ANALYSIS OF THE BALING CONCEPT FOR INCREASED FIBER RECOVERY ON HARVESTED FOREST SITES

by

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INTRODUCTION

The United States consumed approximately 12 billion cubic feet of wood in 1970. In the same year about 3.6 billion cubic feet of wood was left in the forests in the form of logging residue (Wahlgren 1974). If this residue had been recovered and utilized, forest fiber utilization would have been increased by 30 percent.

Technological constraints make the vast majority of logging residue economically inaccessible; however, in the near future social and economic factors may reverse this trend and make residue recovery an environmental and economic necessity. The factors contributing to this reversal are the projected increases in world population with subsequent increases in demand for forest products, the constantly diminishing productive forest land base which must provide the forest industry with increasing amounts of raw materials, and the diminishing supply of readily available nonrenewable resources. Many industries now using nonrenewable resources as raw materials may be forced to substitute renewable resources as a supplement to their raw material requirements.

The petrochemical industry is a good example of the potential for this substitution phenomenon. In 1970 this industry produced 37 billion pounds of plastics, noncellulosic fibers and synthetic rubber. The industry's daily consumption of crude oil was 900,000 barrels. If the cost of crude oil continues to rise as expected, the petrochemical industry will search for new sources of raw material. One possible source is wood. About 95 percent of the materials produced by the petrochemical industry are conceptually derivable from cellulose, hemicelluloses and lignin. The amount of wood necessary to produce these materials would be about 60 percent of that used annually by the pulp and paper industry (National Research Council 1976).

Industry and government may be able to thwart serious future wood shortages through intensified forest management activities, better utilization of available fiber, and improved processing technology. Improved utilization of forest residues is the most promising method of quickly increasing wood fiber supply. An expanded fiber base from which the forest products industry could draw its raw material would be established if an economical method of extracting and processing logging residues were devised. Such an expansion may be crucial to insure adequate fiber supply with increasing demand pressures from a continually rising population. Thus, if the forest products industry is to continue to obtain adequate supplies of raw material in the future, consumer needs may dictate the intensive utilization of logging residues.

Logging residues are becoming an increasingly critical issue, especially to land owners and land management personnel. The deposition of large quantities of logging slash detracts from the aesthetics of forested areas. To the laymen even small quantities of slash destroy the aesthetics and represent wasteful practices by land managers. Recent judicial actions have shown the importance of maintaining the appearance of using good forest practices. As special interest groups continue to become more vocal, land managers may be forced to account for the volume of residues left lying on the forest floor.

Logging residues are not only social issues but biological ones as well. Currently, large sums of money are being spent on site preparation to foster regeneration. While burning is a widely accepted southern forest practice used by foresters to reduce slash, legislative concern over environmental quality has appeared in the form of air pollution controls which may pose stringent restrictions on burning. There are other disadvantages to leaving residues in the forest. In some western forest regions large quantities of slash pose a serious fire hazard. Slash deposits may also become breeding grounds for potentially destructive insects and disease.

The physical characteristics of logging residue are the primary deterrent to recovery with conventional harvesting techniques. The material is generally too small, in either length or diameter, to meet current marketing specifications and its diverse forms creates difficulties in handling and transportation as well.

Studies have been conducted to determine the physical characteristics of logging residues. One such study concerned a northern hardwood timber sale where every piece of residue was measured and weighed (Mattson and Carpenter 1976). The study showed that 41 percent of the tree weight above the stump was left in the woods from sawtimber sized trees and 49 percent from pole-timber sized trees. About 81 percent of the total residue by weight was material with a diameter outside bark of less than 6.5 inches.

A study in West Virginia (Martin 1975) measured all residue on a timber sale which had a diameter outside bark of at least 4 inches and a length of at least 4 feet. The results, therefore, do not include the smaller sized material and perhaps a large percentage of the total residue. Nevertheless, the study found an average residue volume per acre of 467 cubic feet. The average diameter at the small end for all residue was 4.8 inches. The average diameter at the large end was found to be 7.1 inches, and the average length was 12 feet. Only 16 percent of the total volume of residue had a small end diameter of 8 inches or greater.

In 1973, 110 logging sites were examined in Alabama to determine the amount and form of logging residues (Chappell and Beltz 1973). The study concluded that about eight cords per acre were left in residual trees, tops, unused bole sections and above ground portions of stumps. Roughly 25 percent of the gross volume originally standing remained in the woods after logging. The tops and unused bole sections accounted for 48 percent of the residue volume, while the figure for residuals was 42 percent. The above ground portions of stumps accounted for about 10 percent of the residue volume.

It is predicted that once logging residues are made an easily available fiber source, new markets for the material will appear. Currently there are only a few, rather limited markets for forest residues. Most of the residue being harvested today is in chip form, therefore it is primarily marketed as fiber for pulping or as fuel. Other potential markets are the production of particleboard and fiberboard.

The market potential of forest residues as fuel promises to be the most lucrative use of this material. Studies have indicated that it would be infeasible to supply large steam-electric plants with residues for the commercial generation of energy because of insufficient volumes of residues in a concentrated area to adequately supply such a facility (Grantham and Ellis 1974). The studies do indicate, however, that it would be feasible for the wood using industries to use forest residues as a source of energy. The pulp and paper industry, in particular, is in an excellent position to capture much of this energy source. According to Grantham and Ellis (1974) pulpmills which use much process steam and electricity could generate steam from wood residues to power a steam turbine-electric generator set and exhaust to process steam rather than to a condenser.

Escalating fossil fuel costs have been responsible for the utilization of wood residues as fuel at many wood using facilities. Though wood is a less efficient source of energy than fossil fuels, it is much cheaper and more accessible. The fuel values of various materials in Btu's per pound are as follows:

Fuel	Btu's/lb.[1]
Bituminous Coal	13,500
No. 6 Oil	18,000
Natural Gas	18,550
Oven Dry Wood	8,900

It has been found that coal has an 85% combustion efficiency, while oil has an 82.5%, natural gas a 77.8%, and wood about a 65% combustion efficiency. Though wood residues are inferior in combustion efficiency and heating value, its position on supply and potentially on costs is superior.

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[1] Cohan, Regan, and Shenk 1972:30

If current trends toward depletion of oil and gas reserves continue, the utilization of wood residues for energy will become increasingly profitable. Increased utilization of coal has been suggested as a means of alleviating pressure from oil and gas shortages. Eastern coal, however, is too high in sulfur content to meet emission standards, and processes to remove sulfur are costly. Western coals, which contain less sulfur, are far from the major coal markets and incur restrictive transportation costs. Also strip-mining is under a salvo of environmental pressures because it is a source of both stream and groundwater pollution and leads to losses in the economic productivity of unreclaimed land (Rose 1975).

In 1972 the pulp and paper industry supplied 37 percent of its own energy requirements by combustion of bark and spent pulping liquors (Grantham and Ellis 1974). With increased innovations in the combustion process, such as fluid-bed burners, a wider range of materials will become available as fuel sources with increased combustion efficiencies. Recovery of forest residues can advance the wood using industries toward energy self-sufficiency by providing a large volume of previously untapped fuel supply.

The manufacture of particleboard is another potential use for forest residues. The U.S. Forest Service has begun a coordinated national program to harvest and utilize logging residues for possible construction of structural particleboard (Schaffer 1974). In a paper presented at the Forest Biology Conference of the Technical Association of the Pulp and Paper Industry, Harold Wahlgren (1974) proposed that structural particleboard can be produced from logging residues by careful alignment of flakes, ribbons or strands. With continued research on this matter at the Forest Products Laboratory, the technology may soon become available for particleboard constructed from residues to supplement lumber and plywood supplies and lead to the development of house construction systems which would make possible more homes at lower cost.

The U.S. Forest Service's Close Timber Utilization Committee suggested that logging residues could be used in the manufacture of fiberboard. The committee contends that fiberboard would currently be the most practical use for residues due to available existing technologies and markets. They also go on to state, "It seems probable that within a decade the growth in markets for wood fiber products will exceed the supply of economically-usable plant residues for products such as particleboard, and the industry will turn increasingly to roundwood or presently unused logging residues" (Close Timber Utilization Committee 1972:16).

The manufacture of charcoal is another potential use for residues. Milton Applefield of the Southern Forest Experiment Station points out that the margin of profit involved in making charcoal is small and the competition keen. He does, however, note that the demand for charcoal has been rising at the rate of 10 percent per year (Applefield 1972).

Current consumption patterns of forest products may not readily dictate the necessity of logging residue utilization in particleboard or fiberboard. An unpredictable and costly fossil fuel supply, however, makes the exploitation of residues for fuel much more urgent.

Today, the only technologically feasible method of recovering logging residues is the application of the whole tree chipping harvesting system. Other current timber harvesting practices lack the technological capacity to recover forest residues. Whole tree chipping has enhanced the technology of residue recovery; but, high capital investment requirements, restrictive operating constraints, the problems associated with transportation of chips from the landing to the mill, and the limited ability of a chipping operation to merchandise material for its highest value are inhibitive to widespread application.

The nature of logging residues, as documented in studies previously mentioned, indicate that harvesting systems which include the recovery of residues must be capable of handling relatively small diameter, short length material. Unfortunately, conventional harvesting systems cannot economically satisfy this constraint. The lower value of most residues cannot support the application of highly mechanized systems because of their associated high capitalization and therefore high hourly fixed costs. Less mechanized systems cannot afford to recover low value residues because of the additional manpower required and/or lost production per manday associated with accumulating and processing the smaller material. These constraints indicate the need for an alternative to full tree chipping systems for the recovery of logging residues. One approach which appears to have merit is the baling of this material (Stuart 1975). Thus, in the winter of 1975 the concept of baling was tested using an antiquated agricultural baler.

All excess material was removed until the baler consisted entirely of a plunger fixed with a shear, a hole in the baling chamber to allow feeding, and a rectangular outfeed chute. The original power takeoff mechanism driving the plunger was removed and replaced by a single three inch diameter double action hydraulic cylinder.

Limbs and tops of varying diameters and lengths were fed to the baler. As the plunger passed forward the material was simultaneously sheared and compacted. The bales were hand tied with metal strapping while still inside the outfeed chute.

The results of the experimentation with the prototype baler were encouraging. It was found that limbs and tops could be sheared and compacted to high bulk densities at moderate hydraulic pressures of about 1500 pounds per square inch. The material once baled formed near rectangular packages which could be easily handled for transportation. Due to a limited clearance between the knife and the plunger, the largest material that could be sheared was four inches in diameter. Due to the ease with which the modified hay baler processed the material, the staff experimenting with the prototype were confident that with minimal engineering effort a better prototype could be developed which would be an efficient fiber recovery mechanism. The success of this experimentation illustrated the mechanical feasibility of physically baling logging residues.

The application of the baling concept was envisioned as consisting of an industrial type horizontal baler capable of shearing and compacting bulky, difficult to handle forest residues into a high bulk density package. The baler should be an integral part of the harvesting process to facilitate handling of raw residues.

In the preliminary projections of a baler's productive capacity, it was decided that bales would be produced which were four feet long, three feet wide, and three feet high. These dimensions appear to best suit the conventional modes of transportation. Bales can be of varying width, but once the bale chamber is built, the length and height become fixed.

The baler infeed mechanism could conceivably consist of an inverted reciprocating grapple. The grapple reciprocates toward and away from the bale chamber in a perpendicular direction to the longitudinal axis of the baler. The grapple reciprocates a distance of four feet, which forces enough material into the baling chamber to fill the length of the bale. Once the material has been forced into the bale chamber a hydraulic ram forces the plunger with its attached shearing blade forward. The material is simultaneously sheared and compacted. Each additional compaction stroke forces the material further down the outfeed chute where the bales are automatically tied. Several types of automatic tying devices are currently available and most are capable of wire tying the bales.

The action of the reciprocating grapple and the movement of the plunger could possibly be synchronized and made totally automatic. This design might eliminate the necessity of assigning a full time operator to the baling process. The loader operator, aloft in his position on the loader, could have a manual override to the automatic cycle. The loader would then be used to feed material into the baler infeed mechanism and off load the bales as well as perform its usual loading function.

