Results of biomass harvesting in Alabama

A project was initiated in 2007 in an effort to develop a small scale harvesting system that will economically and efficiently deliver a biomass product to an alternative energy plant. Several criteria were considered important in the development of this system:

a) The system has to operate in an environmentally friendly manner. Landowners are becoming more selective and aware of good harvesting practices that meet important state best management practices and increasing aesthetic expectations.
b) Capital requirements for the system should be kept to a minimum. Most small businesses cannot afford large up-front investments.
c) The system should be fuel efficient – fuel is not only expensive, but it is important to keep the strong positive energy balance derived from using forest products.
d) Daily operating costs need to be minimal to economically deliver a product to a market that does not have much price allowance for their raw material costs.

Various equipment for the harvesting system were procured in late 2007 and early 2008. The system consists of the following three pieces of equipment:

1) ***Felling:*** Felling was completed by a small excavator (John Deere 75C) with a Fecon shear head (Figure 1). This was a new type of harvester that has not been evaluated. The ability of this machine to reach for trees rather than driving from tree-to-tree enhanced productivity with the small stems. It also minimized residual stand damage and ground disturbance. Initial testing of this machine demonstrated some inefficiency in the boom design and speed of the shear; we hope to address both of these problems with continued studies.
2) ***Extraction:*** The primary extraction machine was a small 50 h.p., hydro-static drive Turbo Forest skidder (Figure 2) mounted with a Fecon swing arm grapple. There is currently only one manufacturer of a small skidder in North America, so demonstrating the viability of a small machine might open this market for additional manufacturers. Operation of this skidder determined the current machine is slightly underpowered and the swing grapple did not grab enough trees; thus limiting production.
3) ***Processing:*** Once the material was brought to the landing, it was fed to a Morbark Typhoon 325 horsepower chipper (Figure 3). The chipper was equipped with a small loader for easy handling of the material and eliminated the need for a separate loader. This configuration was chosen because it allowed one operator to complete all the work on the landing.

Figure 1. John Deere 75C with a Fecon shear head.

Figure 2. Turbo Forest skidder with a grapple attachment.

Figure 3. Morbark Typhoon chipper with a loader attachment.

If the entire system was purchased new, the complete cost could be less than $300,000 (<50% of the cost of a conventional mechanized system). Fuel consumption was also determined to be low, with the feller-buncher and skidder both using less than 2 gallons per hour and the chipper around 10 gallons per hour. Under production, this system was able to put the chipped material into a van for about 1 gallon of fuel per green ton of chipped material. Considering many of the biomass to ethanol conversion processes estimates 80 gallons of ethanol per dry ton of biomass, this should keep a very positive energy balance for this system.

Stand description and treatment applications

Two stands were harvested on Auburn University's Mary Olive Thomas Educational Forest just outside of Auburn, AL. The first stand was a thirteen year-old loblolly pine plantation with a small to moderate amount of natural regeneration. At the time of harvest the stand had no previous silvicultural or operational treatments applied to control the natural regeneration or to thin the stand. The second stand was a thirteen year-old naturally regenerated loblolly pine stand with a small hardwood component. This stand was subject to a burn approximately one year prior for the purpose of thinning the stand and controlling the small hardwood component.

Both stands were approximately five acres in size. Each stand had rows approximately 30 feet apart marked for the operator. All rows in the stand were cut on the first pass and then the feller-buncher thinned between rows on a second pass. The silvicultural objective of the biomass harvest was to thin both stands to a residual basal area of 70. Trees per acre and removal per acre can be seen in Table 1. The residual stands reached their target basal area with the Plantation having a 67.83ba and the Natural stand having a 72.51ba

Table 1. Stand data and removals volumes of harvested areas.

Stand	**Beginning (TPA)**	**Residual (TPA)**	**Removal (tons/acre)**
Plantation	676	292	45
Natural	1022	252	48

Equipment production

The operators had previous experience harvesting both pine and hardwood tracts. Data was collected by several methods, including the use of data recorders, videotaping the machines during operation, and in some cases manually recording data. The following tables include data to estimate the production of the three machines. More time is needed to develop curves indicating the impact of tree size on felling performance and how distance affects skidding production.

