CHAPTER 6:

Centralized Biochar Production Facilities

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INTRODUCTION

In this chapter we describe the state of centralized production facilities and the challenges and opportunities for centralized biochar production. The authors considered strategies to develop centralized production, considering parameters such as markets, technology development, product development, environmental emissions, carbon efficiency, and education and training. Funding and investment opportunities were considered including developing an action plan, successful business models such as private public partnerships, strategic partnerships, and financial tools.

Centralized Facilities

Centralized facilities carbonize biomass to biochar at large scales and process it into value-added products. Centralized processing involves supplying biomass to the facilities and converting the biomass to biochar as a main product or as a co-product of electrical energy such as at a power plant, and/or heat energy such as might be used to cure lumber or dry grains (Miles 2021). Industrial-scale biomass operations (usually more than 100,000 tons per year [TPY] biomass feedstocks resulting in more than 30,000 TPY of biochar [300,000 cubic yards, CY]) require high capital investment to build large facilities, purchase several machines, and maintain a large operations crew. One-way hauling distances to these facilities are typically less than 100 miles.

There are examples of facilities of this scale in the U.S. and in the Pacific Northwest (PNW) region. The largest biochar plant in the U.S. (*National Carbon Technologies* in Minnesota) has the capacity to convert 150,000 tons of dry biomass to 50,000 tons of biochar, annually. The only charcoal plant in the PNW region (*Kingsford* in Springfield, Oregon) has capacity to convert 150,000 tons of wood residues to 50,000 tons charcoal for barbeque briquettes, annually. Now that some biochar markets have developed, the plant is making some biochar for soil application. The largest centralized biochar plant in the region, operated by the *Karr Group* in Onalaska, Washington, converts 20,000 TPY of mill residues to biochar.

Feedstock from Forests

Forest fuels removal to reduce the risk of wildfires could result in large quantities of biomass which could be converted to biochar. In many locations, the need for processing large quantities of biomass will be best met with centralized facilities. For example, California may have 9 million dry tons of agricultural residues and 14 million tons of forest residues available each year which could be converted to low carbon fuels while supplying substantial quantities of feedstock for biochar production (Williams et al. 2015; Breunig et al. 2019). Large-scale centralized facilities are needed to produce the quantities of biochar required to improve soil health, improve water quality, enhance compost, improve soils, and build green infrastructure in the region. Centralized facilities should have the economies of scale to make biochar at affordable prices for use on cropland and improvement of degraded land. A facility producing 50,000 TPY of biochar could supply enough biochar to treat 1,000,000 tons of compost at 5% (by weight) or treat 10,000 acres at 5 tons biochar per acre. If 50% of California's forest residues were converted to biochar, it would take 320 years until all of California's agricultural land would have received an application of biochar equivalent to 1% (w/w) in the top 6 inches of soil (Hunt & McIntosh 2019).

Feedstock from Other Woody and Agricultural Sources

Existing wood products industry, construction and demolition industries, biomass energy facilities, wood mills, and agricultural processing facilities provide an abundance of residues. The majority of mill residues in Oregon and Washington are used in engineered wood products. In Oregon, just 14% of mill residues are used for energy and only 0.01% of mill residues are not used (Oregon Department of Energy n.d.). Centralized facilities to process forest and mill residues could be co-located at existing energy plants, or at wood mill and agricultural processing facilities where they could share infrastructure, such as fuel transportation, storage, sizing, drying, and handling. Co-location at wood mills can take advantage of the availability of woody feedstocks, existing boilers that can be adapted to produce biochar, and established transportation infrastructure for wood and energy production processes. For more information, see *Chapter 9: Biomass Supply* and *Chapter 10: Biomass Handling*.

Biochar Recovery from Biomass Boilers

Some biomass boilers in the region recover biochar from the "fly ash" (small particles < 6 mm) captured from effluent gas streams or from "bottom ash" (particles that are too large to go up the stack and contain a higher carbon content than fly ash). Fly ash and bottom ash can be collected from boilers and, with some processing, can yield high quality biochar. Biomass boilers can be altered to produce more high carbon ash (Jensen & Moller 2018). When the carbon is harvested as biochar rather than burned as fuel, the outcome is either a correlated increase in feedstock throughput (to maintain the same energy output), or a correlated decrease in energy output. Since competing energy sources such as natural gas, wind, and solar have reduced the prices of energy below the breakeven point for biomass, converting biomass boilers to produce biochar could be attractive if biochar markets expand.

