4. Biomass Preparation

Biomass feedstocks have to be prepared, stored, and transported to the energy conversion process before they can be used to generate power or produce steam. This chapter describes the requirements and costs of preparing solid biomass fuel and biogas fuel for power generation.

4.1 Solid Biomass Fuel Preparation

The steps of preparation, storage, and transportation of a biomass feedstock comprise the ***preparation yard*** (prep-yard). The major requirements of a standard prep-yard can be divided into four categories:[46]

1. Receiving: truck tipper, conveyor, and radial stacker
2. Processing: reclaim feeder, conveyor, metal separator, dryer, screener, and grinder
3. Buffer storage: storage bin (24 hours)
4. Fuel metering conveyors, meters, and pneumatic transport

Two typical prep-yard configurations are shown in **Figures 4-1** and **4-2**. Figure 4-1 includes manual feedstock handling steps that reduce capital costs but increase labor requirements. The manual approach to feedstock handling would be primarily used for smaller facilities. Figure 4-2 shows a fully automated prep-yard, which is more capital intensive but requires less labor. An automated system is only cost-effective for large biomass conversion systems. Both of these configurations are based on woody biomass feedstock. The discussions throughout this chapter are based on three systems:

- 100 tons/day system based on manual biomass handling
- 450 tons/day system based on automatic handling
- 680 tons/day system based on automatic handling

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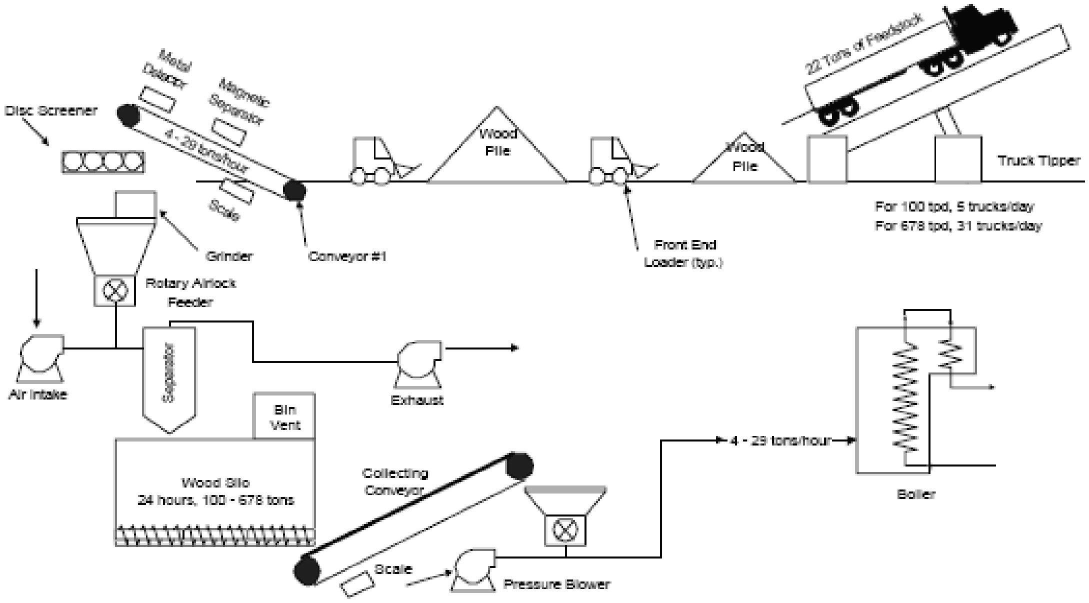
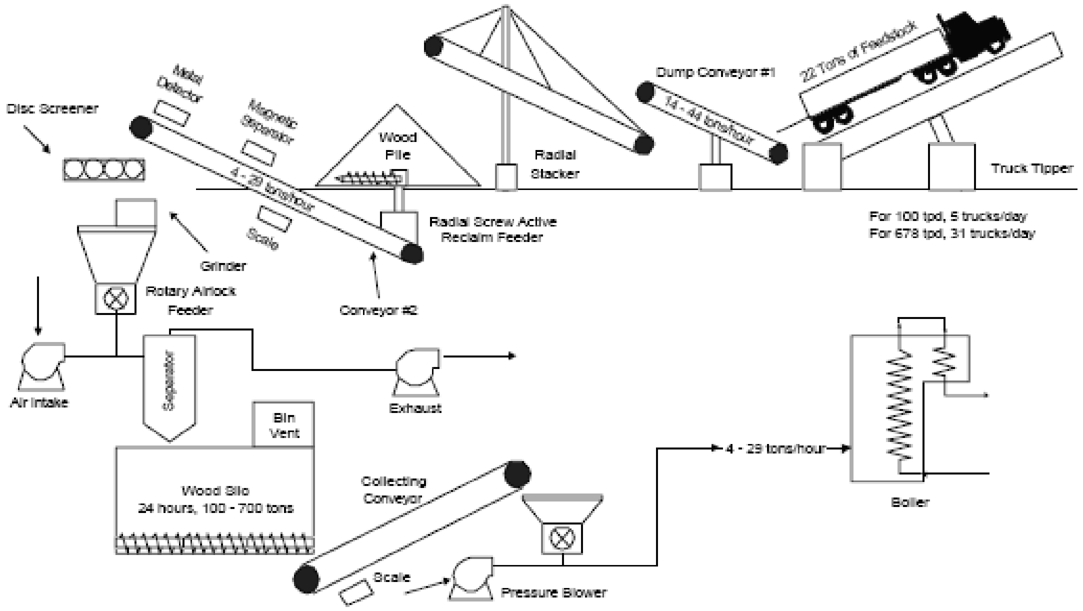
[46] The costs and schematics for this section are based on Antares Group, Inc., 2003.