The productivity data for the feller-buncher is summarized in Table 2. Both stands showed very similar results. Data was further divided into cutting rows and thinning between rows; this data showed some discrepancies in cycle times with thinning between rows being slightly more time consuming.
Bunch size was limited by the size of the grapple on the skidder and the operator did a good job of sizing the bunch to optimize the pull. Heavier TPA counts in the Natural stand did lead to slightly more residual down woody debris.

Table 2. Trees per minute and Trees per Bunch for the John Deere feller-buncher

Site	N	Trees/Minute	Trees/Bunch
Plantation	249	2.10	4.06
Natural	242	2.17	4.34
Total	491	2.13	4.20

Turn times and turn distances were collected for the skidder using a MultiDAT recorder. Four-hundred and thirty-five cycles for the skidder were recorded (Table 3). Distance was measured for the full roundtrip cycle as was turn time. With an average turn time of 4:53 minutes, the operator was able to make approximately 13 turns per productive hour. Turn volume was estimated by recording tree size, and was also calculated by determining the volume in a truck divided by the total number of turns.

Average volume per turn for the study was 0.55 green tons/turn. For this study on these sites, total skidder productivity was determined to be 7.15 tons per productive hour.

Table 3. Skid distances and cycle times for the skidder from GPS data.

		Distance (feet)			Time (minutes)		
Site	N	Mean	Min	Max	Mean	Min	Max
Plantation	172	856.08	167.54	1742.08	3.83	1.17	7.42
Natural	263	1339.49	546.88	2396.07	5.00	2.32	12.20
Total	435	1148.34	167.54	2396.07	4.53	1.17	12.20

Collecting production data for the chipper was less comprehensive because it could far out-produce the other two machines. Several vans were filled in just over 1 hour each; others took longer because of tree size or crooked material. Average load size was 24.71tons/load. Production for the chipper was determined to be ~20tons/productive hour.

System costs

An excel spreadsheet program developed by Robert Tufts called CashFlow was used to estimate the total cost per ton to load the material into a van. This program uses the current depreciation schedule as required by the IRS, and includes costs for maintenance, fuel and interest costs for loans on equipment to do an after-tax analysis. It summarizes the total cost of owning and operating a machine over the economic life of the machine.

Several assumptions were made for the analysis including:

1) Fuel cost of $2.50/gallon for off-road diesel
2) Economic life of 5 years for all three pieces of equipment
3) Loan life of four years with no down payment
4) 6 percent interest rate on loans
5) Total production rate of 14,523 tons per year
6) 33% indirect cost was added onto total equipment estimates

Capital costs for the three machines were estimated at $95,000 for the feller-buncher, $90,000 for the skidder, and $110,000 for the chipper. Total cost to run the system and load vans was calculated to be between $16.00 and $16.50/ton, depending on the type of stand, over a five-year ownership period. Slightly over two truckloads per day are being produced depending on the skid distances and stand types. When you add in trucking and something for stumpage and profit, this cost estimate is higher than most biomass markets can currently pay. Higher production is needed to make the system economically feasible. Most likely, three to four loads a day should provide the volume needed to make the system cost effective.

System production was based on observation of the machines running on each site for a specific amount of productive time. For the cost analysis, utilization was set at 75%, which is higher than was attained by the students. This higher utilization is justified because the students had downtime due to data collection, trucking delays, and the swing grapple on the skidder causing problems. The swing grapple configuration will likely not be used by the manufacturer of a small skidder; a more conventional grapple will be installed on machines coming to market.

To attain the goal of three to four loads per day, several improvements could be implemented. The first has already been mentioned; changing the grapple configuration to a more conventional arrangement. This modification will have two benefits: it will reduce downtime, but should also allow for greater sized bunches to be pulled to the landing, thus making the skidding function more productive. The feller-buncher could also become more productive with some slight modifications (which we cannot do on a leased piece of equipment). Purchasing the machine without a boom and retro-fitting the machine with a boom better configured for a woods application will make the machine more productive. Also, getting more flow to the shear head through use of an auxiliary hydraulic pump will improve the felling cycle times. The chipper is currently being underutilized, so attaining additional production requires no changes.