For example, *Biomass One* (Medford, Oregon; Figure 6.1) is a biomass power plant generating 32.5 megawatt electrical (MWe) (28.5 MWe goes to the grid). This plant consumes 200,000 TPY of dry biomass and can recover 50,000 cubic yards (CY) of biochar

Figure 6.1. *Biomass One in Medford, Oregon is an example of a centralized production facility. Production plant shown in background with hogfuel in foreground and supersacks of finished biochar. (Photo: Karl Strahl)*

annually. Process modifications allow Biomass One to recover biochar midstream, allowing a higher yield of biochar than if it were recovered through fly ash.

Opportunities exist to upgrade several plants to recover biochar. Biochar could be produced along with energy, or fuels in the case of torrefaction, a mild form of pyrolysis at temperatures typically between 200 and 320 °C. Boilers or torrefaction plants could add carbonizers and recover excess heat to dry fiber or generate steam. Wood pellet mills are centralized facilities that could make and use biochar to generate heat for their wood dryers. Concentrated agricultural residues like oat hulls also present opportunities for centralized production of biochar.

Compost as an Endpoint

Composting is an important strategy for management of urban green waste, food, and farm wastes. The composting industry is beginning to learn the benefits of adding biochar to improve the quality and reduce emissions from compost (see *Chapter 7: Biochar Produced and Utilized at Municipal Compost Facilities*, for further discussion of integrating biochar with compost). California, Washington, and Oregon rank among the top states in terms of organic waste diversion to composting, with amounts in these three states totaling 7.4 million tons per year (ILSR 2014; See *Chapter 9: Biomass Supply* for state agency data). A facility composting 80,000 tons of food and green waste can use 40,000 CY (4,000 dry tons) of biochar for inclusion in the composting process (Compost 2020).

Demand for biochar will increase as green infrastructure and environmental remediation grow in the region. Remediation of abandoned mines is another potential demand for large quantities of biochar. The Walker Mine in California could consume 2,500 CY (300 tons) of biochar (Larry Swan, USFS Region 5, personal communication).

A large, centralized facility could provide enough capacity to offer multiple benefits including:

- Reduction of fire hazards arising from overcrowded forests;
- Associated major benefits in fine particle (PM2.5) reductions and health impacts due to wildfire reduction;
- Reduction/elimination of open burning in agriculture;
- Increase in rural area employment and investment;
- Expansion of baseload renewable electric power;
- Retention within the region of monies spent on carbon credits (generating local employment and economic benefits) rather than sending those funds abroad for renewable fuels from imported feedstocks;
- Reduction in costs of carbon credits due to expanded supply in both Low Carbon Fuel Standards and cap and trade, lowering costs for all consumers across the economy; and
- Reduction of water use and drought-associated crop risk.

The following sections will explore these benefits and describe: 1) challenges for centralized processing facilities, 2) strategies to develop centralized biochar processing, and 3) opportunities for investment in research and infrastructure. Strategies include market development, with a focus on carbon markets, technology development, education, and training. Funding and investment opportunities include developing an action plan, initiating successful business models such as cooperative arrangements, public/private partnerships, and strategic partnerships, and developing decision making tools and financial instruments.

CHALLENGES FOR CENTRALIZED PROCESSING

Scaling up biochar production in centralized facilities is challenged by limited markets, high transport cost of feedstocks, the small scale of the existing industry, and large capital requirements.

Current Markets and Market Impediments for Biochar

Some current markets for biochar are soil amendments for gardens and landscaping where volumes are low and prices are high, so biochars are often more expensive than farmers can afford. Demand can be unstable as markets grow, so a large plant must absorb swings in demand and value of finished product. The production capacity of centralized biochar facilities may be greater than current biochar demand. A large Midwest producer (*National Carbon Technologies*) supplies charcoal produced without fossil fuel energy to the metals industry as a way to subsidize their biochar production. While the benefits of biochar can be demonstrated, developers of centralized facilities are challenged to convince investors that markets are sufficient to support investment in new, larger facilities. Current markets and monetized benefits (e.g., carbon credits, subsidies) are not large enough to generate sufficient cash flow to finance centralized facilities. For carbon markets to evolve, investors require a biochar carbon accounting protocol and guaranteed offtake agreements. Public subsidies have been suggested to stimulate market demand and to enable new plants to supply products during the gaps in demand that occur during new product acceptance. Market development through policy often takes a long time. Biochar has not taken advantage of current carbon markets and policies, such as cap and trade and Low Carbon Fuel Standards (LCFS), even though waste grains, fats, and oils are being imported to supply this market.

