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Biochar Basics: An A-to-Z Guide to Biochar Production, Use, and Benefits

A Little Background

When considering the amount of organic matter in soil, there is too much in some places and not enough in others. Many forests have too much organic material, in the form of dense tree stands and fuels on the ground, while many soils don't have enough. Soil organic matter is needed in degraded range, forest, mine, and agricultural soils that have been stripped of key nutrients.

We know that healthy forests are resilient and support a wide range of human and ecological benefits. But many forests are overgrown and crowded. Too many trees compete for too little water; they become stressed, are vulnerable to disease and insect infestation, and die and become fuel for catastrophic wildfires. Therefore, excess biomass must be removed.

By turning excess forest organic material into economically and environmentally valuable biochar, managers can redistribute the beneficial properties of the organic material from overgrown and unhealthy forests to soils in need of restoration. This process is a key piece of the restoration-economics puzzle. Rocky Mountain Research Station senior scientist Debbie Page-Dumroese says, "Creating a value-added product (biochar) from woody residues that are not valued can provide an economic return to landowners or entrepreneurs." Rocky Mountain Research Station Research Economist Dan McCollum's research shows, "Further, this can change the economics of forest treatments, such as thinning and fuel reduction treatments, and forest restoration projects. By turning a costly disposal problem into a valuable product, some of the treatment costs can be offset. The result might be that more projects are economically feasible, and more projects get done."

Biochar, shown above, is made from excess organic forest material and is proving to be a valuable economical and environmental resource. Photo by Pam Voth Photography.

Biochar production can have environmental benefits in a variety of applications. Biochar has several unique chemical and physical properties that make it very useful for retaining nutrients and water. Biochar ranges from 50 to 90 percent carbon and less than 0.1 percent nitrogen. It can be used to restore soil function in areas where there is a loss of organic matter. Biochar can be used to restore forest, range, or mine soils as a high carbon product that builds soil health to buffer ecosystems from droughts or floods by increasing water holding capacity, water storage, and infiltration thereby reducing wind and water erosion. Biochar works best on degraded or problem soils or coarse-textured soils (or clay soils).

Biochar is also one way to rapidly sequester carbon belowground to mitigate climate change. In a recent Rocky Mountain Research Station study by Page-Dumroese and others in the northwestern United States, forest soils amended with biochar had a 41 percent increase in soil carbon content with no negative impacts to the surrounding forest. Biochar applications can be a vehicle for carbon sequestration made from renewable and sustainable woody biomass, while also improving soil conditions.

Biochar production also brings several economic benefits and has the potential to be a valuable

SUMMARY

For landowners and agencies seeking to implement grassland restoration projects and hazardous fuels reduction projects, biochar can be a key piece of the restoration-economics puzzle. Biochar plays a major role in moving excess organic matter from overstocked forest stands to the degraded range, forest, mine, and agricultural soils that need it. Biochar has several unique chemical and physical properties that make it very useful for retaining nutrients and water and improving soil conditions. It can be used to restore forest, range, or mine soils by adding a high carbon product. Biochar applications can also be a vehicle for carbon sequestration made from renewable and sustainable woody biomass. For these reasons, biochar has the potential to be a valuable by-product of fuels reduction and restoration efforts, creating a beneficial resource out of materials that would otherwise go to waste.

This “A-Z guide” highlights recent Rocky Mountain Research Station (RMRS) science and covers methods to make biochar on site, including using piles, kilns, and air curtain burners. It also details three uses for biochar (agricultural, forest restoration, and mine land reclamation), and methods for application, including biochar spreaders.

For land managers seeking solutions for implementing grassland restoration projects and hazardous fuels reduction projects, biochar is a promising product that can be the cornerstone of an organic matter redistribution system. In this photo, biochar is produced by the CharBoss, a mobile biochar processing air curtain burner. USDA photo by Darcy Weseman.

by-product of forest management activities. Forest restoration projects alone are not always financially feasible for land managers. Thinning and other restoration activities often produce large quantities of low-value materials, including small-diameter wood. By producing marketable products such as biochar from these materials that would otherwise go to waste, projects can become more affordable and efforts to reduce wildfire risk can be more cost effective.

In fire-prone forests, managers can use "in woods" processing methods to thin forest stands for fuels management and then convert the wood to biochar on-site to increase soil carbon. In the west, biochar could generate income that pays to move biomass out of forests and into industries and locations that can utilize woody biomass and residuals. Creating and selling biochar in or near forested lands can also support rural economies.

