CHAPTER 3

FEEDSTOCK AGGREGATION

A major component of the CURBI project will be the harvesting, collection, preparation, and storage of feedstock fuel supplies for the various processes. This chapter of the report was prepared by Mesa Reduction Engineering, based on their extensive experience with feedstock harvesting and preparation. Biomass feedstocks are divided into forest biomass, agricultural biomass, dining hall waste, and alkaline hydrolysate. Cost information is included with this chapter and is summarized in Chapter 9.

3.1 WOODY BIOMASS

CURBI will have access to woody biomass from two main sources. The first is from thinning operations on the 4,000-acre Arnot Teaching and Research Forest and other Cornell forested properties within a 25-mile radius of campus. The second source is forestry cuttings and debris from campus-wide land management operations. In addition to these quantities, Cornell could implement sustainable forest management throughout those portions of Cornell-owned lands that are currently forested (or could become forested) to increase the woody biomass available to CURBI or similar campus bio-energy initiatives.

A. Forest Management. Woody biomass can be sustainably harvested from forest lands under an approved Forest Management Plan (FMP). The FMP ensures that harvests are made in accordance with specified removal rates and a certain amount of biomass remains in the forest to grow, restock, and maintain soil health. Ideally, harvesting in accordance with a FMP improves the overall health of the forest by removing low-grade species that choke out the growth of young higher quality hardwood timber. Cornell University’s Department of Natural Resources has developed a plan for sustainable forest management which incorporates the desire to establish and maintain a diverse and healthy ecosystem throughout the managed forest into the goal of a FMP. This plan is described in Cornell’s CAP (http://sustainablecampus.cornell.edu/climate).

B. Harvesting, Transportation and Preparation. Depending on the type of operation and the use for the timber, harvesting generally falls into two categories: cut-to-length mechanized
(where a felled tree is cut to appropriate length at the stump, leaving limbs and tops) and whole-tree mechanized harvesting (where the tree is forwarded intact to a landing for processing). Due to the need to remove timber from the forest to a landing, and then to move the processed chips to secondary storage, there is no clear delineation between harvest and transport.

1. **Forwarding/Skidding.** Presently, most of the wood removed from Cornell property is brought from the stump to the landing by either a grapple or cable skidder, which drags the material on the ground. A more mechanized option is to utilize a forwarder, a larger machine which loads and carries the material off the ground. Ground skidding tends to embed soil and sand in tree bark, which increases the relative silica content of the feedstock, so the use of the forwarder may be appropriate to avoid grit wear on the feedstock augers and pyrolysis/torrefaction units.

2. **First-Stage Transport** (if needed). Depending on whether the operations is removing log length material, or whole trees (limbs and tops along with the main stem) are being brought to the landing, the initial chipping/grinding process can occur at the landing or at a remote location. Logs can be loaded onto tri-axle trucks or tractor trailers for transport to a consolidation site where they can be stored for a long period of time or processed into chips. Due to the bulky nature of the limbs and tops, whole trees would be chipped at the landing and loaded into tractor trailers for transport to the consolidation yard or conversion facility in almost all scenarios.

3. **Chipping/Grinding.** Residues (limbs and tops) from logging operations will be ground to finer size to achieve higher bulk density using a horizontal grinder, tub grinder, or chipper (larger equipment typically has its own loaders). Processing performance is affected by dirt, foreign matter like nails, and whether the material is frozen. The cost ranges for different chipping options are the same:

- Horizontal grinder with loader: $10 to $12 per ton
- Whole tree chipper with loader: $10 to $12 per ton
- Tub grinder: $10 to $12 per ton

It is likely that chipping and grinding of forest biomass would be performed at a remote location, after which chips would be transported to the CURBI site for storage.
4. **Second-Stage Transport.** Chips are loaded directly into a 100 or 120 cubic yard chip van or walking floor trailers capable of holding approximately 12.5 to 15 dry tons per load. Roll-off containers can also be used, and although they have less volume than chip vans, a pup trailer can be added to haul more chips.

