Processing Woody Biomass with a Modified Horizontal Grinder

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Abstract. This study documents the production rate and cost of producing woody biomass chips for use in a power plant. The power plant has specific raw material handling requirements. Output from a 3-knife chipper, a tub grinder, and a horizontal grinder was considered. None of the samples from these machines met the specifications needed. A horizontal grinder was modified to replace the teeth on the drum with chipping blades in order to process whole trees into biomass chips that met the power plant's size specification. The study was installed on the Shoal Creek Ranger District, National Forests in Alabama, near Heflin, AL. This biomass removal project was the first step in a wildlife habitat improvement treatment to convert a 37-acre stand of off-site planted loblolly pine (Pinus taeda L.) to longleaf pine (Pinus palustris M.). The trees were 15 years old with an average dbh of 4.0 inches and average total height of 30.5 feet. The time and motion study gathered data on whole-tree processing for short fiber chips (up to ½-inch long), short fiber chips from trees that had been partially delimbed to remove needles, and long fiber chips (up to ¾-inch long). The average production rate ranged from 24.9 – 38.2 green tons/productive machine hour (gt/pmh). A machine rate of $161.20/pmh was calculated, resulting in a cost of $4.22/gt for producing the long fiber biomass chips.

1.0 Introduction

A critical barrier to utilizing unmerchantable wood as a renewable energy source is the cost of processing and transporting the material to the end user. Stringent biomass specifications can make the processing more problematic.

The USDA Forest Service, Forest Products Lab funds several grants each year for the purpose of studying woody biomass utilization. One selected project proposed removing small diameter stems and unmerchantable woody material from National Forest lands and delivering it to a power plant in Alabama for co-milling with coal. There are many aspects to this study, and the partners include: The USDA Forest Service, National Forests in Alabama; CAWACO RC&D; Forest Based Economic Development Services; Southern Company, Precision Husky Corporation; Auburn University, Forest Products Development Center; and University of Alabama, Center of Economic Development. The Shoal Creek Ranger District of the Talladega National Forest and Plant Gadsden served as the demonstration areas for the project.

The objective of this study was to determine the costs associated with processing whole tree loblolly pine trees into biomass chips. Specifically, this study included (1) finding a machine that could process whole trees into biomass chips that meet the physical characteristics required, and (2) determining the production rate and cost of the machine.

1.1 Study Area

The study was installed in August, 2007 near Heflin, AL. Personnel of the Shoal Creek Ranger District identified a 37-acre stand of planted loblolly pine (*Pinus taeda L.*) for the study. From the land manager's perspective, the purpose of the biomass removal was the first step in a wildlife habitat improvement treatment to convert the stand from off-site planted loblolly pine to longleaf pine (*Pinus palustris M.*). The operational terrain was mostly flat with gentle slopes ranging from 0 - 15%.

District personnel performed a low intensity cruise (seven, 1/5-acre plots) to estimate the biomass available for removal. Trees ranged in size from 1 to 8-inches in dbh. The average dbh in the 15-year-old stand was 4.0 inches and the average height was 30.5 feet. The majority of the stems to be removed were pine (97%), with soft hardwoods (2%) and hard hardwoods (1%) making up the rest of the stand. The operational terrain within the stand was mostly flat with gentle slopes ranging from 0 - 15%. Trees over 8.5-inches in dbh were not included in the cruise and were not removed during the study. Volume to be removed was estimated to be 90 tons/acre, or 3,335 total tons. Of this volume, only 1,000 tons were needed at Plant Gadsden for the trials.

1.2 Equipment Selection

Felled trees needed to be processed to meet specific handling requirements of Plant Gadsden. Initially, a maximum 1/2-inch chip length was requested by the power plant engineers. Equipment selection began by examining the output from a variety of biomass communition machines.

The first chips examined were from a Precision Husky 1858 whole-tree 3-knife disc chipper. The raw product used was whole-tree small-diameter pine trees from a pre-commercial thinning operation. Fuel chips from this machine resulted in an unacceptable end product. The first problem was that the chip fibers were oriented mostly lengthwise. Since the disc is oriented at an angle to the end of the tree stems, it created chips with long fibers. When these longer chips reach the riffles in the plant's pipes, they will not pass through or break, causing plugging in the plant. The second problem occurred when handling small diameter material. The small branches and small stems tilted upward before being chipped resulting in longer chips. In addition, the thickness and width of the chips could not be adequately controlled with this machine.