Total system costs were re-analyzed with these changes. The capital cost of the feller-buncher was increased by $5,000 for the modifications. Machine production was raised from 9.7 tons/PMH to 12.5 tons/PMH, reflecting the improvements in performance from the modifications. Total system production was raised to 25,000 tons/year, or 75 tons/day(3 truck loads). Indirect costs were kept at 33%. Total system cost decreased to $12.23/ton. If haul distance is kept under 40 miles or so, the market should allow enough to pay the trucker, give the landowner something and still have a profit for the logger.

Residual damage

Damage was divided into stem and crown damage, and further categorized into minor and major damage for each category (Table 4). Minor damage is damage that a tree can typically recover from, whereas major damage could result in adverse effects for the tree. It should be noted that the percent damage is based on the residual stand, and some comparable damage studies base the percentages against the pre-harvest stand (the original TPA).

The natural stand was higher in both residual stem and crown damage. This is most likely due to the heavy initial stand stocking (1022 TPA) in comparison to the plantation site (676 TPA), and that there were no well defined rows established before harvest. Overall, 15% of the natural stand incurred some type of stem damage opposed to 7.6% of in the plantation, while 7.1% of the crown in the natural stand incurred damage opposed to 3.8% in the plantation.

Table 4. Percentage of residual stand damaged.

Stand	Damage of Residual Stand			
	Stem *Minor (<10cm^2)*	*Stem* *Major (>10cm^2)*	*Crown* *Minor (<1/3)*	*Crown* *Major (>1/3)*
Plantation	7.6%	0	3.8%	0
Natural	4.3%	10.7%	0	7.1%

Table 5 is a list of the disturbance classes and their percentage of the sampled plots. Shallow disturbance (litter removed or litter and topsoil mixed), deep disturbance (topsoil disturbed to a greater extent), and slash cover were measured at more precise disturbance levels, but are combined under a general disturbance class for the purpose of this summary.

Soil disturbance results are very similar for both stands. The plantation retained 60% of the stand in an undisturbed state, had a moderate amount of shallow disturbance, and had a very minimal deep disturbance. When we combine this with the fact that there was no recorded major stem or crown damage in the stand, we can be very pleased with the environmental sensitivity of the harvesting system. The natural stand also did well with 50% of the site remaining undisturbed. Shallow and deep disturbance were also very minimal for the site.

Overall, the slash content for the natural stand was higher than that of the plantation. This is most likely due to the heavier stocking of smaller trees in the plantation which resulted in the breaking and knocking down of smaller dead trees during harvest.

Table 5. Soil Disturbance Analysis

Stand	Sample	Disturbance Class				
		Undisturbed %	Shallow Disturbance %	Deep Disturbance %	Slash Cover %	Non-soil %
Plantation	*pre*	89.18	1.43	0	3.88	5.51
	post	59.96	31.02	1.02	7.96	2.04
		-29.22	***29.59***	***1.02***	***4.08***	***-3.47***
Natural	*pre*	80.82	6.53	0.61	9.18	2.86
	post	48.78	34.08	2.24	12.04	2.86
		-32.04	***27.55***	***1.63***	***2.86***	***0***

Summary

The objective of the project was to investigate the feasibility of a small scale harvesting system that would produce a biomass feedstock for an alternative energy plant. The system had to be cost competitive and environmentally friendly. A boom-type, feller-buncher, a small skidder and a chipper were tested as a system. Based on residual damage assessment, the system can do an acceptable job for a landowner, but residual damage seems to increase with a greater pre-harvest TPA counts. This seems logical, as since there are more initial trees in the stand, it will be harder to avoid making contact with residual trees as we work in the stand.

Production from the system did not reach the desired levels, but some modification should make at least the 3 load/day goal attainable. The system was able to produce slightly over two truckloads per day; some changes to the feller-buncher and skidder will be necessary to complete the third load. The system currently can fill a van for ~$16.50/ton, but if the increased production can be attained costs will drop to $12.23. When trucking, stumpage and profit are added, the market will need to be in the low $20 range to make the higher producing system economical.

There are several areas where future research could help. Implementing some of the improvements we listed and documenting the increased production will show the economic feasibility of the system. Also, related to biomass, developing a system to efficiently handle residues from a conventional operation could be a viable application across the South.