Scale, Capital Cost, and Feedstock Transport

The biochar industry is currently small. There are 45 suppliers in the region: 25 in California, 11 in Oregon, and nine in Washington. The industry is stratified with a few large producers and many small producers, many of which broker for larger producers. Much of the biochar is produced as a byproduct at only a few of the existing bioenergy plants in Washington, Oregon, and California. Some biochar is imported into the region from Colorado (U.S. Biochar Initiative, unpublished). Small producers have limited access to capital and must rely on market guarantees to finance investments and on sales to fund operations. With limited sales volumes, producers must cross the so called "valley of death" (the period of time between startup and profitability) in which there is limited access to capital. Centralized facilities are large investments that require demonstration of guaranteed benefits. Capital requirements are large for centralized facilities due to equipment size, the industrial nature of production, and the pollution control equipment required in an industrial plant. Investors may also be concerned about long term supplies of feedstocks for centralized facilities but estimates of biomass availability are large as detailed in *Chapter 9: Biomass Supply*.

Despite the abundance of potential feedstocks, the delivered cost of feedstocks like forest residues can be high relative to their value. Possible solutions to this issue, including the conversion of forest residues into a variety of products in a Biomass Utilization Campus, are discussed later in this chapter.

STRATEGIES FOR CENTRALIZED PROCESSING

Here we discuss strategies for developing centralized processing facilities. These strategies include: 1) increasing supply of low-cost feedstock, 2) developing appropriate production technologies, 3) further developing products, 4) expanding education and training, and 5) tapping into carbon markets.

Increasing Supply of Low-Cost Feedstock

Biochar feedstocks are abundant and market development by existing suppliers has shown promise in disposal and reuse of urban wood and oversized wood ("overs") from composting. CalRecyle estimates that 3.8 million tons of urban wood are available in addition to 1.3 million tons currently used for bioenergy (CalRecyle n.d.). The urban wood could be converted to more than a million tons of biochar. Since urban wood is delivered with a tipping fee, the biochar could potentially be delivered at a lower cost to agricultural consumers. Compost producers often pay high tipping fees to dispose of oversize wood ("overs") from composting. Much of this material is landfilled. Large quantities of compost overs are available from green waste and food waste compost facilities in the region that could supply centralized biochar facilities.

Another potential feedstock for centralized biochar facilities is forest residues from wildfire fuel reduction efforts. California, Washington, and Oregon are among the top ten states with significant risk of wildfire. An estimated 2 million homes in California are threatened by wildfire (Insurance Information Institute n.d.). These states already have some of the infrastructure to harvest forest fuels and deliver them to centralized bioenergy facilities. Biochar production and utilization offers a pathway to offset some of the cost of forest fuels reduction that currently burdens federal, state, and private entities. Centralized facilities can offer partnerships for large-scale forest biomass management.

Current estimates show that forest biomass in California could generate 1.5 million tons of biochar annually which could amend 160,000 acres of land at an application rate of 9 tons per acre, roughly equivalent to 1% soil organic matter in the top 6 inches of soil. That annual application would add 13,000 acre-feet of water holding capacity and could achieve a carbon drawdown of 3.75 million tons of carbon dioxide equivalent (CO_2e) at a cost of $35 per ton when considering carbon dioxide reduction and emission reduction combined (Hunt & McIntosh 2019). A subsidy for forest restoration or fire hazard reduction could be provided to ensure a long-term market, similar to the "Standard Offer No.4" contracts in California that guaranteed a fixed power price for a period of ten years (California Code).

Production Technology Development

The production of biochar at large scale can in principle be accomplished in combination with other products (heat, syngas, liquid fuel) or by targeting the production of biochar alone. This can be achieved with many types of designs, each of which consider varying feeding types, heating mechanisms, construction materials, and reactor positions (see *Chapter 11: Biochar Production*.) From an economic standpoint, heat and biochar production are most efficiently achieved today with modified Stoker boilers. The production of biochar and gases is typically achieved with the use of gasifiers at temperatures over 800 °C. High yields of liquids (over 70% by weight) and biochar are accomplished with so-called fast pyrolysis reactors. In practice, most fast pyrolysis reactors use the biochar produced as a source of internal heat. Slow pyrolysis is by far today the most commonly used technology for biochar production and the most efficient in terms of the fraction of biomass carbon converted to biochar. However, at small scale facilities, the liquid produced can be released to the atmosphere in the form of highly visible aerosols and vapors (i.e., smoke), harming the environment and contributing to the negative public perception of this technology.

