG FireBox series. As pricing for the PG Fire Box Series begins at $700,000, the price point excludes most businesses. However, community waste disposal organizations could potentially receive grant funding to help cover the cost of purchasing the burner, citing the environmental benefit of decreased emissions and carbon sequestration of biochar.

Photo: airburners.com

[17] AirBurners. PGF-100. https://airburners.com/products/pg-firebox/pgf-100/

COMMUNITY PRODUCTION CASE STUDY: WALDRON ISLAND

Biochar production allows communities to act collectively addressing fire danger and improving forest health. The community of Waldron Island in Washington's San Juan Islands received Firewise funding in 2017 to pay for forest restoration along roadside areas identified by the 2012 San Juan Fire Assessment as the most critical fire danger points. As these roadways provide the only exit strategy for many homeowners in the case of a fire, creating fire breaks for traffic access mitigates the human health risks posed by overstocked forest stands.

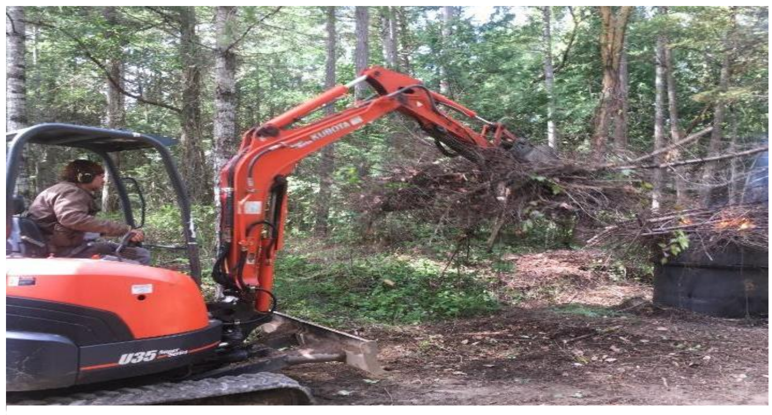

Photo by Forage Media

Designing these fire breaks created a lot of slash that needed to be processed. The community matched the grant funding with volunteer labor to process the thinned slash into biochar. Over three days, with attendance ranging from 7 to 12, volunteers contributed time, hand tools, and even use of an excavator to help manufacture char. Volunteers used three kilns that were cut from a used stainless-steel water tank from a neighbor's junk pile. The two taller kilns were 5' tall by 5' wide, and the smaller one was 4' tall by 5' wide. Lids were made from old metal roofing screwed together and cut with an angle grinder to fit just within the kiln diameters.

In between loading kilns and cleaning roadsides, the group had a midday potluck, roasting beans and potatoes over the biochar kilns. One person drove material close to the kilns with a tractor, while others hand loaded the material and managed the burns. Biochar was then divided among the volunteers based on the time they committed to the project for use in their gardens and farms. Over these three days the community produced about 695 cubic feet (25.7 cubic yards) of biochar from the four acres that received restoration.

Lessons learned

The drier the material, the quicker the burn process

The burns were completed from mid-March through the end of April. With March's increased moisture, burns took 7.5 hours to reach completion. By the end of April, the burn duration was down to 6.8 hours.

Photo: Forage Media

Full kilns produce the most efficient burn

With hand loading, tractor loading with forks, and an excavator, the group found that keeping the kilns full of material, even if material was piled higher than the cylinder's ring, generated the most time-efficient production method. Always make sure to stop adding material if you see green or yellow smoke. Wait until the fire has returned and is generating clear heat waves before adding more material.

Shaking out decomposing needles and leaves reduces gas emissions

The volunteers discovered that one of the most effective methods for reducing green or yellow smoke was shaking off decomposing needles from branches before adding them to the fire. Decomposing leaves and needles hold significant moisture, and also generate a matting effect within the fire box that restricts airflow, reducing the temperature of the fire.

Continually clear material from around the burn site

As you add material to the fire, especially if the feedstock sits above the kiln rim, material will fall around the edges and gather next to the kiln. Contact with the kiln will dry and even ignite this material. The volunteers learned that using a fire rake or a pitch fork to keep material clear from around kilns is an ongoing part of the burn process.

Photo: Forage Media

Transport of feedstock with tractor forks was a successful aggregation method

The restoration work that generated slash for this project occurred along roadways, so a tractor with forks served as the most effective tool for collecting these piles and either placing them in or near the kiln.

Organized piles increase ease of hand loading

The volunteers found that feedstock piled in parallel made removing branches and small-diameter tree trunks easier than crisscrossed piles.

Thoughts for future community biochar burn projects

Having volunteers sign up before the burn day can helps organizers know how many kilns and fires to have operating at once. If there are too many volunteers and too few fires, people can spend time standing around.

This collaborative project in Waldron Island offers an example to inspire other rural, forested communities to consider coming together to steward wooded land and mitigate climate change. Forest restoration and biochar production provide an opportunity for community education around forest restoration, fire danger, and soil health while also offering solutions to these concerns. Improving the coordination of these community systems provides a way for grant funds to be accessed at a scale that no individual forest owner could achieve themselves. Fire danger does not obey property lines, and collaboration, communication, and action are essential to reducing risk of catastrophic fire in congested forests.

CONCLUSION

Biochar production is a constantly evolving, maturing tool, and this summary is just a starting point for further innovation. As Wilson Biochar Associates found in their research, there are significant opportunities to integrate blowers with flame cap kilns and pit burns to decrease emissions, increase gas combustion, and broaden what constitutes acceptable feedstock. Finding ways to improve low-cost and low-tech techniques like flame cap kilns and pit burns will have a broad impact on biochar production in forestry and farming without cost as a prohibitive barrier.

Charcoal produced from different local woods at different temperatures will have unique interactions with local soil types. Research is needed on the ways different crops respond to different levels of char application in a variety of soil types to better understand the benefits of different chars in each local area. However, the significant body of international research gives us a scientific foundation to predict soil response to biochar soil amendment. During a period when agriculture is quickly losing the soil fertility needed to cultivate resilient crops in a changing climate, the implications of biochar's capacity to stabilize carbon and enhance fecundity are especially energizing. Similarly, the carbon sequestered by healthy forests has never been more important, and biochar has exciting potential to increase soil health for tree and understory vigor. Biochar application is no longer based on anecdotal and historical evidence but is grounded in science that has the potential to significantly enhance the practices of regenerative agriculture and ecological forestry now and for future generations.


Photo: Matt Freeman-Gleason

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