Figure 4-1. Manual Biomass Receiving and Preparation System



Source: Antares Group, Inc., 2003.

Figure 4-2. Automatic Biomass Receiving and Preparation System



Source: Antares Group, Inc., 2003.

4.1.1 Receiving System

With the exception of residues generated in-house, virtually all woody biomass is delivered by truck to industrial users. Three types of trucks are commonly used for delivery of wood fuels: 1) dump trucks, 2) live-bottom (self-unloading) semi-trailer vans, and 3) standard semi-trailer vans. The choice of truck is dependent on the quantity of the biomass purchased and the equipment available for unloading. Dump trucks and live-bottom trucks have the advantage of being able to unload themselves directly onto storage piles. Standard semi-trailer vans require truck dumpers to unload. Smaller and less expensive dump systems only raise the trailer van for dumping, a process that requires decoupling the tractor and semi-trailer and is therefore more time intensive. Larger dump units can tilt the whole truck and unload in a manner of minutes, or approximately one-half the time of a trailer-only dumper. Minimizing unloading times is important because haulers can impose financial penalties for excessive unloading times.

A set of drive-on scales is used to determine how much biomass is on the truck. Although mechanical or electronic scales can be used, maintenance costs are generally lower for mechanical scales so those are more commonly used. Sometimes conveyor belt scales are used for determining weights, but these systems are less accurate, more time consuming, and more expensive to operate.

Biomass delivery and receiving methods depend on the size of the installation:

- **Very small installations** of a few tons per day use small dump trucks or standard semi-trailer vans for biomass delivery. Dump trucks drop the load at the site where it is then moved to storage by small front-end loaders. Where standard semi-trailer vans are used, a ramp or loading dock is required so that front-end loaders can remove the load—a process that takes about an hour per load.
- **Small-scale users,** 10 to 50 tons/day, typically use self-unloading semi-trailer vans. These trailers have a live-floor system that walks the load from the van, allowing a single person to unload a van in 10 minutes. The trailers are 30 to 45 feet in length and can carry 20 to 30 tons of biomass.
- **Intermediate-scale installations** 50 to 100 tons/day might add a light-duty frame-tilt hydraulic dumper for unloading fuel. For these systems, the trailer must first be disconnected from the tractor. Front-end loaders or bulldozers move the fuel from the concrete pad and stack the biomass on the storage pile. A system sized for 100 tons/day would handle about four to five trucks per day.
- **Large-scale installations** of greater than 100 tons/day typically use standard semi-trailers and hydraulic dumpers that can lift and tilt the whole truck up to an angle of 75°, emptying the entire load in a matter of minutes. The system includes a live-bottom receiving hopper. From the concrete pad, the fuel is conveyed to a woodpile. An automated storage radial stacker is used to stack the fuel on the pile for future processing needs. A system sized for 400 tons/day capacity would handle about 20 trucks per day.

