CHAPTER 10:

Biomass Handling

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Biomass handling consists of gathering, comminution (reduction of particle size), and transportation. Biomass resources for biochar production include 1) urban woody biomass, 2) agricultural residues, and 3) woody biomass from land management operations. We briefly discuss the handling considerations with urban woody biomass and agricultural residues, then go into greater depth of handling of woody biomass from land management operations, which comprises the bulk of the available biomass resources in the Pacific Northwest (PNW).

BIOMASS TYPES

Urban Woody Biomass

Urban woody biomass generally consists of two categories: 1) materials collected through municipal green waste collection systems (yard waste, landscaping waste) and 2) construction and demolition debris (Dooley et al. 2018; Springer 2012). In both cases, existing collection systems are in place to gather the material for composting, landfilling, or production of bioenergy. In some cases, further sorting may be needed to exclude feedstocks that are problematic for biochar production (e.g., painted or treated wood). While some sort of sorting and/or comminution has already been performed (in the case of materials headed for other types of utilization), additional pre-processing of those materials may need to be implemented for the purpose of biochar production. The exact configuration of the comminution and transportation stages of handling will be quite dependent on the specifics of the biochar production system, particularly if it is co-located with a compost operation. (See *Chapter 7: Biochar Produced and Utilized at Municipal Compost Facilities*.)

Agricultural Residues

Agricultural residues can include wheat straw (Garcia-Perez 2012), hop vines, and orchard prunings (Ntalos & Grigoriou 2002; Pari et al. 2018). Comminution and transport will depend on the specific needs of the biochar production system and the properties of the biomass. Generally, biochar production systems using agricultural residues will be fairly small scale because of the widely distributed sources. For more background on costs associated with transport, drying and comminution of urban woody biomass and agricultural residues, see Lehmann & Joseph (2015, p. 821-826).

Woody Biomass from Land Management Operations

For the remainder of this section, we focus on woody biomass residues from land management operations, which comprise the bulk of biomass resources in the PNW. Many of the same considerations for handling methods may apply to other types of biomass resources as well.

Woody biomass that can be converted to biochar is a byproduct of a larger land management operation: landscape management, infrastructure (roads, pipelines, powerlines) vegetation management, wildfire protection, restoration treatments, or harvest of tree boles for use in forest products. The high concentration of biomass following these activities provides an opportunity to use these materials as biochar feedstocks (Figure 10.1). This woody biomass, consisting largely of brush, branches, tops, and thinnings, must be gathered from where it is cut, pre-processed to reduce size (i.e., comminution), and transported to a location where it is aggregated or to a site where it is converted to biochar. For simplicity, we refer to woody biomass from land management operations as 'forestry biomass' in this report.

Estimates of biomass feedstock availability in the PNW are provided in *Chapter 9: Biomass Supply*.

Figure 10.1. *Slash piles from timber harvest near Humboldt, California. Forest residues were piled for burning because they were not economically feasible to collect/process/deliver to a local biomass energy facility. (Photo: Han-Sup Han)*

BIOCHAR SYSTEM SCALE

The methods for accomplishing gathering, comminution, and transport of feedstocks look different for different types of biochar systems and are dependent upon the distance between the source of woody biomass and the biochar production site. The scale and logistics of biomass feedstock supply operations should be matched to the capacity and feedstock specifications of the biochar production system. Some general characteristics of the scales of biochar production discussed previously in this report are described below:

- **Place-based biochar production.** These are small (usually less than 500 tons per year biomass feedstocks), labor-intensive manual operations with short distance transportation of feedstocks (e.g., thinning or logging operations or on-farm production). Biochar production may use small low-tech units (e.g., flame-cap kilns) or managed piles. The defining feature of this scale of biochar production is that it can be replicated to cover large landscapes by adding additional crews and requires low capital investment in equipment. The biochar produced is generally used on-site, rather than being sold elsewhere.
- **Moderate-scale biochar production.** Moderate-scale biochar production converts biomass (usually 1,000-100,000 tons per year biomass feedstocks) into biochar. These systems involve transportation of biomass (less than 50 miles including unpaved forest roads) to a stationary biochar production site at or close to the location of biomass generation sites. Biochar production systems can be integrated into a combined heat and biochar system (CHAB) to provide heat to buildings (e.g., schools, hospitals) or can be part of a biomass utilization campus. Mobile systems such as air burners or gasification units can be used to produce biochar at or near the source of feedstock, which helps minimize transportation costs. At this scale, biochar production can be one of a suite of products such as heat, briquettes, electricity, bio-oil, and torrefied wood chips, which can either be used on-site or transported off-site for use elsewhere. Depending on the production system, there are two different levels of feedstock quality requirements for moderate-scale biochar production systems. Systems using gasification and pyrolysis often have specific requirements for feedstock size and moisture content. Air curtain burners do not require quality control of feedstock.
- **Large-scale, centralized biochar production.** Use of industrial biomass operations (usually greater than 100,000 tons per year biomass feedstocks) require high capital investment to build large facilities, purchase several machines, and maintain a large operations crew. Biomass transportation to a large-scale central biochar production facility assumes a one-way hauling distance less than 100 miles. Biochar is produced either as a main product or as a co-product of energy, food, or fiber (e.g., transport of biomass to an off-site boiler at a lumber mill, including handling, sizing, drying, and on-site power production).

Several factors affect the selection of an optimal scale of biochar production system, including amounts of woody biomass available, market demands, proximity to biochar markets, permit requirements, and the overall cost of operations. Place-based biochar is suited for local use at or near the biochar production site for small amounts (i.e., < 1 ton/day) of biomass, while a large-scale, centralized biochar production operations can most cost-effectively produce biochar in settings where there are industrial biomass operations, such as timber harvesting in industrial forestlands and fuel reduction thinning treatments in national forests, over a long period (>20 years). Biomass handling capacity and optimal operational logistics need to match up with the biomass production capacity. Moderate-scale biochar production utilizes opportunities to convert biomass into biochar near the source of biomass using mobile systems to minimize transportation costs. The Waste to Wisdom project (https://wastetowisdom.com/) illustrates an example of an integration of transportable biochar production system into landscape-level biomass handling logistics (Han 2018).

Further detail on harvest, preprocessing and transport of a variety of biomass feedstocks is provided in Garcia-Perez et al. (2012).

GATHERING

In general, a gathering step occurs whether or not biochar is the end goal for the woody biomass. Currently, it is typical for slash piles to be burned to dispose of residues. Biomass gathering at the small (place-based) scale is often done by a combination of human power and small tractors or loaders.

At the moderate and larger scales, woody biomass needs to be brought to the roadside and prepared for loading into vehicles for delivery to a centralized biochar production facility. Many commercial options exist for mechanized gathering of woody biomass at scales from small skid-steer machines with brush grapples to a team of excavators and forwarders gathering large amounts of forest residues (Figure 10.2). For a large capacity (>300 tons/day) biomass feedstock operation, it is important to note that biomass gathering productivity directly affects the subsequent comminution operation and should match the capacity of biomass comminution. Bisson et al. (2016) refers to this situation as "a balanced system" which helps minimize overall biomass handling cost.

Figure 10.2. *Gathering forest residues using a loader and a modified dump truck on a recent timber harvesting site near Humboldt, California. (Photo: Han-Sup Han)*

COMMINUTION

Woody biomass is often reduced in size (e.g., sawn to length, ground, or chipped) at the source to increase hauling payloads and enable bulk handling in regard to downstream conversion process and conversion equipment requirements (Figure 10.3). Key considerations for comminution include piece-size requirement (Table 10.1) and transportation (distance, loading/unloading, and bulk density). An additional consideration is moisture content. While dry materials are generally preferred for biochar conversion processes, chipping dry materials (<20% wet basis) may cause fire or excessive heat between knives and wood.

