Evaluation of a Cut-to-Length System Implementing Fuel Reduction Treatments on the Coconino National Forest in Arizona*

John Klepac, Bob Rummer and Jason Thompson
USDA Forest Service, Southern Research Station, Auburn, AL
Email: jklepac@fs.fed.us; rrummer@fs.fed.us; jasonthompson@fs.fed.us

Abstract
A Cut-to-Length (CTL) system was evaluated for production and cost while implementing fuel reduction treatments in two stands on the Coconino National Forest in Arizona. Product recovery and fire behavior within each stand after treatment were also examined. Only trees less than 16 inches diameter breast height (DBH) were harvested. After logs were forwarded to a landing, the remaining slash in each stand was removed by the forwarder for fire hazard reduction. Time-and-motion data collected revealed the harvester produced 364 cubic feet (cf) per Productive Machine Hour (PMH) while harvesting sawlogs and 33 cf per PMH while harvesting biomass. Forwarder productivity averaged 690 cf per PMH while transporting sawlogs and 160 cf per PMH while transporting biomass. System cost, with profit and overhead, was estimated at $208 per Scheduled Machine Hour (SMH). Unit costs were $0.88 per cf while harvesting sawlogs and $9.62 while harvesting biomass.

1. INTRODUCTION

Decades of fire exclusion and little active management have resulted in millions of acres of National Forest land in the western U.S. with high fuel loads. These forests contain accumulations of flammable fuel that are much higher than historical conditions (Peterson, et al. 2005). These high fuel loads add to the potential for catastrophic wildfires.

The Coconino National Forest entirely surrounds Flagstaff, Arizona. Approximately 600 wildland fires occur annually in the greater Flagstaff area and about 60 percent of those are caused by lightning (http://www.gcfp.org/firerisk.htm.). From 1970 to the present, an average of 2900 acres burn each year in the area, and a majority of these acres burned catastrophically (http://www.gcfp.org/firerisk.htm.).

The cost associated with removal of fuel load, whether mechanically or through prescribed fires, is high. Historically, the types of small-diameter trees removed in fuel reduction treatments were considered non-merchantable and treated as slash or waste. However, this material should be removed because it can substantially increase fuel loading or attract insects that can subsequently kill remaining trees (Six et al. 2002). However, removal requires either better utilization or costly disposal.

The objectives of this study were to assess the economic and ecological costs and benefits associated with the harvesting and utilization of fuel reduction treatments and to evaluate in-woods decision-making regarding tree selection, residuals left on site, product suitability, and market opportunities. This paper addresses harvesting costs and productivity associated with performing fuel reduction treatments using a Cut-to-Length (CTL) harvest system.

* *The 29th Council on Forest Engineering Conference. Coeur d'Alene, Idaho, July 30-August 2, 2006. W. Chung and H.S. Han, editors. pp. 405-414.*

2. STUDY AREA

The study area was located on the Coconino National Forest near Flagstaff, Arizona and was comprised of two units, each totaling approximately 20 acres in size with ponderosa pine as the dominate tree species. The sale was prepared by marking the residual trees or a leave tree mark (LTM). Terrain was relatively gentle but rocky. Unit 1 had a pre-harvest density of 179 trees per acre (Figure 1) and a quadratic mean diameter (QMD) of 10.2 inches. The prescription called for removal of 105 trees per acre of trees less than 16 inches DBH resulting in 29 percent reduction in basal area. Volume removed totaled 3.98 hundred cubic feet (CCF) per acre for Unit 1 (Figure 2). Unit 2 had a pre-harvest density of 544 trees per acre (Figure 3). Trees were smaller with 57 percent of stems in the 1 to 4 inch DBH class and an initial QMD of 6.4 inches. The prescription was to remove approximately 451 trees per acre with a 56 percent reduction in basal area. Volume removed from Unit 2 totaled 8.03 CCF per acre (Figure 4).

3. HARVEST SYSTEM

The CTL system was comprised of a Timberjack[1] 1270 harvester and Timberjack 1010B 10-ton forwarder. The harvester was powered by a 204-hp engine and was equipped with four Nokia 700/50-25.5 tires on the front and two Nokia 700/55-34 tires on the rear. The forwarder was powered by a 110-hp engine. Products included firewood, sawlogs, and vigas. Vigas are logs used as rafters left exposed for aesthetic purposes in Southwestern homes.