The storage area for the options considered in this section is sized for a 30-day supply of biomass. This quantity of biomass can carry the plant through possible supply shortages in the spring or winter seasons. This amount of biomass storage requires an area between 12,500 and 93,750 square feet (for the 100 tons/day and 680 tons/day systems, respectively), assuming the wood has an average density of 40 lb/cubic foot and an average storage height of 12 feet. The larger area is greater than two football fields, so a significant area would be needed on site for a large biomass processing facility.

4.1.2 Processing System

The processing system treats the biomass prior to charging the energy conversion process. Common steps in processing include separation, sizing, removal of metals and other noncombustible materials, and grinding or other size reduction methods. An automated system conveys the correct amount of biomass required by the energy conversion process. In a manual system, a front-end loader will perform this function.

The sizing equipment separates oversized pieces and sizes them to meet boiler specifications. The disc screener separates the oversized particles and bypasses the undersized feedstock. The oversized particles are sent to a tub grinder to be properly sized. The tub grinder is adequate for wood chips and bark, but urban wood waste needs a hammer hog (hogger) because metal objects in this waste stream would damage a tub grinder. From the grinder or hogger, the material is conveyed into a wood silo to be stored until the boiler needs the fuel. Stoker and fluidized bed boilers can charge material up to about two to three inches in size.

Biomass might also have to undergo drying. If needed, this step occurs immediately after sizing. Of the technologies studied in this report, only gasification requires biomass drying. For all biomass conversion technologies, the lower the as-fired moisture content of the biomass feedstock, the higher the energy efficiency of the conversion process. If part of the fuel, moisture must be heated and vaporized and this energy is lost in the stack. In direct-fired conversion processes described in Chapter 5, each additional 10 percent of moisture in the fuel lowers the conversion (or boiler) efficiency by about 2 percentage points. Therefore, as-received biomass with moisture contents of 30 to 50 percent result in process efficiencies of 6 to 10 percentage points lower than bone dry feedstock. Efficiency reductions due to moisture contained in the biomass also occur in cofiring, but the effect is considerably reduced because the biomass is only a small part of the total fuel used. Typical practice in direct-fired and cofired applications, however, is not to dry the feedstock before charging in the boiler. In a well designed boiler, most of the available stack heat is already being extracted in steam production and other energy recovery options. Therefore, diverting stack heat from the process for drying would reduce what is available for steam generation. Gasification processes, on the other hand, typically require biomass feedstock drying for proper process function and control. Feedstock drying is an integral part of most gasification designs. Therefore, costs of drying are only considered in the section on biomass gasification.

4.1.3 Buffer Storage

A biomass silo serves as storage buffer in the 100 to 680 tons/day cases outlined here. The silo has a live bottom that moves the fuel to collector conveyors. The silo’s capacity varies by fuel consumption rate. Prep-yard costs can be reduced by lowering the buffer size.

4.1.4 Fuel Metering

Fuel metering consists of the controlled delivery of the required amount of biomass to the energy conversion process. In the systems considered here, the biomass is metered as it is discharged from the silo to the collecting conveyor. An auger at the base of the silo feeds a conveyor, which then feeds a surge bin. From the surge bin, the fuel is metered into the boiler or other energy conversion device, passing through a rotary airlock. The metering rate is controlled by the boiler control room. The fuel is pneumatically transferred to the boiler after passing the airlock.

4.1.5 Prep-Yard Capital Costs

This section summarizes installed capital costs for biomass prep-yards of 100, 450, and 680 tons/day. The 100-tons/day plant utilizes a manual feedstock handling system. The two larger plants use an automatic system.

Table 4-1 shows installed capital costs, including the major equipment components described in the preceding sections. Installation costs, controls, civil/structural work, electrical work, engineering fees, and contingency costs are also shown. Prep-yard capital costs decline sharply on a per ton basis as the plant gets larger.