The six primary markets for biochar are (1) large-scale agriculture and livestock industry, (2) forest and rangeland management (e.g., through postfire vegetation responses), (3) mine land reclamation, (4) urban forests and golf courses, (5) horticulture, forest nursery, gardening, and vegetable production, and (6) industrial applications (e.g., activated carbon). Beyond these, innovations are occurring, and markets are developing in water treatment applications and building materials.

B Biochar—How It's Made

Piles

Following restoration or fuel reduction treatments, leftover biomass is often collected into piles and left to decompose or utilized for burning. However, traditional slash pile burning can damage the soil underneath caused by high-intensity heat in a concentrated area, leading to a need for even more restoration action. Alternative biomass removal options like changing the way slash piles are constructed or using kilns or air curtain burners provide forest managers opportunities to not only remove unwanted biomass but also to benefit from the biochar created in the process.

Scientists Debbie Page-Dumroese (from the Rocky Mountain Research Station) and Matt Busse (from the Pacific Southwest Research Station) collaborated with Forest Service managers from the Pacific Northwest Region, including woody biomass coordinator Jim Archuleta and air quality specialist Rick Graw, to develop an alternative method for building slash piles. Their goals were to reduce the amount, extent, and duration of soil impacts from burning and to create more charcoal for use in soil

Traditional slash pile burning can damage soil, leading to a need for follow-up site rehabilitation. New, alternative biomass removal options like changing the way slash piles are constructed can prevent damage and create beneficial biochar in the process. USDA Forest Service photo.

restoration in or near the piles. To maximize the creation of charcoal, burn piles should be elevated above the soil surface on large logs, with smaller material piled perpendicularly on top. Grapplers can then be used to build a pile on the base logs. If the piles are built so they can be burned from the top, then a "flame cap" develops that reduces particulate and smoke emissions.

Kilns are widely used for small-scale projects where open burning is restricted. Kilns contain wood and fire and when burned they also develop a flame cap to reduce emissions compared to pile burns and wildfire. Kilns vary in size from small (3 ft diameter circular kiln) to large (12 ft long x 5 ft wide x 5 ft deep). Wood should be dried about 6–12 months after harvest before burning in piles or kilns.

When open burning in kilns or slash piles, keeping a flame cap across the top of the burning material will reduce smoke and particulates. Courtesy photo by Kelpie Wilson of Wilson Biochar.

Mobile Biochar Processing and the CharBoss

Air curtain burners, also called air curtain incinerators or fireboxes, are another method for onsite biochar production. Page-Dumroese, Forest Service managers, and the U.S. Biochar Initiative worked with Air Burner Inc. to innovate ways to create useful biochar from woody biomass by using the air burner concept. The team was recently awarded a patent for their mobile biochar production system designed for their air curtain burner. The new system is called the CharBoss. Page-Dumroese says, "Mobile processing of woody residues into

The CharBoss is an air curtain burner-style mobile biochar production machine that can consume material from most burn piles with minimal to no preparation. USDA photo by Darcy Weseman.

biochar means that there will be less open burning resulting in fewer slash piles burned, less smoke and particulates emitted, and ultimately a higher value product that can increase forest health and soil resilience."

The CharBoss has fewer size and moisture content limitations than existing mobile biochar production machines, and it can consume material from most burn piles with minimal to no preparation. The new technology immediately quenches the coals to reduce the risk of fire and increase the rate of application or transport to another site. The CharBoss burns at a rate of 1 to 2 tons per hour.

Page-Dumroese says, "Using mobile processing helps rural economies by providing a way to get people into the woods doing forest restoration, applying biochar to forest soils, or using it to reclaim local abandoned mine sites." Income from jobs supported by forest restoration and other treatment projects goes on to support more jobs in local communities. Forest treatments and the application of biochar also result in nonmarket, but still very real, benefits or values to people and communities. Among those values are: healthier and more resilient forests and soils, better air quality and reduced incidence of air pollution driven health problems, reduced runoff and soil erosion, reduced risk of catastrophic wildfires, and carbon sequestration.