5. **Stumpage.** Payment to the landowner in the form of a stumpage fee may be a cost item for forest biomass, again depending on the type of operation and the use for the timber. This would not present a cost to CURBI as long as Cornell uses its own lands for harvesting.

The U.S. Forest Service’s Forest Residues Transportation Model (FoRTS) was used to compare alternative methods of moving biomass from the forest to the CURBI site. Mesa estimates a price of $35 per ton to remove, transport, and prepare forest biomass applicable to the CURBI project. Cornell’s Department of Natural Resources, in their own independent analysis as part of the CAP, assumed a final cost of just over $50 per ton to supply wood (in the form of wood chips) to the Cornell heating plant for combustion (intermixed with coal). This higher cost included the expense of a comprehensive forest assessment, survey, and education program integrated into the wood harvesting operations to ensure a higher level of sustainability; and to support Cornell’s education, research, and outreach mission.

C. **Storage.** Once chips or round wood logs have been brought to a final storage or consolidation area, they are unloaded into a pile for storage. Typically, a wood chip pile can be left uncovered if properly maintained, which consists of periodic turning every 90 days. Even with proper maintenance, wood chips will experience some dry matter loss, estimated at approximately $0.25 per ton. Mesa estimates costs of $1 per ton for chip pile storage applicable to the CURBI project.

D. **Drying/Size Reduction.** For most pyrolysis technologies, green wood chips will need to be dried from 30 to 50 percent moisture content when they are in storage, to 12 to 15 percent moisture content. The quickest and most precise way to control moisture content is triple-pass heated drying, although this adds the most cost ($2.57 per ton) and requires the most energy. It is envisioned that waste heat from the pyrolysis process could be used for drying, reducing costs and added energy. Passive drying is not recommended, as it is difficult to precisely control moisture content and takes a significantly longer amount of time compared to thermal drying.
Once the wood chips have been dried, technologies (i.e., Mesa’s Collision Mill) can be used to bring the chips to the precise millimeter size suitable for pyrolysis. Prior to this step, the chips must be passed through a conveyor with ferric/non-ferric screening to catch and remove foreign material. Typical foreign material in wood chips can include ice, rocks, dirt, and metals such as nails. Removal of foreign materials adds $1.50 per ton to the cost. From there, reduced wood needs to be stored in a surge bin or silo at a cost of $1.52 per ton. At this point, the woody biomass is ready for conversion. Table 3-1 shows the steps from forest to conversion point and the cost inputs for each step.

3.2 AGRICULTURAL CROPS

Cornell grows nearly 350 tons/year of energy crops for research purposes. For example, the College of Agriculture & Life Sciences Bioenergy Feedstock Project, managed by the Forage Breeding Program in the Department of Plant Breeding and Genetics, is part of a multi-disciplinary renewable energy research effort currently underway at Cornell. The project seeks to increase production of perennial grasses and other agricultural crops for use as biomass feedstocks to support the growth of the alternative energy industry.

Switchgrass is the perennial grass most often cited as a potential biomass crop, and is one of the more intensively researched grasses as part of the feedstock project. Switchgrass will be examined in this analysis, although the harvesting, processing, and storage options will mostly be identical for other grasses grown for biomass. The steps for production of biomass crops include field preparation (tillage, application of pre-seeding herbicide, discing, harrowing, or cultipacking), seeding, amendments, and weed control. The use of these inputs and their costs will vary greatly, depending on soil conditions, climate, precipitation, pests, and other factors. Generally, however, an acre of switchgrass could require at least $250 of inputs for first-year establishment.