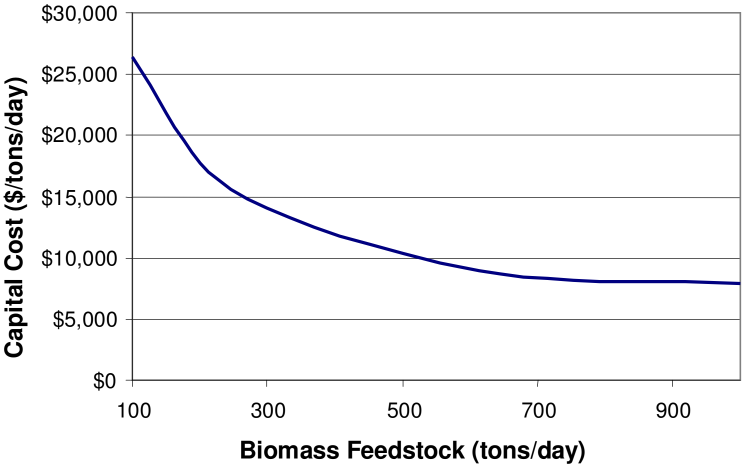
Table 4-1. Installed Capital Costs for Solid Biomass Receiving and Preparation

	Tons/Day Fuel (as received)		
Component	**100**	**450**	**680**
Receiving System			
Truck tipper	$230,000	$230,000	$230,000
Conveyor to wood pile		$40,000	$45,000
Radial stacker, adder		$190,000	$205,000
Front end loaders, adder	$100,000		
Receiving Equipment Subtotal	**$330,000**	**$460,000**	**$480,000**
Processing System			
Reclaim feeder		$230,000	$230,000
Conveyor		$149,000	$160,000
Metal separator	$40,000	$40,000	$40,000
Screener	$150,000	$220,000	$250,000
Grinder	$250,000	$400,000	$600,000
Processing Equipment Subtotal	**$440,000**	**$1,039,000**	**$1,280,000**
Buffer storage	$60,000	$98,000	$135,000
Fuel metering	$252,000	$313,000	$364,000
Controls	$115,000	$166,000	$196,000
Equipment Subtotal	**$1,197,000**	**$2,076,000**	**$2,455,000**
Equipment installation	$500,000	$1,093,000	$1,220,000
Civil/structural work	$370,000	$787,000	$877,000
Electrical work	$170,000	$275,000	$305,000
Direct Cost Subtotal	**$2,237,000**	**$4,231,000**	**$4,857,000**
Engineering (10% of direct cost)	$223,700	$423,100	$485,700
Contingency (8% of direct cost)	$178,960	$338,480	$388,560
Indirect Costs Subtotal	**$402,660**	**$761,580**	**$874,260**
Total Prep-Yard Cost	**$2,639,660**	**$4,992,580**	**$5,731,260**
Prep-Yard Unit Cost ($/tons/day)	**$26,397**	**$11,046**	**$8,453**

Source: Based on Antares Group, 2003.

These three plant sizes were used to develop a capital cost curve as a function of plant biomass throughput, as shown in **Figure 4-3**. Above 680 tons/day, the biomass prep-yard costs were assumed to increase as a function of a 0.85 power factor of the ratio of prep yard throughput.

Figure 4-3. Estimated Unit Prep-Yard Capital Cost As a Function of Throughput



4.1.6 Labor for Operating the Prep-Yard

There are also labor costs associated with operating the receiving and processing portions of the prep-yard. The amount of labor needed for the three options is based on baseline firing rates of 100, 452, and 678 tons/day. The labor requirements are shown in **Table 4-2.** Each employee is assumed to have a loaded compensation rate of $80,000/year. Each plant requires a delivery coordinator; larger plants need an additional person for this function. The manual handling system of the 100-tons/day plant requires three people to operate the front-end loaders, including a supervisor. The automatic operation of the larger plants eliminates this requirement. For the larger plants, two operators can manage the handling and processing equipment; for the 100-tons/day plant, only one is required. Overall, the 100-tons/day plant requires five people, and the two larger automatic prep-yards require four people.