4. METHODS

4.1 Stand Inventory

Prior to harvest eight 0.1-acre circular plots were installed on a grid within each study area. Within each plot DBH and total height were recorded for each tree along with a code indicating whether it was a cut or leave tree. Trees less than 18 inches DBH were measured to the nearest 0.1-inch using calipers and larger trees were measured with a D-tape. Tree heights were measured to the nearest 0.5-ft using a hypsometer. A numbered card was attached to each cut tree within a plot to account for volume cut during data collection. Percent slope and level of rockiness (low, med, high) were also recorded for each plot.

4.2 Harvest System

Production data were collected on each machine to estimate the machine production rate (volume per hour). The cost per hour and the production estimate were used to calculate cost per unit. The harvester was recorded on videotape as it cut through each study plot. The camera operator called out tree numbers as they were cut. To obtain additional detailed production data on the harvester, the harvest of trees outside of measured plots were also recorded on videotape.

---

[1] Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government.

These trees were tagged for another aspect of the study and DBH and total height were known. The diameter of surrounding non-tagged trees to be cut were measured and verbally recorded as they were cut. The harvester felled and processed trees at the stump into either sawlogs, vigas, or firewood. Regression analysis was used to determine the effect of tree size on time per tree.

Since Unit 2 had a large number of trees per acre in the 1 to 4 inch class, a feller-buncher was used to cut trees in this size class. The harvester was then utilized to cut and process more merchantable material.

For both units the forwarder hauled wood to roadside for loading onto trucks. Its productivity was measured using stopwatches to record cycle times. Elements recorded within a cycle included travel empty, load, intermediate travel, travel loaded, and unload. Regression analysis was used to determine the effect of haul distance on cycle time. Delays which occurred during a cycle were also measured and noted. Turn volume was estimated by classifying pieces as either large or small and estimating mean volume for each class size. The mean volume was estimated by measuring a sample of cut pieces throughout the unit prior to forwarding. Measurements of large and small end diameter, mid-point diameter, and length were collected on a sample of 155 pieces (Table 2). Volume of each piece was calculated using Newton's formula. To determine the cost of using the forwarder to haul slash from the site to roadside, forwarder bunk size was measured and a packing ratio of 0.1 (PNW GTR-364) was used to yield an estimate of solid wood volume (oven-dry) per cycle. This was done on only 10 acres of the unit.

5. RESULTS

5.1 Stand Inventory

Inventory data from the study site showing initial, cut, and residual stand density and volume per acre are displayed in Figures 1 through 4 below. In Unit 1 only trees less than 16 inches DBH were harvested which yielded a residual QMD of 13.4 inches and residual basal area of 71 ft^2 per acre. Residual QMD for Unit 2 was 10.4 inches with a residual basal area of 54 ft^2 per acre.

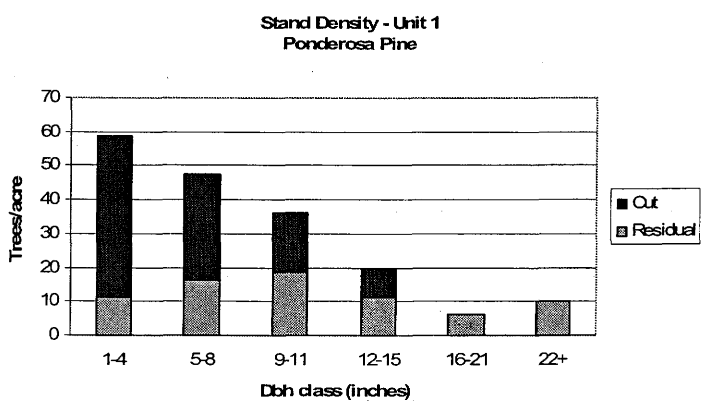

Figure 1. Diameter distribution for total, cut, and residual trees for Unit 1.