Some of the chips from the first analysis were re-processed using a ProGrind 2000 tub grinder to try to further reduce the size of the comminuted material. Although this process resulted in an output that met the size and fiber orientation requirements, a new problem surfaced. The edges of the fuel chips were not sharp or clean. The grinder created fuzzy fibers on the edges of the chips that caused the wood particles to stick together. This new property would cause unacceptable handling problems within the plant.

Horizontal grinders were also considered. The fiber orientation and chip length could be more readily controlled with the horizontal drum as opposed to a chipper disc mounted at an angle.

However, the comminution action is by grinder teeth rather than knives, resulting in fibrous edges.

Chip width, length, thickness, fiber orientation, and clean edges were just some of the characteristics that were further defined due to the physical handling requirements in the plant. After review of output from several types of chippers and grinders, plus consideration of reprocessing in-woods whole tree chips, a proto-type machine was selected. Precision-Husky offered to modify one of their horizontal grinders (a ProGrind H-3045) to produce the biomass characteristics required for the power plant trials. Precision-Husky of Leeds, AL modified the basic machine to replace the coarse grinding teeth with cutting knives to meet the biomass specifications with one-pass processing.

1.3 Operation

A logging contractor, and his sub-contractor, provided all of the equipment (other than the Precision-Husky H-3045) used to create the chips for the power plant. A Hydro-Ax 670 drive-to-tree feller-buncher was used to fell and bunch trees. Bunches were skidded to the landing by a John Deere 648 G-III grapple skidder. At the landing, the skidder deposited bunches directly under the grapple of a Prentice 210D loader. Once the skidder left the immediate area around the loader, the loader operator picked up groups of stems and fed them into the Precision-Husky. The Precision-Husky was controlled by wireless remote from the loader. Chips were conveyed from the grinder's out-feed into open-top walking floor chip vans. All equipment operators had 20 years of experience or more.

2.0 Methodology

A time and motion study was performed on the loader. Landing operations were observed by researchers prior to starting the time and motion study to identify cycle elements. A cycle was defined as the time it took to process enough material to fill a chip van. A stopwatch was used to time individual elements on 17 loads. Trucks were weight scaled at the power plant. The total study time was 57 hours.

Only one productive cycle element was identified for the chipper, processing stems. The cycle element ended when the chipper was out of wood. A cycle for the chipper began when the loader began feeding stems and ended when the last chips came off of the out-feed conveyor.

The loader was either in productive time feeding stems, or in non-productive operational delays (wait for skidder, wait for truck to move van forward for loading, mechanical adjustments) or administrative delays. The number of stems per loader grapple were counted and recorded to determine the number of stems per load.

Moisture samples were collected by taking a composite sample from various areas of each of the sampled loads. Fourteen samples were collected in labeled 2-gallon plastic zippered bags to limit moisture loss during transport. Samples were collected using the same procedure that was used by power plant personnel. Moisture content was determined using ASTM Standard D4442-92(1997).

During the course of the field operations, an initial trial was run using the in-woods chips at Plant Gadsden. The initial test using the small (3/8 – 1/2 inches in length), specified chip yielded positive results with no feeding or handling problems. Based on the initial results, power plant engineers requested four different chip types for additional tests. The original size was the small, whole tree chips (short fiber). One of the alternate chips requested was short fiber, clean chip with fewer needles. Without having a gate delimber or other delimbing equipment available to make cleaner chips, the skidder backed drags (bunches) into an area of standing trees to break off limbs and small tops, in order to remove as many needles as possible. The other two alternate chips required an adjustment to the cutting blades on the grinder. The blades were adjusted outward from the rotor to make a chip with a longer fiber (1/2 – 3/4 inches in length). "Delimbed" and whole trees were used to create the long fiber clean and dirty chips. Data were collected on the delimbed and whole-tree short fiber chips, and on the whole-tree long fiber chips.

The hourly costs for the equipment were calculated using the machine rate approach (Miyata, 1980) with assumptions described in Brinker et al. (2002). Because this operation was implemented on federal land, federal wage rates were used (US Department of Labor, 2006).

3.0 Results and Discussion

Time and motion data for the Precision-Husky ProGrind H-3045 were collected on 17 loads consisting of: 7 clean small fiber loads, 7 dirty small fiber loads, and 3 dirty long fiber loads. The average productivity for a load was 29.22 green tons/productive machine hour (gt/pmh). The average moisture content was 53.78% (wet basis). Production rates for the three fiber types observed are listed in Table 1.