The next logical step in analyzing the feasibility of baling was to investigate the economic feasibility of the concept. Thus the objectives of this study are:

1) To examine the economic feasibility of baling as an alternative method for recovering forest residues in the eastern United States.
2) To examine the value of baled forest residues as an alternative energy source for the wood using industries.

METHOD OF EVALUATION

Rather than examining the variables associated solely with the baling function, a systems approach was taken to objectively evaluate the economic feasibility of the baling concept. Since baling of forest residues is indeed a concept, many assumptions were made regarding its utilization. To minimize the uncertainty and risks associated with such assumptions, a range of possible values of any critical variable were utilized in the analysis. The examination of the concept was separated into three segments: (1) In-woods evaluation of baling, (2) Transportation aspects of the baling concept and (3) Utilization of baled forest residues for energy production at pulp and paper mills.

In-Woods Evaluation of Baling

To evaluate the economic feasibility of baling as a fiber recovery mechanism, a comparison between a system which incorporates baling as an integral part of the operation and several conventional systems was necessary. Specifically, a system equipped with a residue baler was compared to a whole tree chipping operation and a shortwood operation which produced primarily pulpwood and some grade products.

The Harvesting Systems Simulator developed by the American Pulpwood Association's Harvesting Research Project was the primary tool used in the analysis. Cost and production data and stand characteristics data were used for simulation of the whole tree chipping system, the shortwood system, and a baler equipped system. These three systems were simulated on two stand types, a pine plantation and an upland hardwood stand. The results of the simulations were used to evaluate the relative efficiency with which each system was capable of recovering the available fiber. The most significant results of the simulations included the amount of available fiber recovered by each system, the per unit costs of production incurred by the systems, the net revenues generated by each operation, length of time for harvest and the exposure of any significant system imbalances. System imbalances were reflected in the percent of each system's costs incurred due to inventory delays. Each system was ranked on the previously mentioned results and the rankings exhibited in tabular form. The results of the baling system simulations were also incorporated into an analysis of the payback period and break-even levels of production for the residue baler. A detailed description of each of the two timber stands and three harvesting systems follows.

Pine Plantation

The source of data for the pine plantation was one of the forest models established by the American Pulpwood Association's Harvesting Research Project (1970). Forest Model Number 51 is a one acre portion of a loblolly pine plantation. When the model was established every tree within the one acre area was intensively examined and measured. Individual cubic foot tree volumes were also calculated and recorded. From the Forest Model data set, the diameter at breast height, merchantable height and merchantable cubic foot volume of each tree up to a 4 inch top diameter was acquired. The merchantable weight of each tree was calculated using a conversion factor of 59.9 pounds per cubic foot (U.S. Forest Products Laboratory 1974). To determine the slash weight of each tree a formula developed by the U.S. Forest

Service's Southeastern Forest Experiment Station was utilized (Wade 1969). The formula predicts loblolly dry slash weights from diameter at breast height as follows:

$$\text{Log } Y = 2.538(\text{Log DBH}) - 0.573$$

A moisture content of 100 percent was assumed for green loblolly pine, and the dry slash weights were doubled to obtain green weight. Weights were converted to cubic feet with a conversion factor of 59.9 pounds per cubic foot and were then converted to cords using 90 cubic feet of wood and bark per cord as a conversion factor.

To use the stand information for the simulations, all stand variables were converted to a forty acre basis. Table 1 displays the important stand characteristics for the pine plantation. A combined stand and stock table for the pine plantation is shown in Table 2.

Upland Hardwood Stand

Stand characteristics of the upland hardwood stand were obtained from a whole tree chipping overrun study conducted at Virginia Polytechnic Institute and State University (Ford 1976). The study measured and weighed every tree with a one inch or greater diameter at breast height. Total weights were first determined for each tree, then the merchantable portions of the tree were cut out and weighed. One of the plots used in the study was a 1.5 acre area located on the school forest near Blacksburg, Virginia. The data for this sample plot was expanded to a forty acre basis for simulation purposes. Primary stand characteristics appear in Table 1. A combined stand and stock table is shown in Table 3. Merchantability limit for pulpwood was

Table 1. Stand characteristics of the two timber stands used in the simulations.

	Loblolly Plantation	Upland Hardwood
Tract Size	40 acres	40 acres
Pulpwood Volume	1287 cords	777 cords
Sawtimber Volume	0	81.6 MBF
Slash Volume	359 cords	663 cords
Trees Per Acre	671	179
Merchantable Cords Per Acre	32	24
Trees Per Cord	21	7
Basal Area Per Acre	160	105
Species Mix:		
Loblolly	100%	--
White Oak:	--	38%
0 - 4.5" DBH	--	12%
4.6 - 10.5" DBH	--	15%
> 10.5" DBH	--	11%
Gum:	--	3%
0 - 4.5" DBH	--	2%
4.6 - 10.5" DBH	--	1%
> 10.5" DBH	--	0%
Hickory:	--	0.4%
0 - 4.5" DBH	--	0.1%
4.6 - 10.5" DBH	--	0%
> 10.5" DBH	--	0.3%
Miscellaneous Hardwoods:	--	58.6%
0 - 4.5" DBH	--	36%
4.6 - 10.5" DBH	--	18%
> 10.5" DBH	--	4%

Table 2. Stand and stock table for the forty acre loblolly pine plantation used in the simulations.

DBH (Inches)	Number of Trees	Pulpwood (Cords)	Slash (Cords)
3	40	0	1
4	1960	0	42
5	5600	146	33
6	9240	357	86
7	7680	434	106
8	3480	266	68
9	760	74	20
10	80	10	3
TOTAL	28,840	1287	359

Table 3. Stand and stock table for forty acre upland hardwood stand used in the simulations.

DBH (Inches)	Number of Trees	Pulpwood (Cords)	Sawtimber (MBF)	Slash (Cords)
1	107	0	0	0
2	2667	0	0	13
3	2533	0	0	24
4	1733	4	0	28
5	1040	12	0	22
6	1120	37	0	21
7	933	50	0	20
8	720	53	0	28
9	507	53	0	27
10	613	75	0	42
11	320	48	2.4	27
12	400	75	8.3	49
13	613	115	17.1	80
14	133	27	5.0	33
15	240	80	6.4	38
16	160	49	11.5	30
17	53	20	1.8	8
18	133	52	11.8	51
19	27	0	0	28
20	53	20	10.1	16
21	53	0	0	66
22	27	11	7.2	8
TOTALS	14,185	781	81.6	659

a minimum top diameter outside bark of four inches. Minimum diameter outside bark at the small end for sawlogs was ten inches. A weighted average conversion factor of 65 pounds per cubic foot was used to convert weight to cubic feet (U.S. Forest Products Laboratory 1974). Cubic foot volumes were converted to cords assuming 90 cubic feet of wood and bark per cord. Sawlog volumes were converted to thousand board feet by using a weighted average conversion factor of 13,767 pounds per thousand board feet (Avery 1967).

Whole Tree Chipping System

The flow diagram of the whole tree chipping operation appears in Fig. 1. Felling occurs by one of two methods, either manually with a chainsaw or mechanically with a feller-buncher. The chainsaw feller is primarily assigned to fell the oversized material which the feller-buncher is incapable of shearing. When the chainsaw feller completes this task, he will assist the feller-buncher in felling the remainder of the material. To take advantage of the bunched material a grapple skidder is assigned to skid the material felled and bunched by the feller-buncher. A choker skidder will be used to skid the manually felled timber.

At the deck a sawyer using a chainsaw will buck out any high quality sawlogs. The bucker was eliminated; however, when the system worked in the pine plantation, since there were no available grade logs. On both stands all material not removed as grade sawlogs was chipped.

To proportion the equipment costs of this and all other systems a cash flow costing method rather than machine rates was used. The

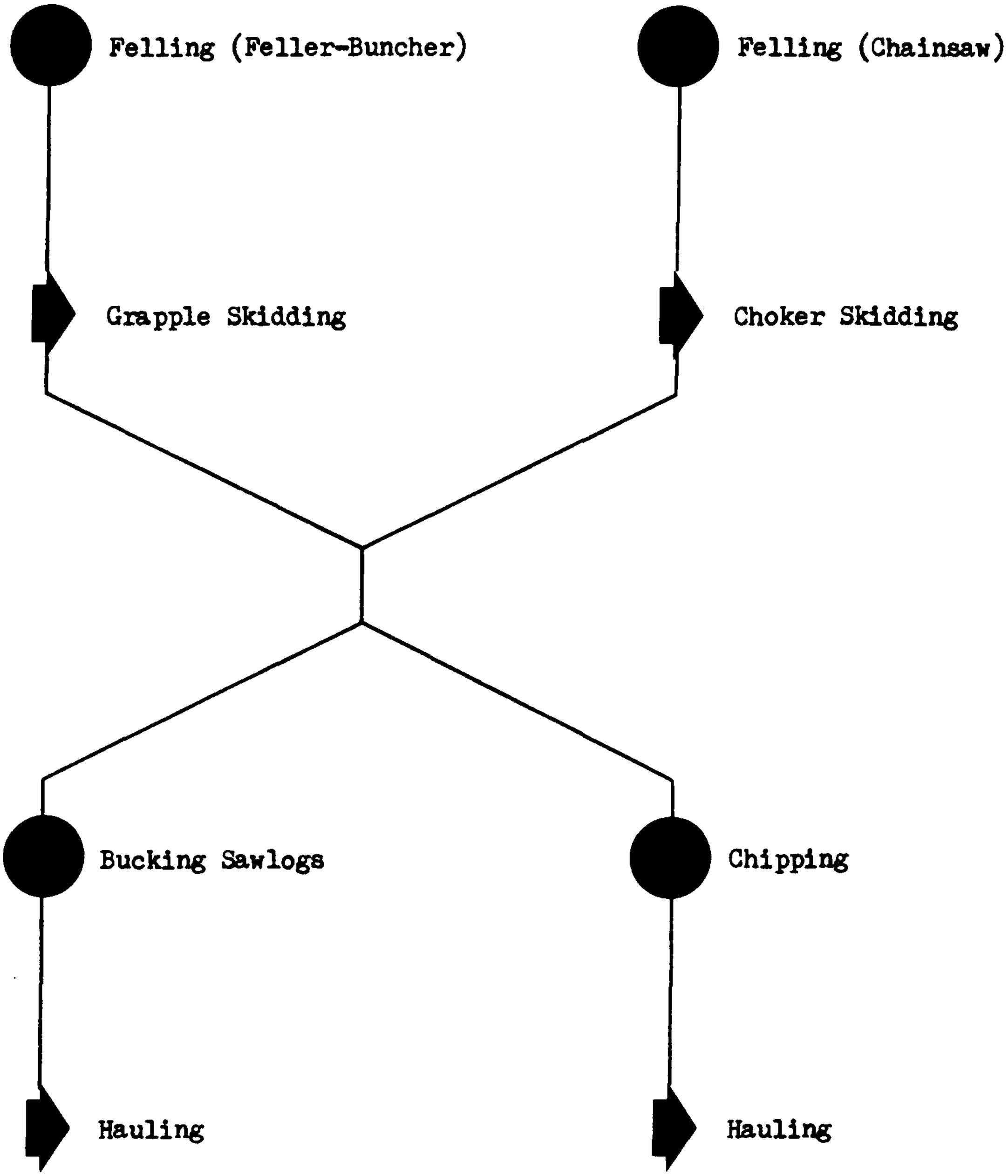

Fig. 1. Flow diagram of whole tree chipping operation used in simulations.

primary difference that the cash flow method imposes is the manner in which fixed costs of equipment are assigned. The cash flow method attempts to capture the actual payments a logging contractor makes to pay loans on purchased equipment. The machine rate, by contrast, assumes equipment payments to be approximately equal to the yearly straight line depreciation on the equipment.

It was assumed that the feller-buncher, grapple skidder, choker skidder and whole tree chipper were purchased with separate bank loans under the following conditions. Each loan was financed for three years at 12 percent add-on interest plus 1 percent creditor life insurance and 2 percent fire and theft insurance. The chainsaws' purchase price was expensed the year of purchase. Appendix Tables I through V show the fixed, variable and labor cost assumptions for each piece of productive equipment. These assumptions are based on 1975 prices. Down payment was calculated as 20 percent of the purchase price. Property taxes per year were calculated as 2 percent of the average fixed investment. It was assumed that this operation would achieve 225 worked days per year with 5 eight hour shifts scheduled per week.