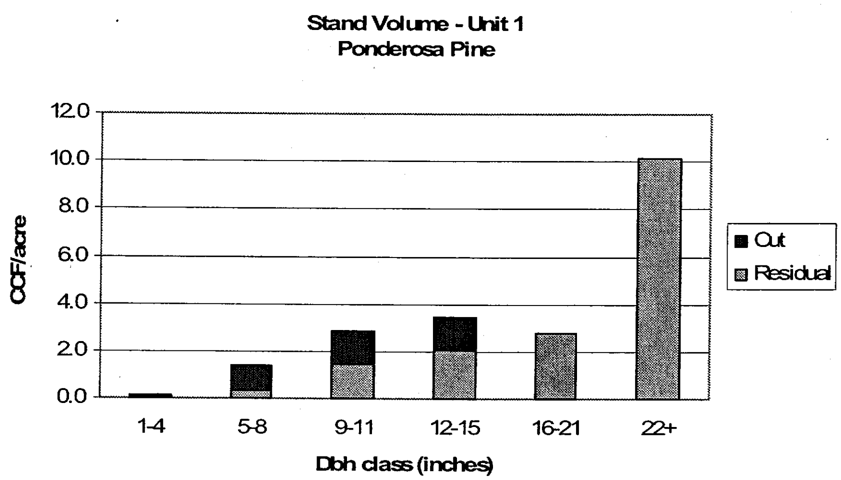

Figure 2. Total, cut, and residual volume per acre by diameter class for Unit 1.

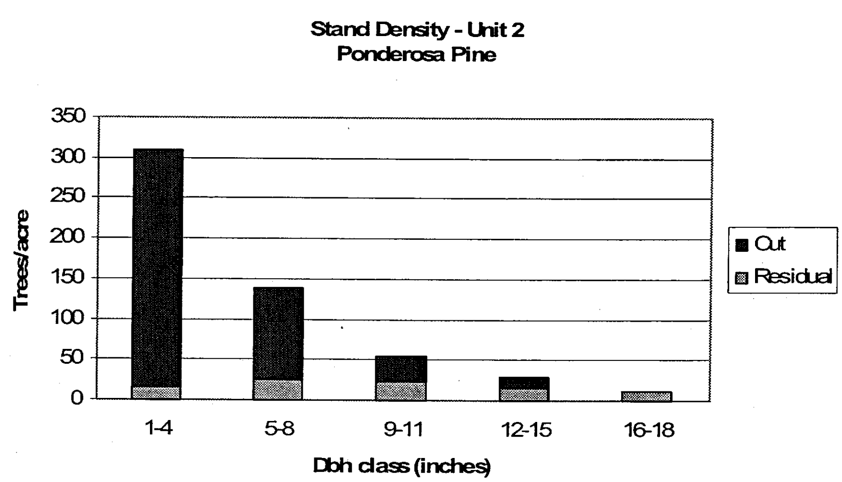

Figure 3. Diameter distribution for total, cut, and residual trees for Unit 2.

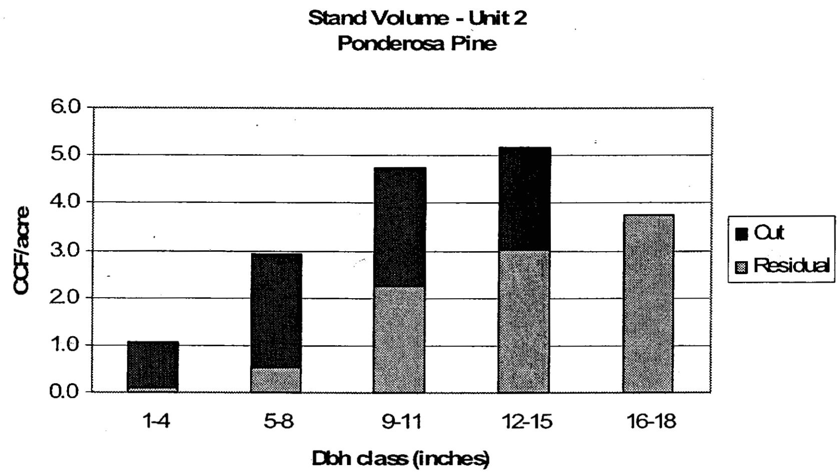

Figure 4. Total, cut, and residual volume per acre by diameter class for Unit 2.