Carbon Sequestration and Biochar

Biochar can be used as a tool to mitigate climate change. When biochar is applied to the soil, it rapidly sequesters carbon below ground and keeps it there, thanks to its resistance to microbial

BioChar—Rocky Mountain Research Station

For landowners and agencies seeking to implement grassland restoration projects and hazardous fuels reduction projects, biochar can be a key piece of the restoration-economics puzzle. Biochar plays a major role in moving excess organic matter from overstocked forest stands to the degraded range, forest, mine, and agricultural soils that need it. Biochar has several unique chemical and physical properties that make it very useful for retaining nutrients and water and improving soil conditions. It can be used to restore forest, range, or mine soils by adding a high carbon product. Biochar applications can also be a vehicle for carbon sequestration made from renewable and sustainable woody biomass. For these reasons, biochar has the potential to be a valuable by-product of fuels reduction and restoration efforts, creating a beneficial resource out of materials that would otherwise go to waste. Visit this Vimeo Showcase to see the CharBoss in action.

decomposition and long residence time. Naturally occurring charcoal from wildfires and human-created charcoal-rich soils can last for hundreds to thousands of years.

Biochar has variable effects on greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) flux when measured in agricultural soil, where biochar is mixed into the soil profile. A recent Rocky Mountain Research Station study of biochar in forest soils by Page-Dumroese and other scientists measured greenhouse gas emissions, soil carbon content, and tree growth at managed forest sites in Idaho, Montana, and Oregon. They found that forest soils amended with biochar had a 41 percent increase in soil carbon content with no negative impacts to the surrounding forest.

Applications of biochar to forest sites do not have long-term detrimental impacts on greenhouse gas emissions and tree growth. At the same time, amended soils contain more carbon than soils without biochar. Therefore, applying biochar to forest soils can be a climate mitigation tool that will sequester carbon and will not adversely affect soil greenhouse gas emissions or conifer diameter growth in the western United States.

D Deliver the Benefits—How and Where to Apply Biochar

Agriculture

Biochar can benefit agriculture production at many scales, from nursery applications to large fields. Biochar provides nursery managers with opportunities to produce seedlings more sustainably, particularly by reducing irrigation inputs. In fields, biochar combined with animal manure or other composts can be more effective at improving crop production than biochar alone. Broadcast application of biochar may not be needed; instead, it can be banded into agricultural fields or only applied to highly compacted or contaminated soils. Crop yields have been shown to increase 10 to 42 percent with biochar additions, with the greatest increases on low-nutrient soils. On agricultural soils, it is critical to ensure that biochar is tailored to meet site-specific needs.

Forest Roads, Postharvest Treatment

Biochar can be used to rehabilitate log landings and skid trails postharvest or obliterate illegal or decommissioned roadbeds. Successful soil restoration

Manager Perspectives:
Jim Archuleta, Forest Service Region 6, Regional Biomass and Wood Innovation Coordinator, Umatilla National Forest

Jim Archuleta works with Forest Service partners to monetize woody debris for State and Private Forestry projects. Through collaboration with Debbie Page-Dumroese from the Rocky Mountain Research Station, Jim's team has been awarded two patents for mobile machinery to do in-woods manufacturing of biochar.

In 2016, the collaborative team began working with Air Burners Inc. to create the mobile biochar air curtain burner, CharBoss. The CharBoss can be deployed by timber purchasers to avoid brush disposal deposits and to reduce wildfire ignition risk outside of normal burn windows when the material is wet. Jim looks forward to future adaptations of the CharBoss for unique applications, such as the elimination of invasive plants and unwanted pathogen vectors through high-temperature burning.

Addressing Biochar Challenges

"The most difficult aspect of biochar production is air regulations. Capturing charcoal while producing biochar can limit the amount of fine particulate matter (PM2.5), as regulated by the Clean Air Act. When capturing charcoal before it is reduced to ash, the regulations are written to regulate equipment over effects," Jim says. "Bringing regulators into the process early has been the most helpful. This is the one case where it is best to ask for permission over forgiveness."

Jim's Tips for Land Managers

- *Your biomass has value, either as a product for a consumer or as an application to help you solve your land management issues.*
- *Biochar effectively augments soil organic matter. The increase in soil organic matter can also increase water storage and available water to keep vegetation green longer, which keeps wildlife and livestock out of riparian areas and reduces erosion and overland flow.*

combines ripping the compacted soil layer followed by biochar incorporation. Rates of biochar use range from 2 to 10 tons/acre. Biochar improves waters holding capacity of soil, can reduce invasive species colonization, and keeps the compacted soil layer from recompacting. Sites with biochar additions often experience improved native vegetation success and increases in pollinator plants and insects due to the enhanced soil health.

