Results of biomass harvesting in Missouri

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. This project was funded from various sources, including the Missouri Forest Product Association. 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 inefficiencies 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

Five stands were harvested in the Mark Twain National Forest on the Poplar Bluff Ranger District (Table 1). Two stands (17, 46) in compartment 50 of the Pine Ridge East Project had a silvicultural prescription to remove all trees less than 9 inches DBH. This cut was intended to meet the desired management objective of a “shelterwood w/reserves”. The other three stands (94, 68, and 51) in compartment 137 of the Cane Ridge East Project had a silvicultural prescription to remove all trees less than 9 inches DBH, but with a follow-up commercial harvest that will meet the desired management objective of an “Open Woodland”.

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

Stand	Beginning (TPA)	Residual (TPA)	Removal (tons/acre)
46	184.4	80	17.38
17	202.9	44.3	12.78
68/51	371.3	112.5	19.06
94	242.5	97.5	14.69

Stands 17 and 46 were harvested for the same treatment, shelterwood, and were chosen to harvest because of their similar stand characteristics but varying slopes. Stand 17 (7 acres) was the low slope treatment, <10%, and stand 46 (4.1 acres) was the high slope treatment, 10% - 25%. Both stands had been harvested for sawtimber approximately 1 year beforehand. The biomass harvest was required to fulfill the silvicultural prescription, and leave the residual stand with a 30-50 BA.

Stands 94, 68, and 51 were all partially harvested for the same treatment, open woodland, and were also chosen because of their similar stand characteristics and varying slopes. Only portions of these stands were harvested due to their larger acreage size and positioning. A combination of stands 68 and 51 was used to create a high slope (10% - 25%) treatment area of 8 acres. Stand 94, which was originally 23 acres, received a low slope harvest treatment on 8.4 acres. The open woodland treatment is a two-stage treatment with a biomass harvest occurring first and a sawtimber harvest occurring at a later date. The final stand after both stages of harvest should have a 30-50 residual BA.

Stand volume and removal varied for each stand (Table 1). The variability in stands 46 and 17 were primarily due to the sawtimber harvest and the residual sawtimber sized trees that were left on the stand. Stand 68/51 was the most heavily stocked of all the stands, resulting in the highest tons per acre removal. The average removal for the entire study was 15.78 tons per acre.

Equipment production

The operators were given a few days to get experience and understanding on harvesting the mostly hardwood stands, especially where slope was involved. Data was then 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. Stands 46 and 17 were harvested after a commercial operation, so trees were spread further apart. In the other two stands where the

biomass thinning occurred first, there was less travel between trees and therefore greater productivity. There was also an indication of a learning curve, but more analysis is needed.
Bunch size was limited by the size of the grapple on the skidder and the operator did a good job of sizing the bundle to optimize the pull. It took between 5 and 6 trees to make most bundles, and it took around 40 bundles to fill a truckload.

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

Site	N	Trees/Minute	Trees/Bundle
46	255	1.13	4.72
17	251	1.64	5.48
68/51	95	1.68	5.28
94	571	1.97	6.07

Turn times and turn distances were collected for the skidder using a MultiDAT recorder. Over 600 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 3.67 minutes, the operator was able to make approximately 16 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 0.64 tons/turn. For this study on these sites, total skidder productivity was determined to be 10.5 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
46	105	782.32	131.99	1674.82	4.35	0.63	11.68
17	178	926.13	17.48	3442.46	3.91	1.10	11.57
68/51	213	665.18	100.77	1361.05	3.78	0.98	10.80
94	149	706.99	114.12	1464.97	2.73	0.95	5.37
Total	645	764.81	17.48	3442.46	3.67	0.63	11.68

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 23.85tons/load. Production for the chipper was determined to be 18tons/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 $3.75/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 16,800 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 $17.31/ton over a five-year ownership period. Just less than three truckloads per day should be produced. When you add in trucking, 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.

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 80%, 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 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 10.5 tons/PMH to 15.6 tons/PMH, reflecting the improvements in performance from the modifications. Total system production was raised to 25,000 tons/year, or 100 tons/day. Indirect costs were kept at 33%. Total system cost decreased to $12.73/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

Residual tree damage varied from site to site. On sites 46 and 17 all sawtimber harvest damage was omitted and values reflect only that damage caused by the biomass harvest. 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 only notable damage was the amount of minor stem damage in stand 46. This stand was a high slope treatment with heavy slash. It appears that the combination of slash and high slope caused difficulties for the skidder driver in avoiding residual trees. Additionally, no damage was recorded in stand 94, a stand with low slope and no slash.

Table 4. Residual tree damage for harvested sites

	Percentage of Damage of Residual Stand			
Stand	*Stem Minor (<10cm^2)*	*Stem Major (>10cm^2)*	*Crown Minor (<1/3)*	*Crown Major (>1/3)*
46	32	2.5	0	2.5
17	3	3	3	3
68/51	1	2.2	0	1
94	0	0	0	0

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 strongly correlated with treatment. More specifically, the disturbance differences in treatment types can most likely be attributed to the sawtimber harvests on stands 46 and 17. As can be seen from the table, the open woodland treatment areas (68, 94) had a much higher initial undisturbed area than that of the shelterwood treatments (46, 17). Yet, post harvest disturbance shows that the undisturbed areas are relatively similar, with open woodland treatments being only slightly less disturbed. Shelterwood treatments also have higher slash contents than the open woodland treatments; this is a direct result of the previous sawtimber harvest. Overall, the vast majorities of harvested stands are undisturbed or have shallow disturbance. Of those stands with deep disturbance, the majority of it is less than 5 centimeters deep.

Table 5. Percentage of soil disturbance after biomass harvesting on the 4 sites

		Disturbance Class				
Stand	**Sample**	Undisturbed	Shallow Disturbance	Deep Disturbance	Slash Cover	Non-soil
46	*pre*	41.43	41.19	1.43	12.38	3.57
	post	30.25	45.5	8.25	14.50	1.50
		-11.18	***4.31***	***6.82***	***2.12***	***-2.07***
17	*pre*	39.29	42.86	7.38	10.00	0.48
	post	34.00	51.5	1.50	10.50	2.50
		-5.29	***8.64***	***-5.88***	***0.50***	***2.02***
68/51	*pre*	95.71	2.14	0.00	0.00	2.14
	post	36.43	46.67	9.77	3.81	3.33
		-59.29	***44.53***	***9.77***	***3.81***	***1.19***
94	*pre*	87.00	9.75	0.00	0.00	3.25
	post	42.62	43.57	8.33	2.86	2.62
		-44.38	***33.82***	***8.33***	***2.86***	***-0.63***

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, especially on flatter ground and in first harvest. Slope will require the operator to spend more time traversing the site more carefully.

Production from the system did not reach the desired levels, but some modification should make the 4 load/day goal attainable. The system was able to produce about three loads/day; some changes to the feller-buncher and skidder will be necessary to get the last load. The system currently can fill a van for $17.31/ton, but if the increased production can be attained costs will drop to $12.73. 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.