5.2 Harvest System

5.2.1 Harvester

An unusually high number of delays were observed for the harvester while working thru the stand. A total of 60 delays were encountered during the 9-day period. Of these 22 (37%) were saw related. In-shift delay time totaled 27.65 hours for the study period. Out-of-shift delay time totaled 3 hours. Sixteen hours of delay time were attributed to waiting on parts for the head to arrive. Figure 5 shows the total and percent of delay time by category. Waiting repair time included machine down time due to waiting on parts to arrive. Active repair time consisted of repairing hose leaks, replacing thrown chain back onto bar, sharpening chain, and working on rollers. Service time included fueling, replacing bar, and replacing chain. Non-mechanical delays included removing hung bar, measuring logs for length, talking, and other miscellaneous occurrences. Personnel time included breaks and lunch.

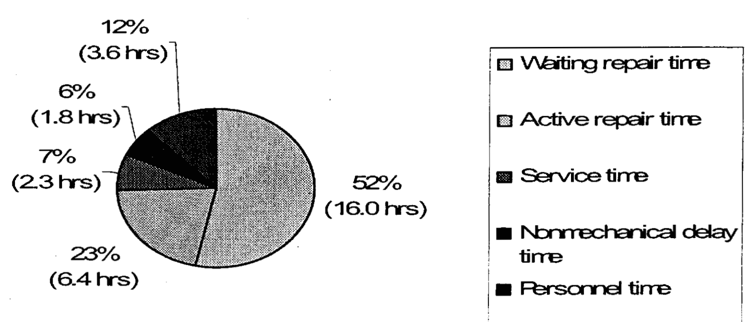

Figure 5. Breakdown of harvester delays by category.

The effect of DBH on cost per cf is shown in Figure 6. Harvesting trees in the 3 to 5 inch DBH class is very cost prohibitive. Cost per unit decreases dramatically for trees above 5 inches DBH.

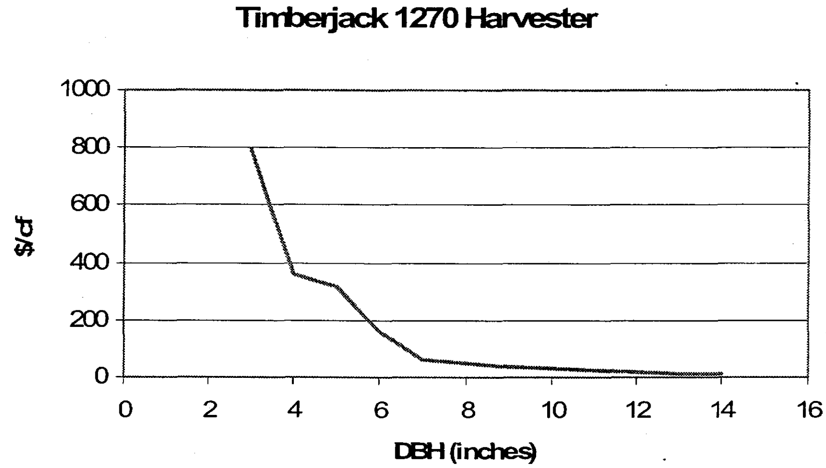

Figure 6. Effect of tree diameter on unit cost.

Gross time study data revealed that the harvester operated slightly over 24 hours of productive time, treated 17.6 acres, and harvested 1306 trees. This resulted in a production rate of 54.3 trees per hour, or 0.73 acres per hour. Analysis of detailed time study data from study plots revealed a production rate of 364 cf per PMH. General Linear Models procedure (SAS 1988) showed that DBH squared ($p < 0.0001$) was the most significant variable that influenced time per tree.

$$\text{Time per tree (sec)} = 24.796 + 0.31419 \cdot Dbh^2$$

$n = 138$; $R^2 = 0.50$

Time per tree included move, swing, cut, fell, and process elements. Processing included cutting products from the tree, delimbing, and topping. The relationship between DBH and time per tree is illustrated in Figure 7.