Appendix Table VI shows the labor and labor rates used on this operation. Wage rates without fringes varied from $3.50 to $4.50 per hour depending upon the laborer's assignment. If a laborer was an operator of a piece of productive equipment, his wages were charged against the use of the machine. All other labor was classed as overhead. Overhead items, excluding labor, are shown in Appendix Table VII with their annual owning and operating costs. The annual overhead totaled to $50,900.00 for this system. It was assumed that this system was owned by an independent contractor who did not work with the system. Instead, a full time supervisor was employed. The summarized cost estimates for this system are shown in Table 4.

Estimates of productivity for each function were determined for simulation input purposes. Appendix Tables VIII through XI show the pure productive capacities of the feller-buncher, chainsaw feller, grapple skidder, choker skidder, chainsaw bucker and whole tree chipper. The productivity rates shown are pure in that they do not include mechanical, operator or system oriented delays. Scheduled and stochastic delays occur throughout the simulation depending on the relative frequency of occurrence and their duration as provided by the user. The simulated productivity will therefore by somewhat lower than the rates displayed in the Appendix Tables.

The productive rates shown for the skidders in Appendix Table X include only the time required to acquire and dispose of a load of logs. For the choker skidder this is the hook and unhook time. Skid distances are calculated by the program and applied to the travel rate to determine travel time. The productive rate of the whole tree chipper is expressed as an average and is applied across all diameter material. Production rate distributions, however, are shown for the feller-buncher, chainsaw bucker and chainsaw feller. The program weighs these rates against the volume of wood in each diameter class to determine the frequency with which each rate is sampled during the simulation.

Income for this system is generated by producing whole tree chips

Table 4. Summarized cost assumptions for the whole tree chipping operation.

Item	Dollars Per Scheduled Hour
Equipment Payments	52.19
Property Taxes	1.61
Overhead	28.28
Labor	51.69
TOTAL FIXED COSTS:	133.77

and grade sawlogs where available. Delivered prices for these materials were assumed to be $26.00 per cord for chips and $40.00 per cord for sawlogs. Stumpage charges were $4.00 per cord for hardwood pulpwood, $17.00 per cord for hardwood sawtimber and $8.00 per cord for pine pulpwood.

Shortwood System

The flow diagram of the shortwood system is shown is Fig. 2. The equipment spread for this system consists of three chainsaws, one cable skidder, one hydraulic knuckleboom loader and two tandem axle haul trucks. All trees with a DBH of 4 inches or more and containing at least one stick of pulpwood are chainsaw felled. This process is followed by another individual who chainsaw limbs and tops at the stump. The material is then choker skidded to the landing where it is sorted and bucked to either 5 foot 3 inch pulpwood or 8 foot sawlogs. Sawlogs are cold decked until several loads accumulate. All pulpwood is loaded directly after bucking. When the feller has felled all material, he will aid the bucker at the deck.

The skidder and loader were purchased with three year loans obtained at 12 percent add-on interest plus 1 percent creditor life and 2 percent fire and theft insurance. Cost assumptions for the choker skidder and chainsaws used in this system are the same as for the costs assumed for these machines on the whole tree chipping operation. The cost assumptions for the loader are shown in Appendix Table XII. This system was also assumed to work 225 days per year with 5 eight hour shifts scheduled per week.

Crew organization and labor rates are shown in Appendix Table XIII.

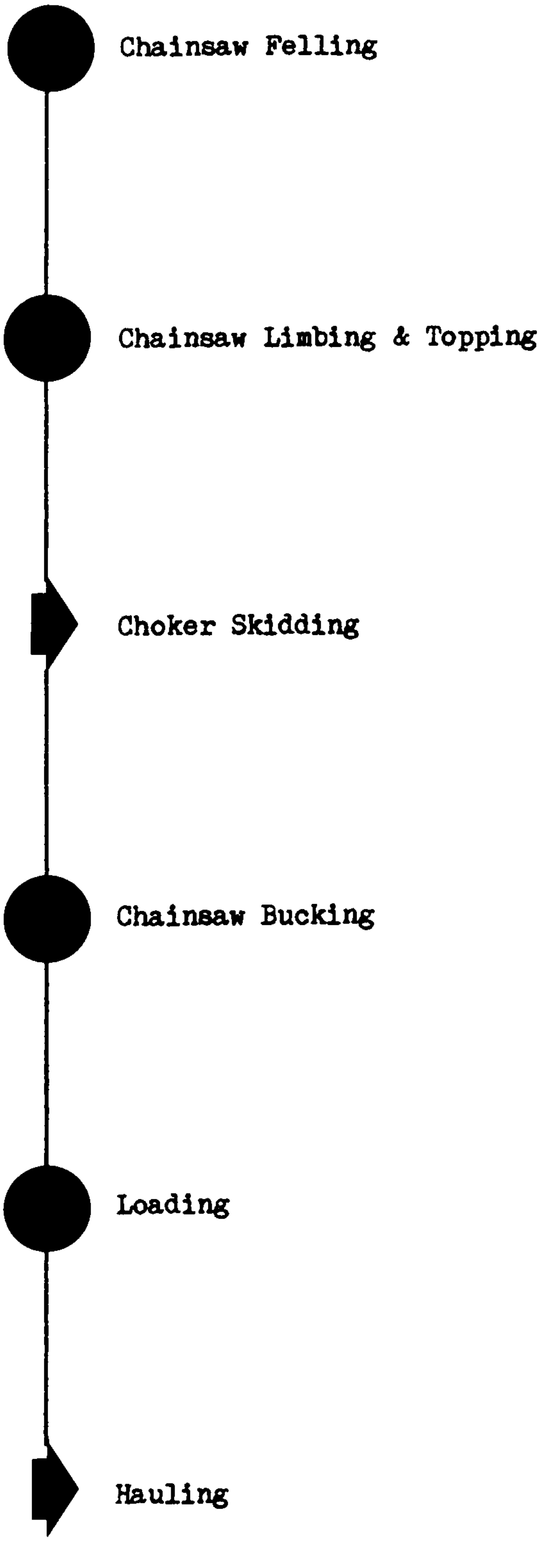

Fig. 2. Flow chart of shortwood system used in the simulations.

Wage rates without fringes varied from \$3.50 to \$4.50 per hour depending on the laborer's assignment. Overhead items and their annual costs are displayed in Appendix XIV. Annual overhead amounted to \$19,500.00 for this system. It was assumed that this system was also owned by an independent contractor; however, in this case the contractor serves as the loader operator and draws a personal salary of \$300.00 a week. The summarized cost estimates for this system are shown in Table 5.

Productivity rates of the chainsaw feller, chainsaw bucker and choker skidder are the same for this system as those used for the chipping operation. Production rate distributions for chainsaw limbing and topping are shown in Appendix Table XV, and production data for the loader is shown in Appendix Table XVI.

Delivered prices of pulpwood and sawlogs were assumed to be \$26.00 per cord and \$40.00 per cord, respectively. Stumpage charges were \$4.00 per cord for hardwood pulpwood and \$17.00 per cord for hardwood sawtimber. Pine stumpage was \$8.00 per cord.

System Equipped With Residue Baler

This system is depicted in the flow chart in Fig. 3. All material with at least a minimum DBH of 4 inches is chainsaw felled and choker skidded to the landing. The material containing roundwood products is chainsaw limbed and bucked. All material with a stem diameter less than 6 inches is forwarded to the baler. This eliminates the necessity of delimbing the most limby section of the tree and enhances bucking productivity. The tops and limbs as well as any material skidded to the landing containing no roundwood products are transferred by the loader to the baler infeed. Once the material is placed in the

Table 5. Summarized cost assumptions for the shortwood system.

Item	Dollars Per Scheduled Hour
Equipment Payments	12.23
Property Taxes	.36
Overhead	10.83
Labor	29.70
TOTAL FIXED COSTS:	53.12

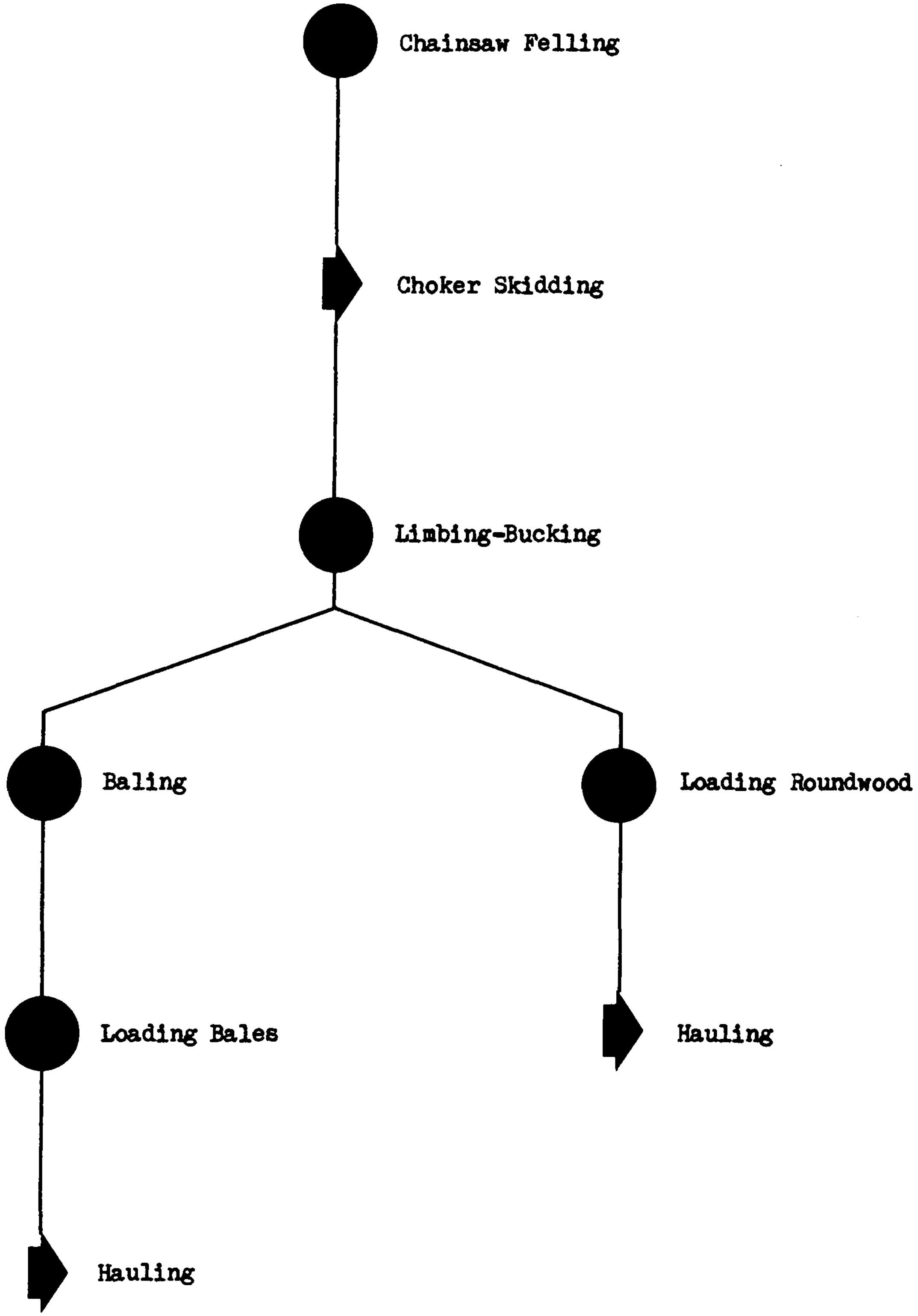

Fig. 3. Flow chart of harvesting system functions used on the baler equipped system.

infeed mechanism, the baler operates automatically. The material is advanced into the baling chamber, sheared to length and compressed. The loader performs three functions. It loads roundwood products, transfers baling material to the baler infeed and loads or stores bales. After the feller has completed felling all trees, he will assist the limber-bucker at the deck.