Table 4-2. Labor Requirements

	Tons/Day Fuel (as received)		
Employee Position	**100**	**450**	**680**
Delivery Coordinator	1	1	1
Assistant Coordinator		1	1
Employee Supervisor	1		
Front End Loader Operator	2		
Operators	1	2	2
Total Employees	**5**	**4**	**4**

These labor estimates contribute to the O&M cost estimates presented in Chapter 6.

4.2 Biogas Fuel Preparation

Biogas fuel is generated from the anaerobic decomposition of organic material and is typically composed of about half methane, half CO_2, and small amounts of non-methane organic compounds and other contaminants. Like solid biomass, biogas fuel must be collected and treated for use in power generation. The following discussion reviews the preparation requirements and associated capital and operating costs for biogas fuel generated at wastewater treatment facilities, farms, and landfills.

4.2.1 Gas Collection Systems

Both wastewater treatment biogas and manure biogas are generated in anaerobic digesters. (Anaerobic digester physical descriptions vary by digester type; see Appendix C for information about different types of anaerobic digesters.) The biogas produced by the anaerobic digesters is collected from the gas space between the organic material (wastewater treatment sludge for wastewater treatment facilities and manure for farms) and the digester cover using a low-pressure blower. The biogas typically goes through a free water knockout vessel before being conveyed to the combustion device.

For LFG, collection typically begins after a portion of a landfill (called a cell) is closed. In 1996, EPA promulgated rules requiring the collection and destruction of LFG under New Source Performance Standards and Emissions Guidelines. If a landfill's non-methane organic compound emissions are greater than or equal to about 50 metric tons (megagrams) per year, the landfill rule requires the installation of a gas collection and control system. Sources must collect the LFG and destroy it at 98 percent efficiency. Two collection system configurations are generally used: vertical wells or horizontal trenches. Vertical wells are by far the most common type of well used for gas collection. Trenches might be appropriate for deeper landfills and can be used in areas of active filling. In a conventional vertical well system, vertical wells of approximately 2 to 3 feet in diameter are drilled into the waste at a typical spacing of one well per acre. Perforated polyvinyl chloride pipe approximately 6 inches in diameter is inserted into the well, and the hole is filled with gravel and capped with an impervious material. Each wellhead is connected to lateral piping, which transports the gas to a main collection header. Each wellhead is fitted with valves and a pressure tap so that the operator can monitor and adjust the gas flow from each well, as necessary. A blower is necessary to pull the gas from the collection wells into the collection header and convey the gas to the treatment system. The size, type, and number of blowers needed depend on the gas flow rate and the resistance in the collection system.

An important part of any LFG collection system is the condensate collection and treatment system. Condensate forms when warm, humid gas from the landfill cools as it travels through the collection system. If condensate is not removed, it can block the collection system and disrupt the energy recovery process. Condensate control typically begins in the field collection system, where sloping pipes and headers are used to allow drainage into collecting ("knockout") tanks or traps. These systems are typically augmented by post-collection condensate removal as well.

Another device that is part of LFG energy recovery systems is a flare. A flare is simply a device for igniting and burning the LFG. Flares are considered a component of each energy recovery option to dispose of gas during system start-up and downtime. In some cases, it might be most cost-effective to gradually increase the size of the energy recovery system and to flare excess gas between system upgrades (e.g., before adding another engine). Flare designs include open (or candlestick) flares and enclosed flares. Enclosed flares are more expensive but might be preferable (or required) because they allow for stack testing and can achieve slightly higher combustion efficiencies. In addition, enclosed flares could reduce noise and light nuisances.

4.2.2 Gas Treatment Systems

Some minimal amount of gas cleaning is required for almost any application using biogas. Both anaerobically digested wastewater treatment biogas and LFG contain methane and CO_2, but also contain contaminants including hydrogen sulfide, other sulfur compounds, and a variety of other corrosive gases that evolve from chemical products in the waste. LFG also contains water, particulates, hazardous air pollutants, and chemicals called siloxanes, which are silica-based compounds that derive from various consumer products in the waste stream.