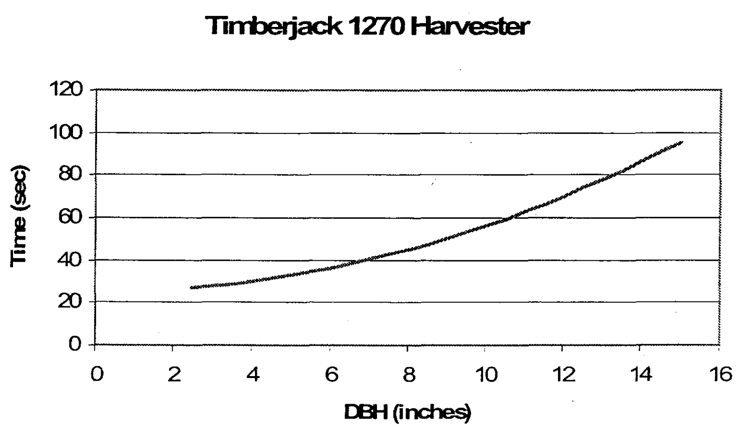

Figure 7. Predicted harvester cycle time for the range in DBH.

The harvester cut trees that ranged from 2.2 to 15.1 inches DBH. Mean DBH was 7.76 inches. A summary of time study variables for the harvester is shown in Table 1.

Table 1. Summary of elementary statistics for the 1270 harvester.

Variable	*N*	*Mean*	*SD*	*Min*	*Max*
Move (sec)	60	18.6	9.35	3.6	44.0
Move per tree (sec)	138	8.3	7.68	1.5	39.4
Reach (sec)	137	11.8	6.23	2.2	36.9
Fell (sec)	138	8.2	5.21	2.5	33.2
Process (sec)	138	13.9	15.75	0	98.9
Pile (sec)	109	5.0	2.15	1.1	14.8
Time per tree (sec)	138	46.1	21.60	18.2	149.8
No. of cuts	138	1.3	0.59	0	2
DBH (in)	138	7.8	2.77	2.2	15.1
Total height (ft)	138	37.6	9.38	10.0	62.5
Volume per tree (cf inside bark)	138	5.0	4.76	0.1	25.9
Productivity (cf per PMH)	138	363.5	272.30	14.3	1396.4

5.2.2 Forwarder

Elements evaluated for the forwarder included travel empty, travel loaded, intermediate travel, load, and unload. For the two units combined, one-way travel distance averaged 816 feet. The forwarder averaged 6.2 CCF per load of solid product which resulted in a mean productivity of 6.7 CCF per PMH. One-way distance for transporting slash averaged 157 feet. Table 3 summarizes elementary statistics for the variables measured.

Table 2. Elementary statistics for piece measurements.

Variable	*N*	*Mean*	*SD*	*Min.*	*Max.*
Large end diameter (in)	155	10.4	2.82	4.6	19.5
Mid-point diameter (in)	155	8.2	2.05	3.8	16.0
Small end diameter (in)	155	6.7	1.94	2.7	12.4
Length (ft)	155	19.1	3.57	10.0	30.0
Volume (cf)	155	8.0	4.69	1.4	27.2

General Linear Models procedure (SAS 1988) was used to develop regression equations for predicting elemental time for each dependent variable while hauling wood. Travel empty and loaded times were combined in the analysis into a total travel time. Total travel distance was the most significant independent variable affecting travel time ($p < 0.0001$). For intermediate travel time load volume ($p = 0.0132$) and total number of pieces loaded ($p = 0.0218$) were the most significant independent variables. Load time was a function of the inverse of the number of swings to load ($p = 0.0012$). For unloading, the mean unloading time was the best estimator. Regression equations for the above mentioned variables are shown below. The effect of total travel distance on cost per CCF for the forwarder hauling sawlogs is shown in Figure 8.

Table 3. Summary of elementary statistics for the 1010B forwarder.