The cost assumptions used on the previous systems for chainsaws, choker skidder and loader were also used for this system. Cost assumptions for the baler were a bit more difficult to estimate. For this reason three values of purchase price were used alternately to determine the sensitivity of the system's income to changes in this variable. The three values used are $20,000.00, $30,000.00 and $40,000.00. Appendix Table XVII shows the costs proportioned by a $30,000.00 purchase price. It was assumed that this system would also achieve 225 worked days per year with 5 eight hour shifts scheduled per week.

Appendix Table XVIII shows the crew organization and labor rates for this operation. Wage rates without fringes varied from $3.50 to $4.50 per hour depending upon the laborer's assignment. Overhead items and their associated cost were assumed to be the same for this system as those used on the shortwood system. This cost totaled to $19,500.00 yearly. This system is also owned by an independent contractor who operates the loader and draws $300.00 per week in personal salary. The cost estimates for this system are summarized in Table 6.

Productivity of the chainsaw feller, choker skidder and loader is

Table 6. Summarized cost assumptions for the baler equipped system.

Item	Dollars Per Scheduled Hour
Equipment Payments*	18.46
Property Taxes	.56
Overhead	10.83
Labor	25.50
TOTAL FIXED COSTS:	55.35

* Assumes baler purchase price of $30,000.00.

the same for this system as the estimates used for the shortwood operation. Baler productivity is estimated at 950 cubic feet per hour for pine and 720 cubic feet per hour for hardwoods. These values will later be modified, however, to determine the sensitivity of system profitability to baler productivity. The production rate data for chainsaw limbing and bucking is contained in Appendix Table XIX.

The delivered price of baled material and the stumpage paid for this material was varied to determine the sensitivity of system profitability to changes in these variables. The delivered price of bales was varied between $15.00, $20.00 and $26.00 per cord. Stumpage for baled material was varied between $2.00, $3.00 and $4.00 per cord for hardwood and $4.00, $6.00 and $8.00 per cord for pine. Delivered price for hardwood pulpwood, hardwood sawtimber and pine pulpwood was assumed to be $26.00, $40.00 and $26.00 per cord, respectively. Stumpage for pine pulpwood was assumed to be $8.00 a cord. Stumpage for hardwood was assumed as $4.00 a cord for pulpwood and $17.00 a cord for sawtimber.

RESULTS OF SIMULATIONS

Due to the differences in timber size between the upland hardwood stand and the pine plantation, there was a great deal of variance among the performance of the three systems on the two stands. For this reason the results obtained on the two sites shall be discussed separately. A general discussion of all results will follow the discussion of the stand results.

Upland Hardwood Stand

The volumes harvested and the length of time for harvest for the three systems were as follows:

1) 1457.8 cords of hardwood chips and 160.4 cords of sawlogs in 5.7 weeks for the whole tree chipping operation,

2) 787.6 cords of pulpwood and 184.8 cords of sawtimber in 4.8 weeks for the shortwood system and

3) 765.3 cords of pulpwood, 191.3 cords of sawtimber and 637.7 cords of baled material in 6.5 weeks for the baler equipped system.

The shortwood system was in this stand the shortest time because it only removed approximately 60 percent of the total stand fiber. The whole tree chipping operation and the baling system, however, removed approximately 99 percent and 98 percent of the total stand fiber, respectively. The baling system required four days more than the chipping operation to complete the harvest, because it was less mechanized and relied heavily on manual processing in the felling and delimbing-bucking functions.

The gross revenues generated by the three systems was:

1) $44,318.69 for the chipping operation,

2) $27,867.75 for the shortwood system and

3) $44,129.93 for the baling system.

The total revenue generated was of course dependent on the amount of material removed from the tract. The revenue for the baling system assumes a $26.00 per cord delivered price for baled material. A $20.00 per cord delivered price for baled fiber would have resulted in $40,303.62 of revenue; whereas, a $15.00 per cord price would have lowered revenue for the baling system to $37,115.17.

The disparity in the total costs for each of the three systems arises from several sources. Stumpage and hauling costs are dependent on the volume of material harvested. Equipment payments, labor and overhead expenses rely upon a combination of time spent on the tract and system capitalization. Fuel, lube, repair and maintenance costs depend on the amount of productive time accumulated on the equipment in each system during the harvest. The total costs for the three systems were:

1) $47,901.39 for the chipping operation,

2) $21,881.68 for the shortwood system and

3) $32,702.93 for the baling system with a $40,000.00 baler purchase price, a 720 cubic feet per hour baler productive rate and a stumpage charge for baled material of $4.00 a cord.

The whole tree chipping operation, which was highly mechanized and contained large investments in productive equipment and overhead, had the highest total cost of the three systems. The costs for each of the three systems are itemized in Table 7. This table shows that the costs per cord for the three systems were $29.60 for the chipping

Table 7. Cost and revenue statistics generated by each of the three types of harvesting systems during harvest of the upland hardwood stand.

	Whole Tree Chipping System (Dollars)	Shortwood System (Dollars)	Baling System (Dollars)
Costs:			
Stumpage	8,557.55	6,291.23	8,864.28
Hauling	5,129.74	4,054.70	6,648.15
Equipment	12,346.46	2,440.23	5,524.67
Labor	6,478.13	3,380.28	3,437.48
Overhead	11,882.53	4,488.52	6,019.82
Fuel & Lube	1,480.66	692.74	1,197.23
Repair & Maintenance	2,026.32	533.98	1,011.23
TOTAL COSTS:	47,901.39	21,881.68	32,702.86
COST PER CORD:	29.60	22.50	20.51
TOTAL REVENUE:	44,318.69	27,867.75	44,129.93
NET INCOME:	-$3,582.70	$5,986.07	$11,427.07
NET PER CORD:	-$2.21	$6.16	$7.17

operation, $22.50 for the shortwood system and $20.51 for the baling system. The chipping system had a net loss of $3,582.70 or $2.21 per cord. The shortwood system obtained a net income of $5,986.07 or $6.16 per cord. The baler equipped operation achieved a net income of $11,427.07 or $7.17 per cord produced.

These differences in net income are primarily attributable to the variation between the fixed costs of the systems. The fixed costs of the chipping operation amounted to $30,707.12 or 64 percent of the total costs. Fixed costs of the shortwood system accounted for 47 percent of the total costs or $10,309.03. The baling system's fixed costs were $14,981.97, but were only 46 percent of that system's total costs. Though the fixed costs in percent of total costs were almost identical for the shortwood and baling systems, the baling system was capable of spreading its fixed costs over 622 cords more than the shortwood system. The high fixed costs of the chipping operation left little room for operating expenses. The system's fixed costs on a per cord basis were $18.98 per cord. This left only a $7.02 margin for variable costs for the system to break even.

Another item of interest is the percent of each system's cost due to inventory delays. Inventory delays reported by the Harvesting System Simulator are of three types. The first type is a no work delay. This occurs when a machine completes its task and has processed all the volume assigned to the machine. The felling function accrued no work delays on each of the three systems simulated. Once all material had been felled the feller either went into a no work delay or was reassigned to assist the bucker at the deck. An excessive inventory delay occurs when the volume processed by one function exceeds a predetermined limit because the next succeeding function was incapable of processing the material at as high a rate as the preceding one. For each of the three systems it was determined that no more than five cords of unprocessed material could be at the deck at one time. If the five cord limit was exceeded the skidders were forced into an excessive inventory delay until the volume at the deck was drawn down to three cords. An insufficient inventory delay occurs when a function has no material to process and it is waiting for the preceding function to forward material. In some of the simulations the bucker at the deck would go into an insufficient inventory delay because he had bucked all the material on the landing and was waiting for the skidder to bring more.

The simulation totals the number of hours the machines in a system are in inventory delays and the costs that the machines accrue while in these delays. This cost amounted to:

1) 38 percent of the total cost for the chipping operation,
2) 32 percent of the total cost for the shortwood system and
3) 31 percent of the total cost for the baling system.

Production information and the utilization of each machine is contained in Appendix Tables XX through XXII. Utilization in this instance refers to the percent of total scheduled time a machine is actually utilized. The achieved production rates shown for each machine may be one or more of three types and are so noted in the table by symbols. A machine's productive rate may be expressed on either a system volume basis, a conventional merchantable volume basis or a machine volume basis. This allows the reader to compare the productive rate of a machine in one system to the productive rate of the same machine in another system. The system volume base refers to the total volume produced by the system. The machine volume base refers to only the volume that a particular machine processes. For example, the system volume and the machine volume differ for the bucker on the chipping operation, because the bucker processed only a small portion of the total volume produced by the system. The merchantable volume base applies only to the chainsaw fellers and feller-buncher. If the rates for these machines had been expressed on a system volume basis only, the rates for the chainsaw feller and feller-buncher on the whole tree chipping operation would have been inflated compared to the rate for the chainsaw feller in the shortwood system. In reality the number of trees felled by the chipping operation only slightly exceeded the number of trees felled by the shortwood operation. Since the shortwood system produced only conventional merchantable roundwood products, however, there are gross differences in the total volumes harvested by the two systems. Therefore, the productive rates of the fellers were expressed on a merchantable volume basis to allow a comparison between different systems.

To determine some measure of total system performance the three harvesting systems were ranked on five performance criteria, and the average rank for each system was ascertained. These ranks and the observed values are exhibited in Table 8. The recovery factor refers to the percent of total stand fiber recovered. The percent of costs due to inventory delays is included in this table to give some measure

Table 8. Observed values and their rankings for five criteria of performance on the upland hardwood stand.

System	Recovery Factor (Percent)	Cost Per Cord (Dollars)	Net Revenue (Dollars)	Time On Tract (Weeks)	Percent of Costs Due To Inventory Delays (Percent)
Chipping	1 (99)	3 (29.60)	3 (-3582.70)	2 (5.7)	3 (38.1)
Shortwood	3 (60)	2 (22.50)	2 (5986.09)	1 (4.8)	2 (31.5)
Baling	2 (98)	1 (20.51)	1 (11427.01)	3 (6.5)	1 (31.1)

Average Ranking:

Chipping System:	2.4
Shortwood System:	2.0
Baling System:	1.6

of system imbalance. Based on the ranks exhibited, the baling system with an average rank of 1.6 appears to have performed the best on this stand.

Pine Plantation

Due to the relatively small timber size in this stand the performance of the shortwood and baling systems decreased significantly. The whole tree chipping operation proved to be less sensitive to the shift to small timber. In fact, the productivity of the chipping operation actually increased. The increase in production for this system is attributable to the high mechanization and the fact that the chipper's productivity increased. The chipping operation spent only 4.5 weeks harvesting this tract. The shortwood and baling system, however, took 10.1 and 11.1 weeks to complete the harvest, respectively. The volumes harvested by each of the three systems were as follows:

1) 1646.0 cords of pine chips for the whole tree chipping operation,

2) 1286.9 cords of pine pulpwood for the shortwood system and

3) 1133.8 cords of pine pulpwood and 509.4 cords of baled material for the baling system.

The percent of total stand fiber recovered was 99 percent for the chipping operation, 78 percent for the shortwood system and 99 percent for the baling system. The recovery factor for the shortwood system was larger for this stand than for the hardwood stand because the plantation grown trees were more uniform in size, contained less limbs and had smaller crowns than the hardwoods.

The gross revenues for the three systems were:

1) $42,795.17 for the chipping operation,

2) $33,460.23 for the shortwood system and

3) $42,721.48 for the baling system.

This assumes a $26.00 per cord delivered price for baled material.

There was less variation between the costs per cord of the three systems on this stand than on the hardwood stand. The chipping operation had the lowest cost per cord of $27.43. Its total cost was $45,144.73. The shortwood system had a total cost of $39,442.71 and a cost per cord of $30.65. Cost per cord for the baling system was $29.25 with a total cost of $48,057.67. This cost is for the system with a $40,000.00 baler purchase price, a 950 cubic feet per hour baler productive rate and a stumpage rate of $8.00 per cord of baled material. Total costs for each system are itemized in Table 9. The table shows that stumpage was the most costly item for all three systems. The whole tree chipping system's fixed costs as a percent of total cost fell to 52 percent from the 64 percent value in the hardwood stand. This is because the system was more productive and spent less time harvesting the plantation. The shortwood system's fixed costs as a percent of total cost rose to 54 percent as compared to 47 percent on the hardwood stand. This rise can be attributed to the lengthened harvest period for the smaller timber. The baling system's fixed costs as a percent of total cost rose to 53 percent as compared to 46 percent on the hardwood stand. This rise can also be attributed to the lengthened time for harvest in the smaller timber of the plantation. The fixed costs totaled to $23,265.13 for the chipping operation, $21,415.65 for the shortwood system and $25,553.25 for the baling

Table 9. Cost and revenue statistics generated by each of the three types of harvesting systems during harvest of the pine plantation.