Abandoned Mine Land Restoration

Biochar can be a part of mine land remediation to improve soil conditions. Biochar application on abandoned mine land can result in increasing mine soil, tailings, and waste rock pH, cation exchange capacity, water-holding capacity, organic matter content, nitrate concentration, biological N-fixation rates, and phosphatase and dehydrogenase activity. Biochar has been shown to bind heavy metals and toxins, keeping them out of the groundwater. The increased soil productivity after biochar application results in revegetation, which helps reduce erosion. Biochar and wood chips applied alone or in combination can be applied to mine soils that are degraded, but the amount varies according to the site conditions. Biochar results might not be seen immediately, but there is typically a detectable soil organic matter, pH, and water retention improvement along with decreased soil erosion 2 years after biochar applications of 10 to 20 tons/acre when combined with native plant seeding or seedling planting. If the goal of the restoration activity is to increase soil carbon from nearly zero to the normal regional level, the amount of biochar may be higher than 30 tons/acre and may need to be applied in increments, so that the soil is not "overloaded" with biochar. Therefore, one application may not be sufficient when mixed with the residual soil during mine land restoration, but soil and biochar testing will determine site-specific needs.

A high-capacity biochar spreader that can be mounted on a log forwarder and used on skid trails and log landings to distribute biochar has been developed by RMRS scientists and the Missoula Technology and Development Center. USDA Forest Service photo.

How to Apply Biochar

Biochar can be applied with salt, manure, or fertilizer spreaders. All of these can be adapted for mine, agricultural, range, or forest use, depending on the need. Small scale application doesn't require machinery for application—only a strong back, a bucket or shovel, and a rake.

One limitation of applying biochar across larger scales has been the inability to spread the biochar using conventional logging equipment. Applying biochar to forest sites can be problematic and costly because of the need to keep the forest floor as undisturbed as possible during and after forest operations.

Know Your pH

Using woody biomass to create biochar results in a product that has a pH of approximately 7.0–8.0. However, some tree species or woody shrubs converted to biochar result in biochar with very high or very low pH—so it's important to know your biochar and your soil before application.

The table below presents examples of varying biochar pH when different feedstocks are converted to biochar using the same conditions.

EXAMPLE pH OF BIOCHAR FROM DIFFERENT FEEDSTOCKS

Feedstock	Biochar pH
Madrone (*Arbutus menziesii*)	4.9
Hog fuel mixed conifer hog fuel	7.4
Mixed conifer-fire salvage	7.5
Scotch broom (*Cytisus scoparius*)	7.5
Oak (*Quercus spp.*)	7.9
Douglas-fir fire salvage	8.1
Mixed conifer	8.1
Western red cedar (*Thuja plicata*)	8.7

Building Biochar into Local Economies

In rural communities, where timber harvesting and wood product industries have historically been sources of jobs and other economic activity, the development of a local biochar market can create and support local jobs in the wood products industry, from harvesting woody biomass to making biochar to delivering and applying the biochar.

Research from Rocky Mountain Research Station economist Dan McCollum and colleagues highlights how a variety of potential uses of woody biomass, including biochar, can generate tangible benefits through jobs and rural economic activity. Biochar production facilities can be more economically feasible than other wood product operations because they can operate at a range of scales and complexities. Facilities can be distributed across multiple rural communities, spreading economic activity and benefits where there are sources of woody biomass.

"In-forest" production of biochar using mobile equipment like the CharBoss has several economic advantages—such as negating the need to transport low-value material to offsite production facilities—and the biochar produced can be economically used to restore or enhance soil productivity onsite. The CharBoss, however, is not able to take advantage of coproducts from the process of biochar production such as heat or synthesis gas. Here, the Forest Service is exploring another potential piece of the biomass puzzle—creating coproducts at operational sites called Biomass Utilization Campuses (BUCs).

A BUC is a collection of companies that make different products but have a common feedstock—in this case, woody biomass. Biochar can be produced at BUCs while at the same time capturing coproducts like heat and synthesis gas to produce electricity or precursors to industrial chemicals. The diversity of producers located on the BUC leads to more complete and efficient use of the woody biomass. When a market for one woody biomass product is strong, more feedstock can be directed to that product and diverted from one facing a weak market. Utilization of coproducts allows a situation where not every coproduct needs to be individually profitable, as long as the portfolio of coproducts is profitable.