Variable	*Sawlogs*					*Biomass*				
	N	**Mean**	**SD**	**Min**	**Max**	**N**	**Mean**	**SD**	**Min**	**Max**
Trv. empty (min)	22	5.1	4.57	0.6	17.3	15	1.6	2.43	0.3	10.1
Int. travel (min)	23	7.9	5.13	0.9	18.5	15	4.9	2.16	0.8	8.6
Load (min)	23	24.4	6.08	14.5	35.0	15	15.6	4.98	7.6	28.1
Trv. loaded (min)	22	6.4	3.76	0.5	13.3	15	1.9	1.06	0.6	3.8
Unload (min)	22	13.2	4.65	4.9	24.1	15	2.6	0.84	1.1	3.8
Total time (min)	22	56.6	6.74	40.6	66.2	15	26.6	7.01	17.1	44.2
Load volume (cf)	23	619.3	187.59	313	1102	15	665.6	0.00	665	665
Productivity (CCF/PMH)	23	6.7	2.37	3.1	13.7	15	1.6	0.38	0.9	2.3
Trv. empty dist. (ft)	23	662.2	576.43	56	1770	15	110.8	71.40	32	280
Trv. loaded dist. (ft)	23	969.2	504.66	90	2001	15	204.1	134.64	45	543
Total dist. (ft)	23	1631.4	1001.68	295	3521	15	314.9	158.39	133	684
# pcs per load	23	71.8	15.71	46	116	-	-	-	-	-
# pcs per swing	23	2.4	0.70	1.8	4.8	-	-	-	-	-
# swings to load	23	30.7	5.51	22	43	-	-	-	-	-

*Travel time (min) = 1.4657 + 0.006102*TDist*
where TDist = sum of travel empty and travel loaded distances in feet
$n = 23$; $r^2 = 0.74$; C.V. = 32.60

*Intermediate travel time (min) = 1.128 + 0.02541*LoadVol – 0.2773*TotalPcs*
where LoadVol = load volume in cubic feet; TotalPcs = total pieces loaded
$N = 23$; $r^2 = 0.27$; C.V. = 57.57

Load time (min) = 47.157 – 678.01(1/Swings)*
where Swings = total number of swings to load
$n = 23$; $r^2 = 0.40$; C.V. = 19.75

Combining the previous equations and adding mean unload time resulted in the following equation for predicting total cycle time for the forwarder.

*Total time (min) = 62.951 + 0.006102*TDist + 0.02541*LoadVol – 0.2773*TotalPcs - 678.01*(1/Swings)*

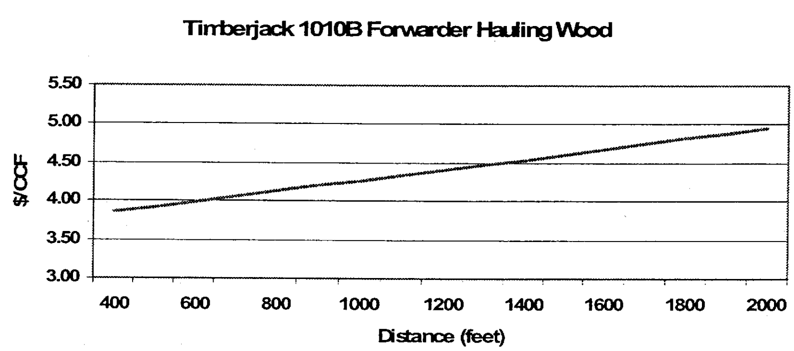

Figure 8. Effect of total travel distance on cost per CCF.

5.3 Costs

Machine costs were estimated using a machine rate analysis (Miyata, 1980), which reflects the average yearly owning and operating cost over the life of the machine. Ownership costs were estimated using a 5 year life, 20 percent salvage value, 10 percent interest rate, 4 percent of AYI for insurance and taxes, and 2000 scheduled machine hours (SMH) per year. Operating costs were estimated assuming a repair and maintenance rate of 110 percent of annual depreciation for the harvester and 100 percent for the forwarder, a fuel consumption rate of 0.02917 gal/hp-hr for the harvester, 0.02488 gal/hp-hr for the forwarder, a fuel cost of $2.15 per gallon, a lube cost of 36.8 percent of hourly fuel cost, and a utilization rate of 65 percent (Brinker, et al. 2002). A rate of $15 per hour was used for operator wage, plus 30 percent benefits. Profit and overhead were assumed to be 20 percent. Table 4 summarizes these costs for the two machines.

Table 4. Owning and operating costs for CTL machines.

