Background

Biomass is a distributed resource. It does not come out of a hole in the ground like fossil fuels. Consequently, the collection of this distributed resource at the utilization point (processing plant, bio-energy plant) is a major factor in the delivered cost.

The activities at Virginia Tech have been organized under the auspices of the "Biomass Logistics Consortium" (BLC). The BLC was organized in April, 2008 with two universities, Virginia Tech and University of Kentucky, and four companies, in addition Penn State joined the BLC at our December, 2008 meeting. Currently, there are three companies, Amadas Industries, Sea Box, Inc., and Multitrade Holdings, LLC that are members of the Consortium.

The BLC was organized specifically to apply the knowledge and technology developed for the container shipping industry to the problem of collecting herbaceous biomass from surrounding production fields and delivering it to a bio-energy plant. This is excellent technology---using it will require a paradigm shift in US agriculture.

Herbaceous Biomass Harvest Systems

Current herbaceous biomass harvesting systems can be divided into two divisions.

1. Bale systems
2. Forage systems

The bale systems are used in locations the crop can be dried in the field, harvested, and handled like a hay crop. The dry material (less than 20% moisture content) is baled in the field and hauled later, an operation known as "in-field" hauling. An advantage is gained by "uncoupling" the harvesting operation (baling) from the in-field hauling operation.

The forage systems are used where the crop must be handled wet (greater than 60% moisture content). The forage chopper has no on-board storage, thus a unit of in-field hauling equipment, wagon or truck, must be in place for the forage chopper to engage in harvesting. This system is a "coupled" system. When the in-field hauling equipment gets to the edge of the field it must dump into highway hauling truck so it can return to the forage chopper. Coordinating the operation of all this equipment is problematic. One delay stops the whole operation, a major disadvantage.

The bale system can be further divided into round bale systems and large square bale systems. Large square bale systems are being studied for wheat straw in Idaho (13 inch annual rainfall) and corn stover in Kansas (6 inch annual rainfall). The round bale systems are being studied in the Upper Southeast where the annual rainfall is 40+ inches.

The round bale, because the rounded top sheds water, protects itself in ambient storage. In effect each bale is a little storage unit with thatched roof. Net-wrapped round bales can be stored in single layer ambient storage for six months with less that 5% storage handling loss. These bales can also be left in the field after harvest and hauled a week or a month later.

Problem Description

In the Upper Southeast, much of the farmland is organized into relatively small farms. It is expected that the best cropland, suitable for grain production, will not be converted into switchgrass production. The land available is grassland, scrubland, and some pastureland. Cattle production is well established in the area of interest and it is unlikely that this activity will be displaced to any significant degree. This leads to the following assumptions/results;

30 mile radius for production area

1. 5% of total land area converted into feedstock production (90,500 ac)
2. 4 tons/ac average yield
3. 5-ft diameter net-wrapped round bales are the harvesting system of choice
4. Average moisture content of material shipped from storage is 15%

Plant Size Results

1. To achieve a reasonable economy of scale and reduction in processing cost ($/unit of energy product), the smallest plant is expected to be 20 to 25 tons/hour range. For a plant operating 24/7, the 25 tons/hour equates to 600 tons/day, or approximately, 42 tractor-trailer truckloads per day. Potential cellulosic ethanol production is 13.4 million GPY.
2. The average delivered-cost of feedstock increases as plant size increases. Therefore, the largest plant is expected to process about 50 tons/hour, or 1200 tons/day, equal to 84 truckloads per day. Potential cellulosic ethanol production is 26.8 million GPY.

Storage

Woody biomass is harvested year-round in the Southeast. Wood-fired electric generating plants operate with about 45 days at-plant storage in the winter and 20 days in the summer.

All herbaceous systems require some storage. The switchgrass system being studied at VT envisions that switchgrass will be harvested for 6 months beginning in August and ending in March before the new growth cycle begins. The crop is allowed to dry standing in the field and is cut and baled directly during the winter months. This compares to corn stover in the Midwest which must be collected after the grain harvest and before the fields are covered with snow, a harvest season of about 5 weeks.

The main reason the Southeast will lead the nation in bio-energy is the availability of abundant quantities of both woody and herbaceous biomass. A bio-energy plant that can campaign feedstocks, meaning they can use herbaceous materials for x months and woody for (12-x) months, will have a lower average delivered cost for feedstock.

Organization of Feedstock Logistics

It is expected that the bio-energy plant will buy the feedstock at Satellite Storage Locations (SSLs), not have individual farmers deliver. The farm gate contract covers the cost to grow, harvest, and store round bales in the SSL. Each producer under contract gets the same farm gate price, no matter how far from the plant. The bio-energy plant contracts with hauling companies to load and haul the material in the SSLs. These companies will use specialized equipment---emulating the container shipping industry---and operate year-round.

Hauling Cost

The hauling cost is divided into three components: loading, trucking, and unloading. The loading cost and unloading costs are both independent of the distance from the plant. Truck cost ($/ton) is dependent on the number of loads per day per truck, thus it always increases with travel distance. This parameter is the reason we have chosen the 30-mi radius for the production area for an individual plant.

Key Interaction within Logistics system

As the distance from the production field to the SSL is increased, the in-field hauling cost per ton increases due to longer haul times with more fuel consumed. The farmer wants a short haul distance. If the SSLs are positioned to limit the distance traveled from the field, then there will be a large number of widely scattered SSLs. Smaller SSLs require the hauling contractor to move the loading equipment from SSL to SSL more frequently, thereby increasing hauling cost. An optimum compromise between the farmers and contractors transporting cost must be found to achieve the lowest delivered cost of the feedstock.

We are studying two system options to address the problem.

1. Option A - The SSLs are located such that the distance from the production field to the SSL will to be relatively small. This option is to have more SSLs and a highly mobile set of loading equipment that can quickly move from SSL to SSL. We expect that the smallest SSL will be loaded out in three days. This option will incur additional cost for transporting the loading equipment from SSL to SSL, but it will result in savings for the farmers.

2. Option B – This option is to have permanent equipment at each SSL. This option will enforce minimization of the total number of SSLs in order to reduce the equipment cost. It envisions fixed equipment at each SSL, which will continuously receive deliveries from farmers and, in return, continuously ship bales to the bio-energy plant. Under this option, the problem is simplified since the movement of the loading equipment is not involved.

The problem that we intend to address first is the determination of the best locations of the SSLs in order to minimize the costs incurred by both the farmer and the haul contractor. This will be followed by a study of the structural properties of the integrated location-allocation and traveling salesman problem.

Overall questions to be answered

1. What is the optimal number of SSLs and how is this affected by the density of fields?
2. What is the optimal size of each SSL and how many fields does it cover?
3. What is the best way to manage inventory of full and empty racks at each SSL and at the plant?
4. How many racks are required for the entire system?

5. How many sets of loaders/unloaders are needed, or should every SSL have its own permanent equipment? (Option A or Option B)
6. How much storage capacity is needed at the plant?
7. In what order, when, and how often should each SSL be unloaded?
8. What storage cost should the plant pay the farmers?