Biochar production can also provide social benefits. When biomass is removed from forests to create biochar, it contributes to forest restoration and improved forest health, reduces the risk of catastrophic wildfire, and reduces hazards resulting from insect and disease killed trees. The social acceptability of biomass removal and utilization from national forests was considered in this 2015 study. Work on social acceptability continues in ongoing research. Learn more about McCollum's work with biochar by watching his webinar presentations about biochar and biochar uses.

Application by hand is difficult and dusty. The Missoula Technology and Development Center (a unit of the Forest Service Engineering Staff that makes equipment, information, concepts, and ideas available to agencies for better land management) and Rocky Mountain Research Station scientists including research forester Nate Anderson and Debbie Page-Dumroese have developed and tested a high-capacity biochar spreader that can be mounted on a log forwarder and used on skid trails and log landings to distribute biochar. This spreader can be modified to carry a variety of payloads and adjusted to apply biochar at many different spread rates.

Manager Perspectives:
Jessie Salix, Forest Botanist on the Beaverhead-Deerlodge National Forest

Jessie Salix has been a forest botanist on the Beaverhead-Deerlodge National Forest for 11 years. She is actively seeking ways to incorporate biochar into the work conducted on the forest.

Testing Biochar Applications on Burned Areas

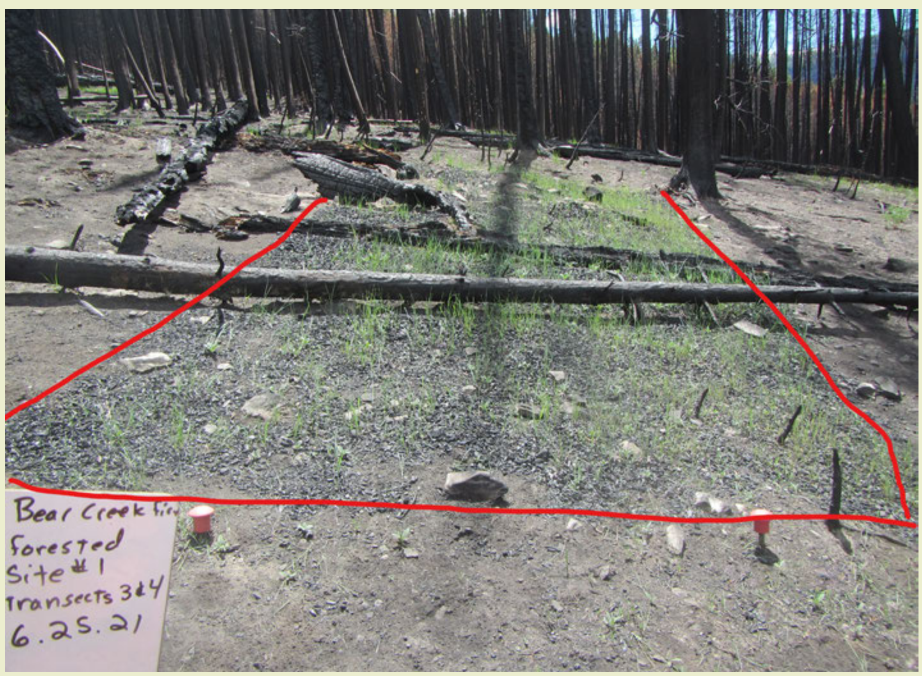
In 2020, following the Bear Creek Fire, the Beaverhead-Deerlodge Burned Area Emergency Response (BAER) team acquired two large bags of biochar to conduct a fall seeding biochar field trial. The BAER team and forest managers wanted to learn whether biochar applied at 10 tons/acre increased vegetation cover following wildfire.

To conduct the study, Salix and her team identified three sites. Within each site, three 10 by 150-ft strips were identified, and each belt was treated with seed and annual grasses, seed only, or no seed (control). Two of the sites are sagebrush ecosystems and the third is forested. On the forested site and one sagebrush site, seed was applied to the entirety of the identified strips, but 10 tons/acre of biochar was applied to only a 20-ft section of the strip. When the first data were collected in July 2021, the team found that the seeds were established only in the area where they were applied with biochar, showing the benefit of biochar application on their land. Data will be collected yearly for the next 5 years.