The yield of biochar can be maximized by new carbonization technologies (e.g., using high pressure or strong acids; T.R. Miles, personal communication). There are ongoing efforts in the U.S. and Canada to scale up these technologies. Further modifications to Stoker grate boilers also have the potential to increase the fraction of biochar produced for a given level of bioenergy output (K. Strahl, Biomass One, personal communication). Our assessment is that in the years to come we will see an increase in biochar and power production in modified Stoker boilers and also major developments in dedicated technologies maximizing biochar production (slow pyrolysis with pollution control or new carbonization methods). Centralized facilities provide opportunities for co-processing, co-generation, and large-scale production of value-added biochar products.

Product Development

The availability of large volumes of a low-cost and sustainable carbon feedstock could catalyze the creation of a "Green Carbon Economy." Centralized biochar production at new or existing facilities could be a major source of low-cost carbon for the development of value-added products.

Expansion of markets will involve companies specialized in carbon products for two separate types of markets: 1) low-cost/high-volume and 2) high-cost/low-volume markets.

Examples of low-cost/high-volume markets are agricultural soil amendments; horticultural applications where biochar can be used as a substitute for peat moss, perlite, or vermiculite; animal feed; construction materials; and environmental services, such as stormwater filtration or wastewater treatment (Boehm et al. 2020; Imhoff & Nakhli 2017; Miles et al. 2016; MPCA n.d.; Ulrich et al. 2015). Biochar suppliers estimate that expanding existing markets could create sufficient demand to support centralized facilities (T.R. Miles, personal communication). The standards and specifications needed to expand markets for these applications are still in development in Washington, California, Delaware, and Minnesota (T.R. Miles, personal communication).

Examples of high-cost/low-volume markets include applications for highly functionalized carbons such as carbon nanotubes, carbon gels, and carbon fibers that can be used as catalysts, and in fuel cells, batteries, and electrodes. For centuries carbon has also been used as the preferred reducing agent in some metallurgic technologies.

Some of the modifications widely used today to enhance carbon performance include increasing surface area through physical activation (with carbon dioxide [CO_2] or steam), oxidation with strong acids or oxidants (oxygen [O_2], ozone [O_3], hydrogen peroxide [H_2O_2]) to form surface carboxyl and carbonyl functional groups, and nitrogen-doping (reaction with ammonia [NH_3] or co-processing with nitrogen sources). Other functionalization strategies such as co-composting and the addition of metals and enzymes have also been explored. Because of the vast number of potential applications and products, it would be highly advantageous to catalyze the creation of carbon companies specializing in targeted products and markets.

Education and Training

In order to deploy improvements in production technology to expand products, it will be necessary to train a large number of specialists with skills that will enable them to work in this industry. We need to develop teaching tools for high school students, undergraduate students, graduate students, and practitioners. It will be very important to take advantage of on-line tools to prepare courses with hands-on tasks to reach thousands of students around the world in the production and use of carbon products. Associations with groups such as Chemists Without Borders, the United States Biochar Initiative (USBI), and the International Biochar Initiative (IBI) could be very helpful in this effort.

Carbon Markets

The widespread development of carbon markets for biochar would strengthen the case for large, centralized facilities to meet the increased demand. At the time of this report, Carbon Future estimated that the net average value of biochar is about 2.5 tons CO_2e per ton of biochar (Carbon Future n.d.). Thus, a facility producing 50,000 TPY of biochar would sequester carbon equal to 125,000 tons of CO_2e (50,000 tons × 2.5 tons CO_2e), which at a (hopeful) future price of $70 per ton CO_2e could generate revenues of $8.8 million per year. That is equal to $175 per ton of biochar or $44 per ton of forest residues delivered to the plant (assuming 4 tons feedstock per ton biochar). If the 50,000 tons of biochar were sold at $500 per ton ($50 per CY, $0.25 per lb), this would generate $25 million per year in gross revenue. If energy was recovered from the plant, it could be sold as heat for an additional $1 million (107,000 MMBtu × $10 per MMBtu) or power for an additional $2.7 million (6 MWe × 0.85 × 8,760 h × $60 per MW-h). Co-location strategies with existing industries should be pursued whenever possible to reduce capital costs. Co-generation opportunities are critical for heat commercialization.