	Whole Tree Chipping System (Dollars)	Shortwood System (Dollars)	Baling System (Dollars)
Costs:			
Stumpage	13,167.73	10,295.46	13,145.20
Hauling	5,036.67	5,366.50	6,851.89
Equipment	9,636.23	5,069.83	9,423.60
Labor	4,319.18	7,020.46	5,861.46
Overhead	9,309.72	9,325.36	10,268.19
Fuel & Lube	1,595.09	1,380.44	1,427.91
Repair & Maintenance	2,080.11	984.66	1,079.42
TOTAL COSTS:	45,144.73	39,442.71	48,057.67
COST PER CORD:	27.43	30.65	29.25
TOTAL REVENUE:	42,795.17	33,460.23	42,721.48
NET INCOME:	-$2,349.56	-$5,982.48	-$5,336.19
NET PER CORD:	-$1.43	-$4.65	-$3.25

system.

All three harvesting systems had a negative net income or net cost while operating on this stand. The chipping operation lost the least with a net cost of $2,349.56 or $1.43 per cord. The shortwood system lost $4.65 per cord for a total net cost of $5,982.48. The baling system's net cost was $5,336.19 or $3.25 per cord.

The percent of costs due to inventory delays follows the trend of the systems in costs and revenues. The chipping operation's percent of costs due to inventory delays fell to 20 percent from a previous value of 38 percent on the hardwood stand. The chipper was more productive in the plantation and this consequently lowered the total job hours. Also the feller-buncher and chainsaw feller compiled less no work delay since they were felling more trees per acre and finishing less time ahead of the rest of the system. The shortwood system's percent of costs due to inventory delays rose from 32 percent on the hardwood stand to 36 percent on the plantation. The most dramatic change occurred with the baling system. Its percent rose to 51 percent from a previous value of 31 percent. The rise for this system is largely due to less residue volume on the plantation and the baler, therefore, being productive less of the total job time. The limber-bucker also became more of a limiting factor on this stand causing the skidder to go into excessive inventory delays more frequently.

Production information for the machines operating on the plantation and their utilization percentages are contained in Appendix Tables XXIII through XXV. These tables clearly display how each machine was affected by shifting to the smaller sized timber of the plantation. The sensitivity of the manual functions to tree size is very evident in the shortwood and baling systems. Since the baler was utilized only 11 percent of the scheduled time on this stand, the potential exists for the baler to be rotated between two or more harvesting systems. In the baler's absence residues could be stockpiled near the landing.

An examination of the utilization percentages for the baling system in Appendix Table XXV indicates that the limber-bucker was the productivity bottleneck on this stand. The baling system's productivity could have been enhanced by the addition of another limber-bucker; however, adding another individual to the system when working in the pine plantation would have clouded the comparisons that have been made regarding the system's relative efficiency in harvesting the two stand types. In reality a contractor would probably have used an additional limber-bucker to increase production and therefore lower the per cord costs of production.

The rankings of the three systems on the five performance criteria for the plantation are shown in Table 10. Based on these five criteria the whole tree chipping operation appears to have performed the best of the three systems on this stand. All three systems did, however, incur a net loss while operating on this stand. For this reason none of the three could be recommended as the proper system to use under these operating conditions.

Table 10. Observed values and their rankings for five criteria of performance on the pine plantation.*

System	Recovery Factor (Percent)	Cost Per Cord (Dollars)	Net Revenue (Dollars)	Time On Tract (Weeks)	Percent of Costs Due To Inventory Delays (Percent)
Chipping	1.5 (99)	1 (27.43)	1 (-2349.56)	1 (4.5)	1 (19.6)
Shortwood	3 (78)	3 (30.65)	3 (-5982.48)	2 (10.1)	2 (36.1)
Baling	1.5 (99)	2 (29.25)	2 (-5336.03)	3 (11.1)	3 (51.3)

Average Ranking:

Chipping System:	1.1
Shortwood System:	2.6
Baling System:	2.3

* Observed values in parentheses.

DISCUSSION OF SIMULATION RESULTS

So far the results of the baling system simulations have dealt with the system that assumes a $40,000 baler purchase price, a baler productive rate of 720 cubic feet per hour in hardwoods and 950 cubic feet per hour in pine, a delivered price for baled material of $26.00 per cord and a stumpage charge of $4.00 per cord for hardwoods and $8.00 per cord for pine. Each of these variables were changed to determine the effect of the changes on system profitability. Table 11 shows the net revenue of the baling system on the hardwood stand for various combinations of the purchase price, productivity rate, delivered price per cord and the per cord stumpage rate.

Profitability of the baling system is most sensitive to the per cord delivered price of baled material. A 23 percent decrease in delivered price to $20.00 per cord results in a $3826.14 decrease in profit. Decreasing the price by 42 percent or to $15.00 a cord, decreases profit by $7014.59. Stumpage costs have the second greatest effect on profit. Decreasing stumpage costs per cord of bales by 25 percent to $3.00 a cord increases profit by $637.69. A 50 percent decrease to $2.00 a cord increases profit by $1275.38. The item which has the third highest effect on profit is baler purchase price. Decreasing purchase price to $30,000.00 or by 25 percent results in an increase in profit of $576.82. A $20,000.00 purchase price or 50 percent decrease increases profit by $1153.64. The baling system's profitability was least sensitive to the baler's productive rate. A 25 percent decrease in the productive rate to 540 cubic feet per hour, decreases profit by $95.17. A 50 percent decrease to 360 cubic feet

Table 11. Net revenue for the baling system under varying combinations of baler purchase price, baler productive rate, delivered price per cord for bales and stumpage charge per cord of baled material on the hardwood stand.

Productive Rate Delivered Price Stumpage	$40,000 Purchase Price	$30,000 Purchase Price	$20,000 Purchase Price
720 Cubic Feet/Hour			
$15.00/Cord			
$2.00/Cord	$5,687.69	$6,264.51	$6,841.33
$3.00/Cord	5,050.00	5,626.82	6,203.64
$4.00/Cord	4,412.31	4,989.13	5,565.95
$20.00/Cord			
$2.00/Cord	8,876.14	9,452.96	10,029.78
$3.00/Cord	8,238.45	8,815.27	9,392.09
$4.00/Cord	7,600.76	8,177.58	8,754.40
$26.00/Cord			
$2.00/Cord	12,702.28	13,279.10	13,855.92
$3.00/Cord	12,064.59	12,641.41	13,218.23
$4.00/Cord	11,426.90	12,003.72	12,580.54
540 Cubic Feet/Cord			
$15.00/Cord			
$2.00/Cord	5,592.52	6,169.34	6,746.16
$3.00/Cord	4,954.83	5,531.65	6,108.47
$4.00/Cord	4,317.14	4,893.96	5,470.78
$20.00/Cord			
$2.00/Cord	8,780.97	9,357.79	9,934.61
$3.00/Cord	8,143.28	8,720.10	9,296.92
$4.00/Cord	7,505.59	8,082.41	8,659.23
$26.00/Cord			
$2.00/Cord	12,607.11	13,183.93	13,760.75
$3.00/Cord	11,969.42	12,546.24	13,123.06
$4.00/Cord	11,331.73	11,908.55	12,485.37
360 Cubic Feet/Hour			
$15.00/Cord			
$2.00/Cord	5,396.47	5,973.29	6,550.11
$3.00/Cord	4,758.78	5,335.60	5,912.42
$4.00/Cord	4,121.09	4,697.91	5,274.73
$20.00/Cord			
$2.00/Cord	8,584.92	9,161.74	9,738.56
$3.00/Cord	7,947.23	8,524.05	9,100.87
$4.00/Cord	7,309.54	7,886.36	8,463.18
$26.00/Cord			
$2.00/Cord	12,411.06	12,987.88	13,564.70
$3.00/Cord	11,773.37	12,350.19	12,927.01
$4.00/Cord	11,135.68	11,712.50	12,289.32

per hour decreases profit by $291.22. The system's profitability was, therefore, highly sensitive to delivered price, moderately sensitive to stumpage and purchase price, and relatively insensitive to the baler's productive capacity.

The baling system's change in net revenue due to a change in the variables is shown in Table 12 for the pine plantation. Profit or in this case net loss is again most sensitive to a change in the delivered price for bales. A 23 percent decrease in the delivered price yields a $3056.34 decrease in profit. A 42 percent decrease yields a $5603.29 decrease in profit. Profit in the pine plantation, however, is less sensitive to the delivered price than in the hardwood stand. Stumpage also repeats itself as having the second greatest impact on profitability. A 25 percent decrease in stumpage costs for baled material results in an increase in profit of $1018.78. A 50 percent decrease results in a profit increase of $2037.56. Profit proved to be more sensitive to stumpage costs on the pine plantation than on the hardwood stand. Baler purchase price also had more effect on profit in the pine plantation than in the hardwood stand. A 25 percent decrease in purchase price caused a $983.58 increase in profit. A profit increase of $1967.16 was caused by a 50 percent decrease in purchase price. Profit appears to be relatively insensitive to the baler's productive rate on the pine plantation, and even less sensitive than on the hardwood stand. A 25 percent decrease in the productive rate yielded a decrease in profit by $54.71. The 50 percent decrease in productivity yielded a $172.84 decrease in profit. The fact that profit was relatively insensitive to the baler's productive

Table 12. Net revenue for the baling system under varying combinations of baler purchase price, baler productive rate, delivered price per cord for bales and stumpage charge per cord of baled material on the pine plantation.

Productive Rate Delivered Price Stumpage	$40,000 Purchase Price	$30,000 Purchase Price	$20,000 Purchase Price
950 Cubic Feet/Hour			
$15.00/Cord			
$4.00/Cord	-$8,901.50	-$7,917.92	-$6,934.34
$6.00/Cord	- 9,920.28	- 8,936.70	- 7,953.12
$8.00/Cord	- 10,938.90	- 9,955.48	- 8,971.90
$20.00/Cord			
$4.00/Cord	- 6,354.55	- 5,370.97	- 4,387.39
$6.00/Cord	- 7,373.33	- 6,389.75	- 5,406.17
$8.00/Cord	- 8,391.95	- 7,408.53	- 6,424.95
$26.00/Cord			
$4.00/Cord	- 3,298.21	- 2,314.63	- 1,331.05
$6.00/Cord	- 4,316.99	- 3,333.41	- 2,349.83
$8.00/Cord	- 5,336.03	- 4,352.19	- 3,368.61
712 Cubic Feet/Hour			
$15.00/Cord			
$4.00/Cord	- 8,956.21	- 7,972.64	- 6,989.06
$6.00/Cord	- 9,974.99	- 8,991.42	- 8,007.84
$8.00/Cord	- 10,993.77	- 10,010.20	- 9,026.62
$20.00/Cord			
$4.00/Cord	- 6,409.26	- 5,425.69	- 4,442.11
$6.00/Cord	- 7,428.04	- 6,444.47	- 5,460.89
$8.00/Cord	- 8,446.82	- 7,463.25	- 6,479.67
$26.00/Cord			
$4.00/Cord	- 3,352.92	- 2,369.35	- 1,385.77
$6.00/Cord	- 4,371.70	- 3,388.13	- 2,404.55
$8.00/Cord	- 5,390.48	- 4,406.91	- 3,423.33
475 Cubic Feet/Hour			
$15.00/Cord			
$4.00/Cord	- 9,074.34	- 8,090.77	- 7,107.21
$6.00/Cord	- 10,093.12	- 9,109.55	- 8,125.99
$8.00/Cord	- 11,111.90	- 10,128.33	- 9,144.77
$20.00/Cord			
$4.00/Cord	- 6,527.39	- 5,543.82	- 4,560.26
$6.00/Cord	- 7,546.17	- 6,562.60	- 5,579.04
$8.00/Cord	- 8,564.95	- 7,581.38	- 6,597.82
$26.00/Cord			
$4.00/Cord	- 3,471.05	- 2,487.48	- 1,503.92
$6.00/Cord	- 4,489.83	- 3,506.26	- 2,522.70
$8.00/Cord	- 5,508.61	- 4,525.04	- 3,541.48

capacity on both stands is very important from a design standpoint. It means that less effort and expense has to be devoted toward the design of a fast acting shear and compacting mechanism. This not only simplifies the design but also leads to the development of a machine which will create less wear and tear on components and consume less hydraulic fluid and fuel.