Table 1. Production Data for Precision-Husky H-3045

	Whole-tree					Delimbed				
Variable	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Short fiber										
Gross time (min)	7	86.1	31.57	61.6	135.3	7	80.8	20.8	60.7	115.1
Productive time (min)	7	71.2	8.49	61.6	87.7	7	64.2	5.09	57.1	72.6
Payload (gt) [a]	7	29.3	3.03	24.7	34.4	7	31.6	1.64	29.2	33.9
Production (gt/pmh) [a]	7	24.9	2.36	21.0	28.9	7	29.7	2.68	25.9	33.0
# stems/load	7	367.6	54.40	305	445	7	297.7	22.08	263	324
Long fiber										
Gross time (min)	3	47.2	1.52	45.7	48.7					
Productive time (min)	3	47.2	1.52	45.7	48.7					
Payload (gt) [a]	3	30.1	1.45	29.1	31.8					
Production (gt/pmh) [a]	3	38.2	2.27	35.8	40.3					
# stems/load	3	310.0	55.05	260	369					

[a] gt=green tons, gt/pmh=green tons/productive machine hour

The difference between the mean production times of the clean and dirty short fibers was significant (p-value = 0.0037, α=0.05). The mean production time for the dirty short fibers was

24.9 gt/pmh. Production time for the clean (delimbed) short fibers was 29.7 gt/pmh. The knives were changed during the last observation of the whole tree short fiber chips because they had been dulled in a test using an excavator to feed the grinder rather than a loader. The duller knives may have contributed to the slower production on the whole tree dirty fiber observations. (Production study data collection did not include any cycles where the excavator fed the H-3045). The mean production rate of the long fiber was the highest observed rate, at 38.2 gt/pmh.

Researchers collected observational data for 57 hours. This study time does not include the initial time spent observing the operation prior to data collection. The utilization of equipment on this study was low. There were lengthy delays waiting for empty chip vans to return from the power plant (120 miles round trip). Only three walking floor trailers were used and not all were available every day of the study. In addition, the skidder driver did not work on one of the study days. So, there were additional delays due to the interactions between the loader and skidder that day. The overall utilization observed during the study was 34%. However, because of the unrealistic utilization due to trucking, higher utilization rates were used in the cost analysis. During the time when trucks were available on site to be loaded and production data was collected, utilization rates of the loader and chipper were more realistic. The utilization rate of the loader averaged 80% and the chipper averaged 83%. These rates are different because when the loader completed the stem feeding cycle, the chipper was still processing stems.

Table 2. Machines Rates for Equipment Used in Study

	Precision-Husky ProGrind H-3045	Prentice 210D Loader	John Deere 648 GIII Skidder	Hydro-Ax 670 Feller-Buncher
Purchase Price	285,000	145,000	175,224	215,000
horsepower	520	142	180	205
Utilization (%)	83	80	60	65
Ownership Costs ($/smh[1])	37.20	16.65	23.90	34.12
Operating Costs ($/pmh[2])	116.38	22.42	36.34	45.29
Labor & Benefits($/smh[1])	0	19.27	19.27	19.27
Total Cost ($/pmh[1])	161.20	67.32	108.30	127.42

[1] scheduled machine hour
[2] productive machine hour

A machine rate for operating the Precision-Husky ProGrind was calculated with the utilization rate observed during data collection (83%). Off-highway fuel prices during the study were $2.85/gal. The cost of $161.20/productive machine hour (pmh) was calculated without an operator, as the operator is included in the cost of the loader. System costs are displayed in Table 2. The cost for the entire system was $464.24/pmh.

In this study, the biomass removal operation was a stand alone operation. No other products were removed. However, if biomass removal is incorporated into a harvesting operation where other products are removed, portions of the costs of the loader, skidder and feller-buncher could be assigned to the other products.

4.0 Conclusion

Stringent biomass size specifications were desired in this project. Chip output was examined from a variety of equipment types, and the Precision-Husky H-3045 was successful in producing a chip that met these specifications. The H-3045 produced short fiber whole-tree chips at an average rate of 24.9 gt/pmh. When the cutting blades were adjusted to create longer fibers, the production rate increased to an average 38.2 gt/pmh. The machine rate calculated for the grinder was $161.20/pmh. For the longer fiber chips, the cost was $4.22/gt. The cost for removing biomass using this harvesting operation was high because biomass was the sole product removed.

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