Centralized facilities can take advantage of the large carbon market demand if products comply with existing standards. In order to access carbon markets, standard biochar characterization methods and protocols must be adopted for multiple uses. Protocols exist and can be used: *Carbon Future*, an emerging carbon market platform, requires either a European Biochar Certificate (EBC) or International Biochar Initiative (IBI) certificate for verification. *Puro Earth*, from Finland, is another voluntary carbon market which will only accept biochar that meets the EBC standard.

DEVELOPING AN ACTION PLAN FOR CENTRALIZED BIOCHAR FACILITIES: OPPORTUNITIES, BARRIERS AND RISKS

Modification of Existing Biomass Plants

Biochar production at centralized facilities can be achieved in many ways. One pathway is to modify existing biomass power plants. This method is considered “low hanging fruit,” as it is relatively quick, low cost, and can result in large-scale production of high-quality biochar.

Modification “Lite”

Several biomass power plants in the region burn wood in a furnace combined with a boiler to make steam for electricity generation or heat to dry lumber. They are like giant wood ovens with a continuous supply of wood chips and fresh air burning on a grate. The air flow is strong enough that it pulls out most everything but the rocks and sand that fall through the grate. Caught in the draft is a mixture of biochar and mineral ash. Biochar particles are mechanically removed from the mineral ash for the purpose of being re-burned for their energy value. By modifying the equipment and operating procedures of such a facility, biochar can be separated from the ash and harvested for use as biochar instead of being burned for fuel. The equipment to separate the biochar, including air locks, augers, chain drags, and other biomass handling equipment, are readily available. The methods used are novel but have already proven successful at several facilities. The biochar then needs to be properly stored and wetted before transportation. In this case about 2% of the dry fuel fed to the boiler can be recovered as biochar. This modification can be achieved in approximately 2 to 6 months. A 20 MW biomass plant can potentially recover about 5,000 tons (50,000 CY) of biochar per year.

Modification “Super-Lite”

Sometimes, in certain boilers, when the biochar is not screened from the fine mineral ash but rather is allowed to be dumped out as one “unfiltered” product, it can result in a material with charcoal content that is so high that the “ash” is mostly charcoal (biochar). There are modifications in equipment and changes in operating parameters that can make this approach successful even at facilities where it is not otherwise feasible. The resulting biochar will have a relatively high mineral ash content, which can be beneficial in certain applications. This modification can be achieved in a similar time frame as modification "lite" and recover a comparable quantity of biochar.

Modification "Heavy": Adding A Carbonizer

A separate dryer and carbonizer can be added alongside an existing boiler that is using the technologies previously described. A slow pyrolysis system can be carefully controlled so the quality of the biochar could be tuned to particular market needs. It would recover about 30% of the fuel (45% of the carbon) fed to it as biochar. The dryer and carbonizer would share the fuel delivery, storage, and handling systems with the boiler. A third of the energy in the fuel would be available as fuel gas which could be routed to and burned in the existing boiler. There would be a cost in retrofitting an appropriate burner to the existing boiler, but there would be no change in the pollution control equipment in the boiler, or to the electricity generation equipment associated. The fuel dryer would require emissions control. The plant could produce the same amount of power while consuming additional fuel to convert to biochar. One boiler in the U.S. has been retrofitted with a carbonizer. Carbonizers for this application typically each consume 2 to 6 dry tons of fuel per hour and could produce up to 15,000 tons (150,000 CY) of biochar per year per carbonizer installed. The number of carbonizers installed would depend on the design of the boiler and the biomass plant facility. Addition of this biochar process line, including design, permitting, construction and commissioning, could take from one to three years depending on the location and capacity.

Modification costs vary depending on the existing plant design, the available space, and the topography upon which the facility is built. Modification "super-lite" has been accomplished at one facility with zero additional infrastructure cost. Modification "lite" has been accomplished for as little as $100,000 in machinery and labor, but it could cost between $250,000 and $1,000,000 at most suitable biomass power facilities that are in the range of 10 to 30 MW. Adding a dryer and carbonizer can cost from $3 to $6 million per process line depending on the existing infrastructure and the chosen pyrolysis technology.