Salix and her team also initiated a spring seeding biochar trial in 2021 in the same fire area to compare three different rates of biochar application regarding seeding success: 5 tons/acre, 10 tons/acre, and 20 tons/acre.

Pros and Cons of Biochar Applications

Salix says many managers are very excited to try out biochar applications on lands they manage. There is local interest in air curtain burners, and her team looks forward to when they may be able to use one. However, she says that finding local sources of biochar can be difficult in the West because there are still few people making it, but many are interested in applications. “If you make it, they will come,” Salix says. “I’m guessing that if more folks start making biochar that we will be able to incorporate it more into our everyday restoration needs. If there is a curtain burner around, we will use it! Second, even small applications for pollinator islands may be a good option to get things going. Or having a demonstration garden at an office. People need to see it to believe it.”



10 tons/acre of biochar was applied to only the first 20 feet of the 150-ft strip. This photo of a forested site captures the first 20 feet of the strip where biochar was applied denoted with red lines. The seed establishment stops where the biochar application ends. USDA Forest Service photo by Jessie Salix.

The spreader works well on slopes and flat ground and easily navigates difficult ground conditions. It also offers a variety of settings to accommodate different application requirements such as a narrow spreader to cover skid trails or a wider application spread to cover log landings or larger within-stand areas. This technique has been used in research applications but has yet to be implemented in the field. The developers of this biochar spreading equipment are looking for opportunities to use it in forest applications in both research and land management projects. If you would like to use this equipment, contact Nate Anderson.

I Applied Biochar—Now What?

Stand back! Feel good about building soil health. Biochar mixed into the soil shows immediate benefits to agricultural and mine soils, but when applied to forest soils that have an intact surface organic horizon, it takes a couple of years for it to work its way into the soil. Soils that are repeatedly plowed may require additional biochar application at a future time, but more research is needed on this application.

Key Findings/Management Implications

- Biochar can reduce wildfire risk by removing low- or no-value small diameter wood and slash material while also improving soil health.
- Biochar production can have environmental and economic benefits in a variety of applications including agriculture, forest, and rangeland management, mine reclamation, and more, such as increased soil organic matter, increased soil water holding capacity, and creation of a marketable product from otherwise unusable material.
- Alternative biomass removal options like changing the way slash piles are constructed or using kilns or air curtain burners provide forest managers with opportunities at a variety of scales to not only remove unwanted biomass but to benefit from the biochar created in the process.
- Biochar can be applied with salt, manure, or fertilizer spreaders. All of these can be adapted for mine, agricultural, range, or forest use, depending on the need.
- Biochar applications can be a vehicle to mitigate climate change by largely increasing soil carbon content using renewable and sustainable woody biomass with no negative impacts on the surrounding forest.
- Biochar is slow to degrade and provides long-term carbon sequestration and soil health improvements.

Zero in on some FURTHER READING

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Scientists and Manager Profiles

The following individuals were instrumental in the creation of this Bulletin:

Deborah S. Page-Dumroese is a senior scientist and research soil scientist with research focused on belowground processes, soil disturbance monitoring, and environmental consequences of biomass utilization and biochar additions. Debbie is also part of the North American Long-Term Productivity Study, which involves intensive pre- and post-harvest sampling, and a commitment to ensure long-term data collection.

Nate Anderson is a research forester who researches the intersection of ecology, economics, and public policy. He pursues applied research that bridges the gap between basic scientific inquiry and widespread adoption of new approaches and technologies for sustainable natural resources management. His current research focuses on forest management and economics, forest operations, climate change, and biomass.

Dan McCollum is an economist whose research focuses broadly on the economic valuation of nonmarket goods and natural resources. His recent work has been aimed at more effectively incorporating the public and their preferences into land management planning deliberations and decisions.

Jim Archuleta is the regional biomass and wood innovation coordinator for the USDA Forest Service Region 6 in Oregon and Washington states.

Jessie Salix is a forest botanist on the Beaverhead-Deerlodge National Forest, looking for ways to apply biochar into the national forest.

"Using mobile processing helps rural economies by providing a way to get people into the woods doing forest restoration, applying biochar to forest soils, or using it to reclaim local abandoned mine sites."

–Debbie Page-Dumroese

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About the Science You Can Use Bulletin

The purpose of SYCU is to provide scientific information to people who make and influence decisions about managing land.

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