One disadvantage of non-woody biomass feedstocks is their relatively low bulk density compared with coal or wood. While coal has a bulk density of 800 kg/m$^3$, loose straw has a bulk density of only 80 kg/m$^3$, and baled straw has a bulk density of only 320 kg/m$^3$. This has a major effect on the costs of transportation for the feedstocks, and usually limits the feedstock to fairly local use as an energy source. Densification of grass crops and sawdust to pellet form has significantly improved the cost effectiveness of transportation of biomass feedstocks. For the CURBI project, it is assumed that cultivated energy crops such as switchgrass could be field
dried and baled for local transportation from Cornell’s fields to the CURBI facility. Loose plant material from the greenhouses and plantations would be transported locally to the CURBI site in roll-off containers. The cost of densifying Cornell’s biomass to pellet form is not justified for the relatively short haul distances.

The feasibility study assumes that CURBI will only be responsible for field crops ready for harvest, thus the cost analysis begins with harvest of energy crops.

A. **Harvesting/Staging.** Most one-cut crops will be harvested in early to mid-August and will require mowing, raking/windrowing, and baling at approximately 15 percent moisture content using conventional harvesting equipment. While round bales are less likely to suffer dry matter loss to weather, 3-foot by 4-foot by 8-foot bales are preferred for their transportability and storage efficiency. Bales are staged to the roadside to be picked up and moved to either on-farm storage or to a pick-up area for loading/transport to an off-site storage/processing facility. A conservative estimate for harvesting, baling, and staging switchgrass is $35 per ton, although it can likely be done for less with optimal conditions.

B. **Storage.** Storage can range in sophistication from bales covered in tarps to constructed, closed buildings, with bales stacked as many as 20 bales high with special loading equipment. While tarp coverage has low capital and operations costs, higher dry matter loss with less sophisticated storage is a trade-off, as dry matter loss rates as high as 25 percent can negate these savings. For the CURBI project, proposed storage facilities would include open pole barns with concrete slabs to allow efficient use of front-end loaders for feedstock relocation without picking up stones or soil from the ground. Estimated cost for storage is $16/ton (based on M. Duffy, Iowa State University, 2002, adjusted for inflation).


C. **Transportation/Offloading.** For the CURBI project, it is anticipated that bale transport would be provided by agricultural equipment or over-the-road trucks. An 18-wheel semi can hold as much as 20 tons, or 42 950-lb. bales. Costs would be incurred for loading and unloading
as well as transport. Studies over the last 15 years on transport of bales have estimated costs that range between:


Mesa believes that $10 per ton for transport costs should be used for cost estimating for CURBI. Once the bales are transported to the conversion facility or secondary storage, the truck is typically weighed on and the bales are offloaded using a forklift.

D. **Processing.** Once bales are ready for the conversion process, they must be processed to the necessary size and moisture content. For example, drying may be necessary in some cases to reduce moisture content to 10 percent. Bales are put through an industrial bale grinder to reduce them to chopped material, which is then passed through a conveyor with ferric/non-ferric screening to catch and remove foreign material. Typical foreign material in bales includes rocks, dirt, and metals. The material is then reduced to 15 to 25 mm using a Collision Mill. Material can then be cubed if densification is necessary. The steps in processing include:

1. **Bale Grinding** – Bales are loaded onto an industrial bale grinder.
2. **Drying** – Triple-pass drying system to reduce moisture to 8 to 10 percent ($1.85/ton).

According to the Department of Energy Idaho National Lab, the greatest opportunities to reduce feedstock supply costs are improvement in supply logistics efficiencies and development of a uniform commodity-scale supply system.

Table 3-2 shows the steps in the process to harvest, transport, store, and process agricultural crops like switchgrass for CURBI. As the table shows, Mesa estimates a cost of $68 per ton to use switchgrass bales for CURBI.
3.3 SITE LOCATION AND LAYOUT

Several alternate Cornell properties were considered for the CURBI feedstock storage and processing needs, including:

1. The area southeast of campus just off Dryden Road adjacent to the planned joint CALS and CCVM diary facility and the existing Agricultural Waste Management Lab. This area was rejected due to insufficient space and expected neighbor noise concerns.