Wellhead natural gas contains a variety of contaminants, inert gases, moisture, and particulates. All of these are removed in processing so that pipeline natural gas is a very clean fuel with consistent combustion characteristics. Waste and byproduct biogases are similar in many ways to raw, wellhead natural gas, which creates a variety of challenges to their direct use. Specifically, the contaminants in the gas cause erosion and corrosion of generation equipment.

Some of the specific components of waste and byproduct fuels and their operational problems include:

- **Solids** can cause erosion of critical surfaces or plugging of orifices.
- **Water** retards combustion and can cause erosion, corrosion, or catastrophic damage to critical surfaces or components.
- **Non-methane fuel components** (butane, propane, carbon monoxide [CO], hydrogen) can change combustion characteristics; if present in liquid form can cause physical damage.
- **Sulfur and sulfur compounds** can cause corrosion in engines, increase maintenance requirements (more frequent overhauls and oil changes), and poison catalyst materials.
- **CO_2** reduces heating value and combustibility.
- **Siloxanes** create a glassy deposition on high-temperature surfaces; particles can break off and damage working parts.

After biogas has been collected, and before it is used in an energy project, typical treatments remove moisture that is not captured in the knockout tanks, as well as particulates and other impurities. For small systems, however, particularly at farms, gas cleanup beyond removing moisture from the initial free water knockout vessel is not typically performed due to the high cost of cleanup.

Treatment requirements depend on the end use application. Minimal treatment is required for direct use of gas in boilers and reciprocating engines. This treatment typically includes dehumidification to drop the gas dew-point below winter temperatures, particle filters to remove particulates that could damage engine components, and compression to meet the fuel pressure requirements of the energy application.

For biogas generated at landfills and wastewater treatment facilities, some reciprocating engine applications and many gas turbine applications also require siloxane removal if the level of siloxanes is high.[47] Siloxane removal is typically accomplished with adsorption beds situated after the dehumidification process. Recently, additional cleanup technologies have been introduced for the production of a high-Btu LFG, which could also be used for other types of biogas. These technologies remove CO_2, organic, and sulfur compounds using a variety of gas separation technologies, including: adsorption, absorption, chilling, and membrane separation. The separated CO_2 can be either vented to the atmosphere or cleaned and used in CO_2 applications. The sulfur is often adsorbed onto a medium that can be returned to the landfill or can be recovered for chemical sale. More information about siloxanes and siloxane removal is available through LMOP (see Appendix B).

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[47] Siloxanes are a class of compounds present in a number of consumer products. Siloxanes form hard ceramic-like deposits on combustion. These deposits can shorten the life of engines or gas turbines and also require more frequent oil changes.

4.2.3 Collection and Treatment System Capital and O&M Costs

Wastewater Treatment Biogas

As mentioned in Section 3.2.2, minimal gas treatment is required for direct use of biogas in boilers or small-scale reciprocating engines. Treatment might be required, however, in other applications. Based on analyses completed by the EPA CHP Partnership, fuel treatment costs can range from approximately $194,000 for a 300-kilowatt (kW) fuel cell CHP system ($650/kW) to approximately $369,000 for a 1-MW internal combustion engine CHP system ($370/kW).[48]

Manure Biogas

As mentioned earlier, manure biogas systems are typically too small for gas treatment to be economical.

Landfill Gas

Total collection system costs vary widely, based on a number of site-specific factors. If the landfill is deep, collection costs tend to be higher due to the fact that well depths will need to increase. Collection costs also increase with the number of wells installed.

Table 4-3 presents estimated capital and O&M costs for typical collection and treatment systems at typical landfills generating 500 cfm, 1,000 cfm, and 2,000 cfm of LFG. The capital costs for these systems include installation of the gas wells, gas collection system, emergency flare, and gas treatment system (dehydration, filtration, and compression), along with start-up costs. The annual O&M costs include all labor, materials, electricity, and administrative costs required to operate the equipment described previously. This operation includes the monthly optimization of gas collection at each wellhead.

Table 4-3. Summary of Representative Collection and Treatment Costs ($2006)

Estimated Gas Flow (cfm)	Capital Costs	Annual O&M Costs
500	$1.2 million	$0.23 million
1,000	$2.1 million	$0.45 million
2,000	$4.1 million	$0.90 million

Source: EPA, n.d.

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[48] EPA, 2007a.