The break-even level of production was calculated for each of the three systems on the two stand types. The break-even level of production in this case is the yearly or weekly production necessary for a system's total costs to be exactly equal to its total revenues. The system must, therefore, operate above this level to realize any net income. The break-even level of production was calculated by the following formula.

Yearly Fixed Costs + Variable Costs Per Cord X CORDS = Average Revenue Per Cord X CORDS

The formula is solved for the dependent variable CORDS to determine the number of cords which must be produced each year for the system to just break even.

Table 13 shows the break-even levels of production for the three system types on the two stand types. The levels shown for the baling system assume a baler purchase price of $40,000.00, a baler productive rate of 950 cubic feet per hour in pine and 720 cubic feet per hour in hardwood, a delivered price for baled material of $26.00 per cord, and a stumpage charge of $8.00 per cord for pine and $4.00 per cord for hardwood. The yearly break-even levels assume that the systems are operating the whole year in stands with identical characteristics.

Table 13. Break-even levels of production in cords for the three system types on the two stand types.

System	Pine Plantation Weekly (Cords)	Pine Plantation Yearly (Cords)	Upland Hardwood Weekly (Cords)	Upland Hardwood Yearly (Cords)
Chipping	446	20,087	337	15,164
Shortwood	245	11,039	100	4,516
Baling	213	9,572	116	5,225

Since this is hardly ever the case, the weekly levels are more meaningful because they can be compared directly to the simulated weekly production.

The average weekly production for the three systems in the pine plantation was 336 cords for the chipping operation, 128 cords for the shortwood system and 148 cords for the baling system. Each system operated well below its break-even level of production for this stand. On the upland hardwood stand the average weekly production was 282 cords for the chipping operation, 200 cords for the shortwood system and 245 cords for the baling system. On this stand the whole tree chipping system operated below its break-even level, but the shortwood and baling systems operated well above their break-even levels of production.

The yearly break-even levels of production can also be used to determine the procurement effort involved to economically operate the systems. The whole tree chipping operation must harvest at least 376 acres of hardwoods equivalent to the hardwood stand used in the simulations or at least 488 acres of pine plantations to break even. The shortwood system must harvest at least 186 acres of equivalent hardwoods or 343 acres of equivalent pine plantations to at least break even. The baling system must harvest 131 acres of equivalent hardwoods or 233 acres of pine plantations to at least break even. The baling system, therefore, requires less procurement effort than either the chipping operation or the shortwood system on both the stand types.

Thus far, the discussion of the baler equipped system has concerned the effects of baling on the entire system. It is appropriate at this point to begin concentrating more effort on the baler itself. The costs and revenues associated solely with the baling function are shown in Table 14 for the hardwood stand and Table 15 for the pine plantation. These figures again assume the $40,000.00 purchase price, the 950 and 720 cubic feet per hour productive rate in pine and hardwood respectively, the $26.00 per cord delivered price, and the stumpage charge of $8.00 per cord for pine and $4.00 per cord for hardwood.

Baling forest residues contributed a net revenue of $13.64 per cord of baled material on the hardwood stand and $5.77 on the pine plantation. Baling cost $12.26 per cord for hardwood bales and $20.23 per cord for pine bales. The weekly total cost for baling on the plantation was lower than on the hardwood stand, but so were the weekly revenues.

Since the baler is likely to be operated by independent logging contractors who face a high degree of uncertainty concerning the future and are interested in their cash position and borrowing commitments, the payback period is a useful measure of investment desirability concerning the purchase of a residue baler. Payback periods were calculated by dividing the total initial investment in the baler by the sum of the weekly net income from bales and the weekly baler equipment payment. The baler was found to have a payback period of 23 weeks for the hardwood stand and 65 weeks for the pine plantation. These rapid payback periods make the residue baler an attractive investment for small independent contractors.

Based on system net revenues, break-even levels of production and

Table 14. Cost and revenue components associated with the residue baler as simulated on the upland hardwood stand.

Type of Cost	Total (Dollars)	Per Cord (Dollars)	Per Week (Dollars)
Fixed Costs			
Machine Cost	2,305.98	3.62	354.77
Overhead	0.00	0.00	0.00
Total Fixed Costs:	2,305.98	3.62	354.77
Variable Costs			
Stumpage	2,550.80	4.00	392.43
Hauling	2,659.21	4.17	409.11
Labor	0.00	0.00	0.00
Fuel & Lube	157.52	.25	24.23
Repair & Maintenance	137.83	.22	21.20
Total Variable Costs:	5,505.36	8.64	846.97
Total Cost:	7,811.34	12.26	1,201.74
Total Revenue:	16,580.20	26.00	2,550.80
Net Revenue:	8,768.86	13.74	1,349.06

Table 15. Cost and revenue components associated with the residue baler as simulated on the pine plantation.

Type of Cost	Total (Dollars)	Per Cord (Dollars)	Per Week (Dollars)
Fixed Costs			
Machine Cost	3,934.04	7.72	354.42
Overhead	0.00	0.00	0.00
Total Fixed Costs:	3,934.04	7.72	354.42
Variable Costs			
Stumpage	4,075.20	8.00	367.14
Hauling	2,124.20	4.17	191.37
Labor	0.00	0.00	0.00
Fuel & Lube	94.39	.18	8.50
Repair & Maintenance	82.59	.16	7.44
Total Variable Costs:	6,376.38	12.51	574.45
Total Cost:	10,310.42	20.23	928.87
Total Revenue:	13,244.40	26.00	1,193.19
Net Revenue:	2,933.98	5.77	264.32

payback periods, baler equipped harvesting systems appear to be a viable alternative to whole tree chipping operations for recovering large percentages of total stand fiber. This especially appears to be the case on tracts of large timber size with relatively large amounts of residue volume. On these types of stands baling requires less capital investment and has the potential to generate more net income than whole tree chipping systems. The break-even analysis also demonstrated that baling systems require less procurement effort than chipping operations to obtain an economical level of production. Baling has an additional advantage of being better able to merchandise material into several products. This gives the baling system more flexibility between markets and allows it to respond more quickly to market changes.

Since baling does require a relatively moderate capital investment and can be supported by minimally mechanized systems, it is accessible to many more logging contractors than chipping operations which require large capital investments and very mechanized support systems. These features make baling a particularly attractive alternative to the minimally mechanized logging force typical of the hardwood sectors of the Appalachian and piedmont areas. The independent contractor owned systems found in these areas are usually incapable of supporting whole tree chippers to fully recover forest residues.

In the preceding comparisons in which a residue baler was incorporated into a harvesting system, the baler's productivity was dependent upon the system output. This restricted the machine to 31 percent utilization in the hardwood stand and only 11 percent in the pine plantation. This amount of underutilization of the baler's productive capacity justifies a brief discussion of baling as a separate operation. In this situation a baler and a truck and loader combination would rotate between tracts that were harvested by conventional roundwood systems.

It was assumed that the total initial investment in the baler and truck and loader combination would be $60,000. The operation would require two laborers, a loader operator and a helper. The costing assumptions used previously for other systems were applied to this operation. It was also assumed that the utilization for the baler would be 60 percent of the scheduled time. No charge was made for stumpage in this situation.

The break-even level of production for this operation is approximately 1.2 cords per productive hour. If a production rate of 2 cords per productive hour is achieved, the profit is $8.51 per cord and the payback period for the entire operation is 78 weeks. A profit of $12.95 per cord and a payback period of 46 weeks would be realized if the operation produced 3 cords per productive hour. If 4 cords were produced per productive hour, the profit would be $15.17 per cord and the payback period would be 33 weeks.

These calculations indicate several advantages of baling as a separate operation:

1) The baler could be operated economically at its own pace, rather than being affected by system productivity.

2) Baling can be performed as a separate enterprise serving many systems.

3) Residues can be left on the site by conventional systems, thus allowing a reduction in moisture content and an increase in fuel value of the material before baling occurs.

TRANSPORTATION ASPECTS OF THE BALING CONCEPT

The physical characteristics of baled forest residue greatly facilitates its transportation from the woods to the mill. Baled residues form a rectangular solid and thus offer many potential advantages in the transportation of harvested material. The magnitude of these advantages, however, depend upon the ability of a baler to generate sufficient compaction forces to minimize the air space around material on a loaded vehicle. The end result of increasing the bulk density of loaded residues will be a lowered hauling cost per ton mile up to limits imposed by highway weight restrictions.

An assumed bale dimension of 4 feet by 3 feet by 3 feet would result in a bale weighing approximately 1,440 pounds with a bulk density of about 40 pounds per cubic foot. These dimensions make a nice package for handling and transport. A truck bed with dimensions of 8 feet by 18 feet can be used to haul approximately 6 cords of 5 foot 3 inch pulpwood. This assumes that pulpwood is stacked 8 feet high. These same bed dimensions can be used to haul 36 bales if stacked two bales wide, six bales down the length and 3 bales deep. The total load weight, however, would be approximately 52,000 pounds which exceeds the maximum allowable weight for tandem axle vehicles. To approach the maximum weight requirement, bales can be stacked two wide, six down the length and two bales deep. This loading pattern would yield a load 8 feet wide, six feet in height and 18 feet long. The load would contain 24 bales and weigh approximately 34,000 pounds. These 24 bales would occupy 864 cubic feet of space and contain about 8 cords of wood fiber. When hauling 5 foot 3 inch pulpwood, however, the space occupied is about 756 cubic feet or 6 cords of wood fiber. Baled material, therefore, utilizes available haul space much more efficiently.

Material in baled form simplifies the materials handling and transporting processes. The handling and transportation of baled material requires little or no modifications of existing equipment. Bales can be loaded on board trucks in the woods with existing loading facilities. Bales are in fact easier and quicker to load than material in roundwood form. One bale is volumetrically equivalent to several pulpwood sticks. Since bales are dimensionally uniform, they load out easier than highly variable roundwood. This simplifies the loading process, because the loader operator does not have to concern himself with the placement of material to stabilize the load. Also one basic loading pattern can be used for every truck loaded, regardless of the timber size or species in which the system is operating. For the same reasons, off-loading of baled material facilitates the materials handling process at woodyards.

Truck bed designs are not a critical factor in the transportation of bales. Bales can be hauled on a wide variety of bed designs from flat beds to multi-product beds. This assures some compatibility between bales and a system's conventional product forms. The same truck that is used to haul pulpwood or sawlogs can also be used to haul bales.

Another advantage of handling baled material at woodyards is a potential reduction in storage space requirements. Bales which have a higher bulk density and can be safely stacked higher than roundwood require less ground space to store an equivalent volume of material. Reloading capabilities are also enhanced at woodyards when handling material in baled form. The advantages cited in loading bales in the woods also apply when reloading onto rail cars, barges or trucks.

The advantages to be gained by hauling bales can be seen more clearly when contrasted to the problems encountered when hauling whole tree chips. Road quality is a critical factor when hauling chips. Chip vans place stringent restrictions on road building practices and the types of existing roads over which chips can be hauled. Chips also require specialized and expensive equipment for handling and off-loading at woodyards. Just as chips are restricted to one type of haul truck, they are also restricted to one type of rail car. These special considerations restrict the flexibility and mobility of whole tree chips. Bales on the other hand allow much greater flexibility and are highly mobile over a wide range of transporting vehicles. Fig. 4 shows four possible combinations of transporting vehicles when hauling bales from the woods to the mill.