Table 10.1. *Piece size and content needs for various biochar production systems.*

Type	Scale	Maximum Diameter (inches)	Maximum Length (inches)
Pile	Intact branches and logs	6	42[1]
Flame-cap Kiln	Intact branches and logs	4	48
Mobile Carbonizer (e.g., Air Curtain Burner)	Intact branches and logs	12	120
Gasifier (1-5 tph)	Small chips, sawdust	1	1.5
Auger Pyrolysis	Small chips, sawdust	1	1
Combustion/Boiler, Stoker Grate	Chipped and/or ground	4	16
Combustion/Boiler, Fluidized Bed	Chipped and/or ground	1.5	3

[1] *U.S. Forest Service specification*

Figure 10.3. *A grinder (center) comminuting logging slash and directly loading ground materials onto a truck near Humboldt, California. (Photo: Han-Sup Han)*

Chipped and ground woody biomass is not compatible with biochar production units that require air flow between wood pieces like the flame-cap kiln or the large mobile air curtain burner systems. Those systems need intact branches and stems to allow increased amounts of air flow. Place-based biochar production often gravitates to flame-cap kilns which can use feedstock particle sizes of less than 4 feet in length to fit a 5-foot opening in the kiln (McAvoy & Dettenmaier 2020). Where the transport distance is greater than a few miles, some processing generally occurs to increase the bulk density of the biomass. The most common methods to prepare woody biomass for transport are to grind it with mobile horizontal grinders or to chip it with appropriately scaled mobile chippers.

Moderate-scale pyrolysis systems and gasifiers have been optimized by some manufacturers to accept screened chips and ground biomass, but large "firewood chunks" and sticks must be removed to avoid jamming of feeders. Large-scale systems that produce biochar as a co-product to steam and/or electricity are typically designed to use chipped and ground biomass from a wide range of sources discussed in this report.

Chipping and grinding operations can be scaled from a few tons per day to hundreds of tons per shift. At the small scale, and particularly in urban environments, orchards, and wildland-urban interface wildfire risk reduction sites, tow-behind chippers are directly coupled to small chip trucks. A hand crew gathers the biomass and feeds it into the throat of the chipper. Chips are blown into the truck. When the truck is full or the workday ends, the truck and crew drive to a dumping point. In this case the whole-plant chips would be dumped at a biochar production facility of any scale. A complication for this style of operation is that short blocks of roundwood do not feed into the chipper, so are tossed into the truck with the chips. This leads to a need for screening or other sorting at the biochar facility. The chunks would need to be further processed or diverted to a firewood market.

Large, tracked chippers and grinders of up to 1,000 horsepower can process 40 tons per hour of biomass provided a fleet of trucks and trailers are readily available to haul the material (Han et al. 2015; Bisson et al. 2016). If the comminuted raw biomass is piled on-site for decoupled hauling, transportation logistics could be simpler but the potential for contamination by rocks and debris becomes high. Such systems would require $4 - $6 million of capital for equipment, consume a thousand gallons of diesel per day, and require sophisticated logistics and operations management expertise. With a high level of year-round machine utilization, such systems are the best fit for delivery of woody biomass to centralized large-scale conversion facilities. However, the scale and continuity of biomass generating activities necessary for supporting such systems does not exist in many timber-dependent rural communities. Thus, there is also a need for cost-effective gathering and transport methods that are at an intermediate scale.

Another option (instead of chipping and grinding) is to crush materials using rollers into scrim (long strands) having a mean strand thickness of less than 0.24 inch. (Dooley et al. 2011; Du Sault 1984). The scrim may be cross-sheared to shorter, more flowable particles using a rotary shear machine. A screening system will redirect oversize materials to be re-crushed and recut, and fines, which contain high levels of soil, are stockpiled for use as mulch.