Development of Environmental and Economic Studies

The environmental application of wood ash to soils should be reviewed, as it can provide insight into other ways of easily incorporating biochar into various uses. Several million tons of high carbon wood ash generated at biomass power plants have been land-applied in the western region, spanning at least three decades, covering more than a hundred thousand acres. While high carbon wood ash is not the same as what we would normally consider biochar, it includes biochar as a component: high carbon wood ash commonly has a carbon content between 25% and 45%. Ten million tons of high carbon wood ash with an average carbon content of 35%, therefore, is equivalent to 4.1 million tons of a biochar with 85% carbon content. It can be thought of as biochar floating in ash. And though the responses observed immediately after application may be predominantly a result of the mineral and pH influences of the ash, the charcoal fraction is recalcitrant, and its effect can be observed for decades. This becomes clearer as the influence of the ash diminishes; soils with historic wood ash applications are visibly darker (J. Hunt, personal communication).

Environmental studies should be developed to re-examine and re-emphasize the benefits of land applying wood ash. Historically, wood ash from biomass boilers in the U.S. was land applied, however a large portion of wood ash is now landfilled due to changes in regulations that make the boiler owner responsible for adverse impacts of the ash, difficulties with contractors removing ash, and other factors which appear to boiler owners as liabilities (T.R. Miles, personal communication; Risse & Gaskin 2013). Research into the environmental benefits of wood ash application to soil would work to reverse this trend and turn an ostensible liability back into a resource.

The PNW region has both existing infrastructure and an abundance of available agricultural residues and forest fuels. The economic feasibility of converting existing boilers to produce biochar warrants further investigation to determine circumstances and incentives needed to optimize biochar production. In addition to the cost of retrofits, the cost to produce biochar in these facilities is determined by 1) the value of the electrical energy not generated when the recovered biochar is harvested rather than burned as fuel, or 2) the cost of the additional feedstock required to maintain energy output when biochar is harvested rather than burned. These two different scenarios result in different economic outcomes, effectively determining the cost of biochar production as either energy not sold, or extra fuel purchased. Depending on the value of energy and the cost of feedstock, individual facilities can decide how to optimize their operation to maximize revenue. This can and does change seasonally. It could be useful to the industry if a technoeconomic analysis were developed to model biochar production costs in a variety of situations as mentioned above.

Development of Successful Business Models

The difficulty with any endeavor that involves a promising new and substantial market is to persuade knowledgeable investors to take on the initial expense. These investors must be fully aware of the risk involved in the undertaking. For any business model proposing a first-off facility, the capital investment risk is typically large and usually offset by contractual assurances that the facility's product has a guaranteed buyer. From the perspective of the buyer, the risk can be every bit as substantial, especially if there are alternatives to the product or business as usual continues to be viable. Risk is reduced if there are assurances that the production facility has capital financing and competent staff to build and operate the facility. This "chicken and egg" conflict is the conundrum faced by those producing charred woody products such as biochar and torrefied biomass (discussed below). Biochar has market potential as a proven soil amendment that can promote nutrient and water retention in the soil column for agricultural and forest lands while torrefied biomass is now a proven, renewable fuel substitute for fossil coal at power generation stations. Both applications have carbon-neutral to potentially carbon-negative impacts. New markets are evolving for biochar as a method of carbon removal. The impact on production is not clear since prices in the smaller voluntary markets are high compared with the larger regulated markets.

Successful business models for full-scale manufacture of these products should be developed for centralized facilities. Here we describe two possible examples: a Biomass Utilization Campus and a torrefaction/ biochar facility. Options considered include collective ownership models, integrated processing, public-private partnerships, as well as aids and subsidies such as strategic partnerships, policy, and financial instruments, discussed in the next section.

Biomass Utilization Campus

A Biomass Utilization Campus (BUC) is an integrated processing facility to convert solid wood and residues to a variety of value-added products including biochar. It allows for multiple industries to share the cost of harvesting and transportation. Dimensional lumber, round timbers, post/pole, fiber logs, kiln dried firewood, beauty bark and mulches can be produced while residues from these processes can be converted to energy and biochar, all in a centralized facility. Integrated processing in a BUC may allow for the avoidance of a Brush Disposal Deposit within U.S. Forest service timber sales, which could reduce timber sale bid prices. It could potentially have a cumulative benefit to states where timber sales fund infrastructure, schools, and other public services. There are examples of integrated biomass utilization based on stewardship contracts in Oregon. One facility in Wallowa, Oregon, which makes firewood, posts, and poles, will begin to produce biochar as a co-product of heat they generate for their firewood kilns. Demand for the biochar enhanced soil amendment is from their marketing and distribution partners in Washington, Oregon, and California. This model could be expanded with the integration of companies engineering carbon products at centralized facilities.