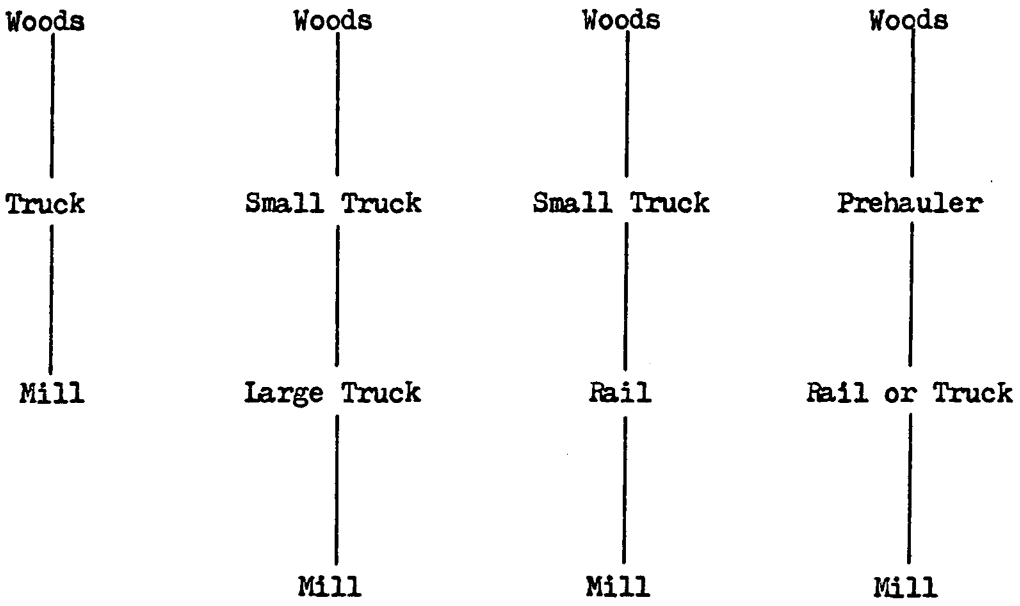

Fig. 4. Four possible combinations of transporting vehicles that can be used to haul baled material from the woods to the mill.

UTILIZATION OF BALED FOREST RESIDUES FOR ENERGY PRODUCTION AT PULP AND PAPER MILLS

The pulp and paper industry is in an excellent position to capture the fuel potential of baled forest residues. Procurement personnel are in constant contact with pulpwood producers who might easily become potential producers of baled residues. Also pulpmill woodyards would require much less modification for storage and processing of these residues than other industries. Thus, it appears that pulp and paper companies are in the best position to exercise control over the marketing and utilization of forest residues.

The utilization of baled residues for fuel would require minimal adjustments to incorporate this material into the fuel system. Once the bales were hogged or chipped at the mill, the fuel system would remain exactly as if the mill were burning bark or whole tree chips for fuel. The use of bales offers advantages over the use of other residue forms. Bales would be much easier and quicker to unload and store on the mill yard than chipped material. Bales would require less storage space than chips, because they can be stacked neatly and safely with minimal waste of storage space.

Bales should not deteriorate as rapidly in storage as chips or bark. In fact, the longer bales are stored, the greater the loss of moisture and the higher the fuel value becomes. After two months of storage in baled form, the material will dry out to an equilibrium moisture content of around 20 percent (Leibold 1976, personal communication), thus increasing the Btu value significantly. Since the storage of baled material is an asset rather than a liability and rehandling costs are minimal, remote storage of this material can be utilized to regulate its flow. Four possible storage locations are:

1) In the woods,

2) Remote yards,

3) Mill yards or

4) Satellite yards near but not on the mill site.

Before a bale of residues could become available for use as fuel, some form of material reduction must occur by hogging or chipping. The type of furnace used to burn the residues would determine the degree of reduction required.

Three hypothetical mills were established to approximate the costs of using baled material for fuel. Each mill had different steam level requirements and used forest residues to generate energy for 80 percent of their required levels. The remainder of the energy was obtained from combustion of spent pulping liquors. Mill A had a total requirement of 300,000 pounds of steam per hour and used residues to generate 240,000 pounds. Mill B, whose total requirement was 250,000 pounds, generated 200,000 pounds of steam per hour with forest residues. Mill C had a total requirement of 200,000 pounds and used residues to generate 160,000 pounds of steam per hour. Appendix Table XXVI shows the dry weight heating values of various species of wood and bark. For this study an average dry weight fuel value of 8900 Btu's per pound of wood residue was assumed. It was further assumed that the average dry weight based moisture content of the residues at the time of combustion was 40 percent. A combustion efficiency of 65 percent was assumed for the wood residue.

The 40 percent moisture content reduces the heat value of the fuel from 8900 Btu's per pound to 5340 Btu's per pound. The 65 percent combustion efficiency further reduces the heat value to 3471 Btu's per pound of fuel. Thus, 288 pounds of fuel will generate 1000 pounds of steam. Mill A, therefore, would use 34.6 tons or about 12.8 cords of baled residues per hour to generate 240,000 pounds of steam. Mill B would generate 200,000 pounds of steam per hour with 28.8 tons or about 10.7 cords of baled material. Mill C would utilize 23.0 tons or about 8.5 cords to provide 160,000 pounds of steam per hour. Table 16 shows the fuel requirements of all three mills for varying time periods.

For comparison, the hourly fuel requirements of all three mills are shown in Table 17 using oil, coal, and wood residue. Table 17 assumes a 20 percent moisture content and an 85 percent combustion efficiency for coal. It was assumed that oil had an 82.5 percent combustion efficiency. The assumed dry weight heat values of the two fuels are 13,500 Btu's per pound for coal and 18,000 Btu's per pound for oil. With these assumptions it was determined that 109 pounds of coal generates 1000 pounds of steam, while 67 pounds of oil (about 8.4 gallons) generates 1000 pounds of steam.

Though coal and oil prices vary widely in differing regions, an attempt was made to show the cost of each fuel by its hourly consumption rate as was shown in Table 17. Table 18 gives the hourly fuel cost for each of the three fuels at each of the three mills. The assumed cost for clean and graded, low sulfur content coal was $40.00 per ton. The assumed cost for #4 oil was $.40 per gallon. Two levels of cost were used for forest residues. It was assumed that the delivered

Table 16. Fuel level requirement of wood residues for varying time periods for three hypothetical mills with varying steam requirements.#

Time Period	Mill A 240,000 lbs. of steam/hour	Mill B 200,000 lbs. of steam/hour	Mill C 160,000 lbs. of steam/hour
Tons Per Hour	34.6	28.8	23.0
Cords Per Hour	12.8	10.7	8.5
Bales Per Hour	48.0	40.0	31.9
Tons Per Week	5,812.8	4,838.4	3,864.0
Cords Per Week	2,150.4	1,797.6	1,428.0
Bales Per Week	8,064.0	6,720.0	5,359.2
Tons Per Month	24,220.0	20,160.0	16,100.0
Cords Per Month	8,960.0	7,490.0	5,950.0
Bales Per Month	33,600.0	28,000.0	22,330.0
Tons Per Year*	290,640.0	241,920.0	193,200.0
Cords Per Year*	107,520.0	89,880.0	71,400.0
Bales Per Year*	403,200.0	336,000.0	267,960.0

Assumes 40 percent moisture content, green weight basis, at time of combustion.

* Assumes 50 worked weeks per year, 24 worked hours per day, 7 worked days per week.

Table 17. Hourly fuel consumption for three different fuels at three hypothetical mills with varying steam requirements.

	Mill A 240,000 lbs. of steam/hour	Mill B 200,000 lbs. of steam/hour	Mill C 160,000 lbs. of steam/hour
Coal (tons/hour)	13.1	10.9	8.7
#4 Oil (gallons/hour)	2016.0	1680.0	1344.0
Forest Residues (tons/hour)	34.6	28.8	23.0

Table 18. Hourly fuel cost for three different fuels at three hypothetical mills with varying steam requirements.

Type of Fuel	Mill A 240,000 lbs. of steam/hour	Mill B 200,000 lbs. of steam/hour	Mill C 160,000 lbs. of steam/hour
Coal	$524.00	$436.00	$348.00
#4 Oil	806.40	672.00	537.60
Forest Residue Delivered Price Paid:			
$ 20/cord	269.11	224.00	178.89
$ 26/cord	346.00	288.00	230.00

price paid by the mill to producers would be either $20.00 or $26.00 per cord of baled material. It was also assumed that it would cost an additional $1.00 per cord to prepare the bales for combustion.

The cost per thousand pounds of steam was $2.18 for coal, $3.36 for #4 oil and $1.44 for baled forest residues with a delivered price of $26.00 per cord. The break-even price paid for fuel was $40.00 per cord for residues and coal. This means that the mill could afford to pay anything less than $40.00 per cord for residues and still achieve an hourly fuel cost less than the hourly cost for coal. The break-even price for residues and oil was $62.00 per cord. Based on these cost estimates, it appears that the utilization of baled forest residues for energy production at pulp and paper mills has tremendous economic potential.

SUMMARY AND CONCLUSIONS

The baling concept has been evaluated from three aspects: (1) the in-woods evaluation, (2) the transportation aspects, and (3) the utilization of baled forest residues for energy production at pulp and paper mills. A baler equipped system was compared to a conventional whole tree chipping system and a conventional shortwood system to determine the in-woods feasibility of utilizing a baler to recover forest residues. These three systems were simulated on an upland hardwood stand and a pine plantation with the Harvesting System Simulator.

The simulation results of the baling system on the upland hardwood stand were:

1) The baling system performed significantly better on this stand than on the pine plantation because of the larger timber size and higher residue volume per acre. The hardwood stand contained 1492 cubic feet per acre of residues and averaged 7 trees per cord.
2) The baling system incurred a total cost of $20.51 per cord of pulpwood, sawlogs, and bales and achieved a profit of $7.17 per cord produced. The whole tree chipping operation, however, incurred a total cost of $29.60 per cord with a loss of $2.21 per cord produced.
3) The baling system recovered 98 percent of the total stand fiber, while the chipping operation recovered 99 percent.
4) The baling system was able to capitalize on its ability to merchandise sawlogs, pulpwood and baled residues.

5) The baling system's profitability was highly sensitive to changes in the delivered price received per cord of baled residue; moderately sensitive to changes in stumpage rates for baled material and to changes in the baler's purchase price; and relatively insensitive to changes in the baler's productive rate.

6) The weekly break-even level of production was found to be 116 cords for the baling system, as compared to 337 cords for the chipping operation.

7) The total cost for baling was $12.26 per cord of bales. The net revenue for bales was $13.74 per cord.

8) The residue baler had a 23 week payback period.

The simulation results of the baling system on the pine plantation showed that:

1) The baling system was hampered by small timber sizes and low residue volumes per acre. This stand averaged 21 trees per cord and contained 808 cubic feet of residues per acre.

2) The baling system's total cost was $29.25 per cord as compared to a $27.43 per cord cost for the chipping operation. The baling system incurred a loss of $3.25 per cord produced. The chipping operation had a loss of $1.43 per cord.

3) On this stand both the baling system and the whole tree chipping system recovered 99 percent of the total stand fiber.

4) Since there were no available sawlogs on this stand, the baling system was unable to capitalize on its merchandising ability.

5) The baling system's profitability was highly sensitive to

changes in the delivered price per cord received for bales; moderately sensitive to changes in the stumpage rate for baled material and the baler's purchase price; and relatively insensitive to changes in the baler's productive rate.

6) The weekly break-even level of production for the baling system was found to be 213 cords. The break-even level for the chipping operation was 446 cords per week.
7) The total cost for baling was $20.23 per cord of baled material. The net revenue per cord for baling was $5.77.
8) The baler had a 65 week payback period.

Although baling appears to be relatively inefficient on the pine plantation when incorporated into one system, it has been demonstrated that baling can exist as a separate enterprise serving many systems and operate very economically.

General observations that were made during the examination of the systems were that:

1) The baling system required much less capital investment than the chipping operation, and is therefore more accessible to a large number of small independent contractors.
2) The baling system requires less wood procurement effort, because it harvest more material from a given stand and has a lower yearly break-even level of production than most conventional systems.

Some of the advantages to be gained in the transportation of baled material are:

1) Baled material reduces the materials handling effort at all

stages of the transportation process, because all of the transported bales are of uniform density, weight and dimension.

2) The reloading and storage potential of baled material is excellent due to reduced materials handling effort and the fact that bales increase in fuel value with storage.
3) Bales can be stacked more neatly on haul vehicles thereby increasing the loaded density and more efficiently utilizing available haul space.
4) Bales are compatible with conventional haul vehicles and are capable of being hauled on a wide variety of transporting modes.