2. The Mt. Pleasant area used for field trials and other research. While this area meets the space requirements and is located away from neighbors, its distance from both Arnot Forest (26.4 miles) to transport roundwood and campus (6 miles from Tower Road on campus) to transport finished product is not advantageous.

3. The Stevenson Road composting area adjacent to the Department of Environmental Conservation Pheasant Game Farm. This area is closer to both Arnot (20 miles from Cayuta using Route 13 north to Ithaca to Stevenson Road) and campus (2.5 miles). This is the preferred area for the feedstock storage, processing, and conversion facility.

3.4 DINING HALL WASTE

Cornell University currently generates approximately 450 tons/year of food waste and paper waste by the on-campus dining halls. Production of dining hall wastes is seasonal, as food preparation needs decrease significantly in January and mid-May through mid-August. While dining hall waste provides a significant potential source for feedstock energy for the CURBI processes, there is also typically a high probability of contamination with foreign objects (primarily plastic and metal). Foreign objects and inconsistent feedstocks could create problems with operation with pyrolysis or anaerobic digestion equipment; however, such dining hall waste should be an acceptable feedstock for the dry fermentation process. Most of Cornell’s dining waste is “pre-consumer,” meaning the separation occurs in the kitchen area and is performed by Cornell dining staff, not students or other dining hall users. Therefore, the level of contamination is much lower than typical and the material may be acceptable for either pyrolysis or anaerobic digestion. For the relatively small amount of composted waste that is “post-consumer,” additional education, screening, and separation programs at the dining halls are in place to produce a higher quality feedstock for the CURBI processes. It is expected that dining hall waste
would be transported on a daily basis from the dining halls to the CURBI site for immediate incorporation into the dry fermentation process. Prompt treatment or composting of dining hall wastes is important to reduce odors and other nuisance problems which could be associated with open storage.

The Cornell dining halls also produce about 6,000 gallons/year of used vegetable oil, which could be readily converted to biodiesel fuel or added to an anaerobic digester for conversion to biogas. Biodiesel conversion equipment could be located at the CURBI site or at another location. Storage tanks for used vegetable oil should be located in a heated area to reduce gelling during cold weather.

3.5 ALKALINE HYDROLYSATE

Alkaline hydrolysate from the CCVM would be produced on a highly variable basis, depending on the needs for disposal of animal remains. Since biological processes such as anaerobic digestion operate most efficiently with consistent feedstock quantity and characteristics, it will be necessary to install storage tanks for temporary storage of alkaline hydrolysate prior to treatment. Since the alkaline hydrolysate has a high potential for strong odors, a sealed transportation and storage system will be necessary. It is anticipated that alkaline hydrolysate waste would be pumped into a transport truck equipped with vapor balance and dry break connections to minimize fugitive odors during loading. Hydrolysate would then be transported to the CURBI site, where it would be loaded into an on-site storage tank, again using vapor balance, hoses, and dry break connections to minimize fugitive odors during the unloading process. Balancing these facility needs is the cost advantage to having an on-campus process to treat this waste. Cornell will be required to pay as much as $0.20 to $0.50 per gallon (2009 dollars) to truck and dispose of this material at a municipal wastewater treatment facility.

Bench-scale tests at the local municipal treatment facility suggest that this waste would be beneficial to the anaerobic treatment process at the plant without neutralization. However, the acceptability of this waste without pH neutralization may be dependent on loading rates of the hydrolysate and other materials and should be verified with bench and field tests specific to the system size and loading characteristics planned for the CURBI facility. In advance of such tests, it should be assumed that the alkaline hydrolysate may need to be buffered to approximately pH 8.0 by addition of strong acids, either at the CCVM facility or at the CURBI site.
The alkaline hydrolysate storage tank at the CURBI site must be located in a heated area or be equipped with heating devices to prevent the alkaline hydrolysate from congealing in the storage tank. Positive displacement metering pumps would be used to provide consistent feed of the alkaline hydrolysate to the anaerobic digestion process.