Public/Private Partnership: Torrefaction/Biochar Facility

The majority of biochar producers in the PNW operate on very small scales and usually as a by-product of a gasification or combustion facility where the produced gases are typically consumed as a fuel to produce electricity. There have been attempts at creating production facilities for torrefied biomass at the rate of 2 to 5 tons per hour but most of these attempts have failed due inadequate funding, lack of contractual offtake, and/or construction delays. One commercial scale facility at 12 tons per hour output is expected to be operational by late 2021 in John Day, Oregon. Upon completion and commissioning, this torrefaction facility will be the only commercial scale torrefaction plant on the planet (*Restoration Fuels*; Figure 6.2). Capital funding for this facility has been provided primarily by the U.S. Endowment for Forestry and Communities (Endowment), a non-profit that is driven by its mission to improve forest health and promote economic development in the forest/ wood products sector. The investment aim is to source the torrefied wood feedstock from overgrown, diseased, and dry inland western forests. Removal of this small diameter, low- to no-value material

Figure 6.2. *Torrefaction system at Restoration Fuels in John Day, Oregon. (Photo: Matt Krumenauer)*

reduces the excess fuel loading that has resulted from nearly a century of forest fire prevention policy. Torrefaction of the green wood is required to increase the energy value and, most importantly, to make the fuel sufficiently friable for crushing in pulverized coal power plants that dominate solid fuel-fired, electrical generating stations worldwide.

The Endowment, with support from the U.S. Forest Service, has accepted the investment risk necessary to develop a market where the demand can be so high that it stimulates a "market pull," initiating a virtuous cycle that further improves forest health and creates jobs to support that market. Coal-fired power plants that substitute renewable torrefied fuel use millions of tons of fuel annually and comprise a substantial market even if the increased cost of torrefied fuel relegates its use to seasonal applications where power costs ramp up from high demand due to air conditioning in the summer and heating in the winter. The same type of market demand can be envisioned for biochar.

The production processes for biochar and torrefied biomass are remarkably similar. Typically, they involve source gathering for the material infeed, chipping, drying, thermal application in a kiln at atmospheric pressure, cooling, and then, depending on transportation distances, densification to a usable form factor (e.g., a pellet or briquette). Densification supports dust control for operational safety, increases bulk density for cost-effective transportation, and when consumed at a power plant, helps to mimic the energy density of coal in the power plant's fuel conveyance system. The main difference between biochar production and torrefied wood production is temperature: torrefaction occurs between 250 and 300 °C while biochar production requires a temperature greater than 450 °C. That said, it is quite possible that a kiln-type torrefaction facility could accommodate a parallel system to produce biochar. This assumes that sufficient footprint and infrastructure are available at the torrefaction facility location.

This "shared-footprint" concept bolsters the evolution of an additional product that supports an entirely different market segment while sharing the capital costs across both processes. As the feedstock material will likely be the same, the original efficacy and rationale of the torrefaction facility increases. Although operational costs and labor will likely increase for the combined facility, given the shared nature of the concept, it is likely that efficiencies will be realized. In contrast, separate facilities where the capital and operational costs might mirror themselves in the worst case may be twice as high as a shared facility.

Moreover, such a shared facility, which is a variant of the Biomass Utilization Campus idea, not only reduces capital investment risk but would also merge societal concerns and industrial segments. Torrefied, biogenic wood fuel displacing fossil coal provides renewable power, involving both forestry and power generation industries. Biochar production and use improves soil health and productivity for forestry and agricultural industries. In both applications, near carbon neutrality is achieved that, when realized at scale, can make a notable contribution to climate change mitigation.

Strategic Partnerships

Regulated electric utilities are granted monopolistic service territories with pricing and service quality monitored closely by a governmental utility agency. In exchange for the monopoly, the utility is granted a guaranteed rate of return on infrastructure investment and has the "obligation to serve" all customers in their allotted territory. Over time this model has changed to one in which larger customers and power users, such as many high tech and consumer brands, have been granted the ability to negotiate their exit from the regulated structure. Public statements and efforts to remove themselves from the regulated market have originated from companies such as Microsoft, Amazon, Mars Inc., Weyerhaeuser, Georgia Pacific, ADM, Cargill, and Walmart, to name a few. Typically, these companies are looking for improved electricity pricing and, more significantly, for electricity from renewable power sources. The latter applies to many companies looking to address their customers' or stakeholders' concerns specifically over impacts of climate change and more generally to make their operations and products more environmentally sustainable.