TRANSPORT

As previously mentioned, in the case of small-scale biochar production, gathering and transport operations are usually combined. As the transport distance increases, gathering becomes decoupled from transport (Figure 10.4). Transport of bulk, unprocessed woody biomass has a high cost per unit distance due to low bulk density (typically 3-5 lb per cu.ft.). If the transport distance is less than 5-6 miles, an option using hook-lift containers or high-cube dump trailers can be cost-effective (Montgomery et al. 2016). Transportation cost can represent more than 50% of the total biomass handling cost in many cases, especially with situations involving long hauling distance (>50 miles one-way) and poor quality of forest roads (Pan et al. 2008). Furthermore, transportation logistics and scheduling should be well-coordinated with comminution and biochar production operations.

Figure 10.4. *A chip van transporting biomass feedstock from a comminution site in the woods near Humboldt, California to a biochar production facility. (Photo: Han-Sup Han)*

Though chipping and grinding commonly occur prior to transport, other strategies for increasing bulk density have been used. In some areas baling into round or large rectangular bales greatly increases the transport density, and thus can reduce cost of hauling with conventional flatbed trucks (Dooley et al. 2018). Baling reduces storage costs and preserves piece size for milling at the destination (Figure 10.5). Bales of densified biomass or windrows and piles of gathered loose biomass are staged for loading onto trucks or for further processing into a bulk flowable format such as grindings and chips. Recently, an innovative large-scale hauling scheme was developed in Washington State that combines transport of bulk unprocessed forest residues in end-dump trailers with a heavy payload of merchantable logs on top. The logs compress the biomass to double its bulk density and provide a high-revenue product in the load (Barrier West 2018).

Figure 10.5. *Wildfire protection thinnings were used to produce 4mm feedstock for biochar production. In this example, biomass was transported intact for comminution and screening at a centralized facility. (Photo: Forest Concepts)*

OTHER CONSIDERATIONS FOR BIOMASS HANDLING

Moisture is a consideration because it affects the time for producing biochar and the energy balance of conversion systems. A moisture level less than 20% is best for optimal use of most technologies, but the specifications vary (Belart et al. 2017; Stokes et al. 1993). With some types of units, excess heat is used to dry feedstock. For example, a mobile gasification unit converting wood chips into biochar requires a feedstock moisture content of less than 25% (wet basis) for an optimal operation (Eggink et al. 2018). Air curtain burners can handle wet biomass (>50% moisture content) after initial start, but dry materials still offer increased production of biochar at a given time.

Since feedstocks account for a large portion of the cost and labor for biochar production (even when the cost is simply gathering and loading), taking a systems approach to all gathering, comminution, transport, and handling is paramount. There is an opportunity to more optimally match at-source (in-woods) feedstock preparation with the biochar production system chosen for any particular project or biochar enterprise (Paulson et al. 2019). In an analysis of system logistics for a biomass recovery operation, Bisson et al. (2016) found that to control costs, it is necessary to maximize comminution, so that capacity of processing stage dictates upstream and downstream activities.

High quality feedstock can be produced by separating stem wood from other residues during timber harvest operations (Bisson & Han 2016; Kizah & Han 2016). Tree tops and small-diameter trees can be delimbed and piled in separate from slash piles for lowering moisture content and efficient transportation. Sorting of feedstocks may make feasible the use of a chipper (rather than a grinder), which would be better for meeting the particle size specifications for some biochar production technologies (Bisson & Han 2016).

Biochar production can be integrated into the existing forest products manufacturing operations to enhance an economically sustainable operation (e.g., lumber pellet, post/pole, firewood). Operations using woody residues such as slabs, chunks, and sawdust as a product feedstock and an energy source, have the opportunity to adapt to add production of biochar. Additional amounts of biomass feedstock can be sourced directly from timber harvesting sites to increase production of biochar and improve utilization of small-diameter trees and forest residues.

For example, recently Integrated Biomass Resources (IBR) a plant in Wallowa, Oregon adapted the plant's boiler to add biochar to the normal power production for the boiler with a grant managed by Wallowa Resources. This system takes advantage of mill residues in the production of post/poles and kiln dried firewood, to capture a new product. By finding similar opportunities, biochar manufacturing can utilize existing transport systems, and thermal conversion (boilers) to take advantage of existing efficiencies.

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