Variable	*Harvester*	*Forwarder*
Purchase price ($ x 1000)	476	276
Salvage value ($)	85,250	55,250
Depreciation ($/yr)	68,200	44,200
AYI ($/yr x 1000)	290	188
Owning costs		
Interest ($/yr)	28,985	18,785
Insurance and taxes ($/yr)	11,594	7,514
Total Owning ($/SMH)	54	35
Operating costs		
Tires ($/PMH)	1.97	2.63
Fuel ($/PMH)	12.79	5.88
Lube and oil ($/PMH)	4.71	2.17
Repair & maint. ($/PMH)	57.71	34.00
Total Operating ($/SMH)	50	29
Labor & benefits ($/SMH)	19.50	19.50
Total Cost ($/SMH)[1]	124	84

[1]Includes 20% profit and overhead.

A comparison of system rates and costs for harvesting sawlogs and biomass are summarized in Table 5. Cost per cubic foot for handling biomass is eleven times more expensive than handling sawlogs.

Table 5. Cost summary for the CTL system.

Machine	*Productivity (cf/PMH)*		*System Rate (cf/SMH)*		*System Cost*			
					Sawlogs		Biomass	
	Sawlogs	Biomass	Sawlogs	Biomass	($/SMH)	($/cf)	($/SMH)	($/cf)
Harvester	364	33	237	22	208	0.88	208	9.62
Forwarder	690	160						

6. CONCLUSIONS

In the current system configuration, the harvester was the limiting machine while producing both sawlogs and biomass. While handling sawlogs, the forwarder could outproduce the harvester by about 2 to 1. With biomass, the difference was nearly 5 to 1. While small trees affected harvester more than forwarder productivity, both machines had significantly reduced output with biomass material. In fact, the cost per ton treated was nearly ten times greater for biomass than for sawlog products.

The most significant issue highlighted here is the inefficiency of using a single-grip harvester to handle small trees for a biomass product. Harvester productivity, on a volume basis, is greatly reduced as tree diameter decreases. In addition, the harvester logged less than 50 percent availability, mostly related to repairs on the harvester head. Given the high cost of treating smaller material with the CTL harvester, such treatments should carefully examine alternatives for the smallest material in a stand. These may include options such as leaving material in the unit, felling and bunching with a less costly machine, or mastication.

7. ACKNOWLEDGEMENTS

This project was supported by funding from the Joint Fire Science Program.

8. LITERATURE CITED

Brinker, R.W., J. Kinard, B. Rummer, and B. Lanford. 2002. Machine rates for selected forest harvesting machines. Circular 296 (revised). Alabama Agricultural Experiment Station. 29 p.

Flagstaff area wildfire risk assessment. A collaborative effort in cooperation with the Ponderosa Fire Advisory Council. http://www.gcfp.org/firerisk.htm. [Date accessed: January 15, 2000].

Hardy, Colin C. 1996. Guidelines for estimating volume, biomass, and smoke production for piled slash. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Gen. Tech. Rep. PNW-GTR-364. 21 p.

Miyata, E.S. 1980. Determining fixed and operating costs of logging equipment. U.S. Department of Agriculture, Forest Service Gen. Tech. Rep. NC-55. 16 p.

Peterson, D.L., M.C. Johnson, J.K. Agee, T.B. Jain, D. McKenzie, and E.D. Reinhardt. Forest structure and fire hazard in dry forests of the Western United States. Gen. Tech. Rep. PNW-GTR-628. Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 29 p.

SAS Institute Inc., SAS/STAT User's Guide, Release 6.03 Edition. Cary, NC: SAS Institute Inc., 1988.

Six, D.L., M. Vander Meer, T.H. DeLuca, and P. Kolb. 2002. Pine engraver *(Ips pini)* colonization of logging residues created using alternative slash management systems in western Montana. Western Journal of Applied Forestry. 17(2): 96-100.

COFE

Council on Forest Engineering

PROCEEDINGS OF
THE 29TH COUNCIL ON FOREST ENGINEERING CONFERENCE

July 30 – August 2, 2006
Coeur d'Alene Resort
Coeur d'Alene, Idaho

Compiled and Edited by
Woodam Chung and Han-Sup Han

Hosted by

University of Idaho — Tradition. Change. Excellence.

The University of Montana

Sponsored by
IUFRO Division 3
Plum Creek Timber Company
Potlatch Corporation
Forest Capital Partners, LLC