This movement has opened opportunities for independent power producers to address the market and provide renewable power to very specific end customers. Although the bulk of the renewable power market focuses on wind and solar power, biomass is also part of this mix and thus, can make inroads to this market demand. Even though in most states in the U.S., biomass, whether pyrolyzed to gas and biochar or used directly as a solid fuel, qualifies as a renewable source of power, broad societal support is needed to advance sustainable use of biomass as a renewable power source. Typically, this means obtaining the concurrence and support from environmental non-governmental organizations (NGOs) for the combustion processes related to the use of non-fossil biomass fuel. It is likely that featuring biochar application as a means to improve soil health could positively influence this support. It would certainly be an attractive and strategic outcome. For example, an NGO such as the Blue Mountain Forest Partnership could team up with Microsoft or Apple for this type of promotion that advances the use of biomass-based, renewable power with co-benefits in healthier forests and sustainable agriculture.

Financial Instruments

Working capital, or the lack of it, can be a determining factor in the growth rate and success of a company, and is particularly important in a nascent industry that can occasionally experience rapid growth cycles. The ability to turn accounts receivable into working capital can help ensure a company is able to meet client demands. If there were to exist a financial group that offered such services specifically catered to the biochar industry, such a financial tool would be very useful for building centralized biochar facilities.

Biochar Sales on Net 5 Year for Agricultural Applications

Biochar can pay for itself if given sufficient time. Generally, where biochar can realize greatest value is in agriculture applications where soil is poor and/or where crop value per acre is high. For instance, were biochar to be applied in a field of wheat (generally low crop value per acre) where the soil is already fertile, the payback may take decades. However, were biochar to be applied to a vineyard (generally high crop value per acre) where soil is poor, the payback may be realized in a single harvest.

At least a portion of farms or crops can be identified as having a high likelihood of yielding a positive return on investment for biochar applications within a five-year period. This could decrease the risk to lenders and, assuming the biochar in question is verified as sustainably produced, there would also exist long lasting benefits to the local environment and governing entities. This appears to be fertile ground for a state-backed or philanthropically minded loan program to help play a role in biochar deployment.

Carbon Credit Advances

In a situation where biochar carbon credits were issued for verified biochar applications and where a biochar production and application event has been planned and confirmed but not yet deployed, the advance distribution of the carbon credit could be very useful in solving some of the working capital constraints that might otherwise exist. This carbon credit advance could be issued directly by the carbon trading entity, or potentially by a fee-based third party.

Other tools that could support biochar industry growth, but not discussed in more detail here, are purchase order financing, invoice financing, and factoring catered to growing the biochar industry.

CONCLUSIONS AND KEY RECOMMENDATIONS

The PNW region presents opportunities to produce biochar and co-products in centralized facilities. The region needs forest fuel reduction in watershed uplands and soil improvement and carbon sequestration with biochar in watershed lowlands. Simply, when we stand back and gain a broad perspective, some watersheds in the dry western U.S. will benefit from a redistribution of organic matter. This redistribution can be achieved with biochar production. Biomass resources are abundant. Existing infrastructure exists to supply centralized facilities. Centralized processing provides many benefits we have considered. Challenges to centralized processing include pricing and market issues associated with an embryonic industry, delivered costs of feedstocks, and capital financing.

Our key recommendations for expanding production of biochar in centralized facilities are as follows:

- Develop and scale market opportunities.
- Develop appropriate technologies that take advantage of centralized processing.
- Develop products for enhanced carbon applications.
- Educate and train an army of carbon specialists.
- Modify existing biomass plants to recover carbon and co-produce biochar.
- Develop economic and environmental studies that show the benefits of centralized processing such as the expanded application of high carbon wood ash, conversion of existing facilities, and optimization of carbon markets.
- Develop successful business models such as biomass utilization campuses and public private partnerships.
- Develop financial instrument such as purchase order financing, invoice financing and factoring or biochar sales arrangements based on five year soil improvements.
- Exploit carbon markets such as cap and trade and Low Carbon Fuel Standards (LCFS).
- Advance carbon credits to finance the use of biochar in agricultural applications up front thereby facilitating adoption.

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