A comparison of fuel availability and cost indicates that utilization of baled forest residues for energy production at paper mills can provide a readily accessible and relatively inexpensive source of fuel. Residues offer a potential savings on fuel cost of 34 percent of the cost for using coal and 57 percent of the cost for using #4 fuel oil.

The baling of forest residues has intrinsic forest management advantages as well as monetary ones. Baling forest residues would lower site preparation cost, extend the usable forest resource base and aid in the alleviation of environmental pressures for cleaner harvesting practices. Due to the potential monetary and intrinsic returns to be gained by baling and utilizing forest residues, baler equipped harvesting systems are not only feasible but desirable. The potential advantages of baling forest residues justifies additional research and the application of the baling concept by the wood-using industries. Therefore, the next obvious steps toward development of this concept are:

1) Production of a full scale working prototype.

2) Further exploration into the potential utilization of baled material for fuel and fiber.

3) Evaluation of existing or potential plant facilities for separation, sorting and processing baled material for its highest value end use.

4) Determination of the best possible method and material to use for binding baled material.

5) Initiate research into the possible application of baling as a means of recovering fiber from timber stand improvements such as thinnings of plantations.

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Appendix Table I. Cost assumptions for feller-buncher used on the whole tree chipping operation.

Item	Dollars
Purchase Price	56,000.00
Down Payment	11,200.00
Principle on Loan	44,800.00
Interest & Insurance	20,160.00
Monthly Payments	1,804.44
Property Tax Per Year	672.00
TOTAL FIXED COSTS:	12.40/scheduled hour
Repair & Maintenance	4.30/productive hour
Fuel, Oil and Lube	3.75/productive hour
TOTAL VARIABLE COSTS:	8.05/productive hour
Operator Base Pay	4.00/scheduled hour
20% Fringes	.80/scheduled hour
TOTAL LABOR:	4.80/scheduled hour
TOTAL COSTS PER PRODUCTIVE HOUR	$25.25
TOTAL COSTS PER NONPRODUCTIVE HOUR	$17.20

Appendix Table II. Cost assumptions for grapple skidder used on the whole tree chipping operation.

Item	Dollars
Purchase Price	49,000.00
Down Payment	9,800.00
Principle on Loan	39,200.00
Interest & Insurance	17,640.00
Monthly Payments	1,578.89
Property Tax Per Year	588.00
TOTAL FIXED COSTS:	10.85/scheduled hour
Repair & Maintenance	2.95/productive hour
Fuel, Oil and Lube	2.00/productive hour
TOTAL VARIABLE COSTS:	4.95/productive hour
Operator Base Pay	4.00/scheduled hour
20% Fringes	.80/scheduled hour
TOTAL LABOR:	4.80/scheduled hour
TOTAL COSTS PER PRODUCTIVE HOUR	$20.60
TOTAL COSTS PER NONPRODUCTIVE HOUR	$15.65

Appendix Table III. Cost assumptions for choker skidder used in the simulations.

Item	Dollars
Purchase Price	26,000.00
Down Payment	5,200.00
Principle on Loan	20,800.00
Interest & Insurance	9,360.00
Monthly Payments	837.78
Property Tax Per Year	312.00
TOTAL FIXED COSTS:	5.76/scheduled hour
Repair & Maintenance	2.55/productive hour
Fuel, Oil and Lube	2.00/productive hour
TOTAL VARIABLE COSTS:	4.55/productive hour
Operator Base Pay	4.00/scheduled hour
20% Fringes	.80/scheduled hour
TOTAL LABOR:	4.80/scheduled hour
TOTAL COSTS PER PRODUCTIVE HOUR	$15.11
TOTAL COSTS PER NONPRODUCTIVE HOUR	$10.56

Appendix Table IV. **Cost assumptions for whole tree chipper used on the whole tree chipping operation.**

Item	Dollars
Purchase Price	110,000.00
Down Payment	22,000.00
Principle on Loan	88,000.00
Interest & Insurance	39,600.00
Monthly Payments	3,544.44
Property Tax Per Year	1,320.00
TOTAL FIXED COSTS:	24.36/scheduled hour
Repair & Maintenance	6.90/productive hour
Fuel, Oil and Lube	4.75/productive hour
TOTAL VARIABLE COSTS:	11.65/productive hour
Operator Base Pay	4.50/scheduled hour
20% Fringes	.90/scheduled hour
TOTAL LABOR:	5.40/scheduled hour
TOTAL COSTS PER PRODUCTIVE HOUR	$41.41
TOTAL COSTS PER NONPRODUCTIVE HOUR	$29.76

Appendix Table V. Cost assumptions for chainsaw used in the simulations.

Item	Dollars
Purchase Price	370.00
TOTAL FIXED COSTS:	.21/scheduled hour
Repair & Maintenance	.30/productive hour
Fuel and Oil	.90/productive hour
TOTAL VARIABLE COSTS:	1.20/productive hour
Operator Base Pay	3.50/scheduled hour
20% Fringes	.70/scheduled hour
TOTAL LABOR:	4.20/scheduled hour
TOTAL COSTS PER PRODUCTIVE HOUR	$5.61
TOTAL COSTS PER NONPRODUCTIVE HOUR	$4.41

Appendix Table VI. Crew organization and wage rates for whole tree chipping operation.

Laborer	Wages Including 20% Fringes (Dollars)
Feller-Buncher Operator	4.80/scheduled hour
Grapple Skidder Operator	4.80/scheduled hour
Choker Skidder Operator	4.80/scheduled hour
Chipper Operator	5.40/scheduled hour
Chainsaw Feller	4.20/scheduled hour
Chainsaw Bucker	4.20/scheduled hour
Truck Driver	4.80/scheduled hour
Truck Driver	4.80/scheduled hour
Mechanic	12,000.00/year
Supervisor	13,000.00/year

Appendix Table VII. Overhead items and their annual costs for the whole tree chipping operation.

Item	Annual Owning and Operating Costs (Dollars)
Truck-Tractors (2)	14,000.00*
Chip Vans (5)	3,000.00
Dozer	10,600.00
Haul Truck	4,500.00**
Half Ton Pickup	4,500.00
Spare Chainsaws (3)	450.00
Service Truck	4,250.00
Crew Carrier	5,000.00
Tools & Spare Parts	600.00
Equipment Van	100.00
Chip Van Forwarder	1,200.00
Lowboy	200.00
Air Compressor, Portable Welder, Fuel Trailer, Acetylene Torch	2,500.00

* Owning costs only for two trucks. An additional hauling cost of \$3.06 per cord is assigned to every cord produced. This assumes a truck operating costs of \$.55 per mile and haul distance of 25 miles.

** Owning costs only for one 6 cord capacity truck for hauling sawlogs. An additional hauling cost of \$4.17 per cord is assigned to every cord produced. This assumes a truck operating cost of \$.50 per mile and a haul distance of 25 miles.

Appendix Table VIII. Production rate distributions for the feller-buncher on both the pine plantation and upland hardwood stand.

DBH (inches)	Pine Plantation (Cubic Feet/Hour)	Upland Hardwood (Cubic Feet/Hour)
3	143	55
4	207	94
5	384	122
6	571	356
7	834	576
8	1129	792
9	1437	1120
10	1870	1319
11	--	1503
12	--	2132

Appendix Table IX. Production rate distributions for chainsaw felling on both the pine plantation and upland hardwood stand.

DBH (Inches)	Pine Plantation (Cubic Feet/Hour)	Upland Hardwood (Cubic Feet/Hour)
4	290	215
5	344	280
6	427	383
7	521	472
8	618	556
9	717	635
10	815	711
11	--	785
12	--	856
13	--	925
14	--	993
15	--	1058
16	--	1122
17	--	1184
18	--	1245
19	--	1304
20	--	1363
21	--	1418
22	--	1473

Appendix Table X. Average productivity rates for the whole tree chipper, grapple and choker skidder on both the pine plantation and upland hardwood stand.

	Pine Plantation	Upland Hardwood
Grapple Skidder:		
Hook & Unhook	1200 cubic feet/hour	1100 cubic feet/hour
Travel Rate	430 feet per minute	430 feet per minute
Choker Skidder:		
Hook & Unhook	850 cubic feet/hour	770 cubic feet/hour
Travel Rate	430 feet per minute	430 feet per minute
Whole Tree Chipper:	908 cubic feet/hour	631 cubic feet/hour

Appendix Table XI. Production rate distributions for chainsaw bucking on both the pine plantation and upland hardwood stand.

DBH (Inches)	Pine Plantation (Cubic Feet/Hour)	Upland Hardwood* (Cubic Feet/Hour)
4	179	161
5	242	198
6	312	280
7	378	342
8	436	392
9	487	431
10	531	463
11	--	503
12	--	533
13	--	557
14	--	577
15	--	574
16	--	609
17	--	598
18	--	641
19	--	--
20	--	684
21	--	--
22	--	696

* These rates may not be progressive because the rates for bucking sawlogs and pulpwood were weighted against the volume of these products in each diameter class.

Appendix Table XII. Cost assumptions for the hydraulic knuckleboom loader used in the simulations.

Item	Dollars
Purchase Price	28,000.00
Down Payment	5,600.00
Principle On Loan	22,400.00
Interest & Insurance	10,080.00
Monthly Payment	902.22
Property Tax Per Year	336.00
TOTAL FIXED COSTS:	6.20/scheduled hour
Repair & Maintenance	1.75/productive hour
Fuel, Oil and Lube	2.00/productive hour
TOTAL VARIABLE COSTS:	3.75/productive hour
TOTAL COSTS PER PRODUCTIVE HOUR	$9.95
TOTAL COSTS PER NONPRODUCTIVE HOUR	$6.20

Appendix Table XIII. Crew organization and wage rates for the shortwood system.

Laborer	Wages Including 20% Fringes (Dollars)
Chainsaw Feller	4.20/scheduled hour
Chainsaw Limb & Topper	4.20/scheduled hour
Skidder Operator	4.80/scheduled hour
Chainsaw Bucker	4.20/scheduled hour
Truck Driver	4.80/scheduled hour
Loader Operator (Owner)	300.00/week

Appendix Table XIV. Overhead items and their annual costs for the shortwood system.

Item	Annual Owning and Operating Costs (Dollars)
Haul Trucks (2)	9,000.00*
Service Truck	4,250.00
Crew Carrier	5,000.00
Tools & Spare Parts	600.00
Lowboy	200.00
Spare Chainsaws (3)	450.00

* Owning costs only for two 6 cord capacity trucks. An additional hauling cost of $4.17 per cord is assigned to every cord produced. This assumes a truck operating costs of $.50 per mile and a haul distance of 25 miles.

Appendix Table XV. Production rate distributions for the chainsaw limber-topper on both the pine plantation and upland hardwood stand.

DBH (Inches)	Pine Plantation (Cubic Feet/Hour)	Upland Hardwood (Cubic Feet/Hour)
4	254	376
5	303	426
6	378	491
7	463	558
8	554	626
9	647	695
10	743	765
11	--	836
12	--	906
13	--	977
14	--	1048
15	--	1119
16	--	1190
17	--	1260
18	--	1331
19	--	1401
20	--	1473
21	--	1544
22	--	1616

Appendix Table XVI. **Average productivity for loading on both the pine plantation and upland hardwood stand.**

	Pine Plantation (Cubic Feet/Hour)	Upland Hardwood (Cubic Feet/Hour)
Pulpwood	1350	1350
Sawlogs	1800	1800
Bales	1530	1530
Limbs & Tops To Baler	450	450

Appendix Table XVII. Cost assumptions for the residue baler with a $30,000 purchase price.

Item	Dollars
Purchase Price	30,000.00
Down Payment	6,000.00
Principle On Loan	24,000.00
Interest & Insurance	10,800.00
Monthly Payments	966.67
Property Tax Per Year	360.00
TOTAL FIXED COSTS:	6.64/scheduled hour
Repair & Maintenance	1.75/productive hour
Fuel, Oil and Lube	2.00/productive hour
TOTAL VARIABLE COSTS:	3.75/productive hour
TOTAL COSTS PER PRODUCTIVE HOUR	$10.39
TOTAL COST PER NONPRODUCTIVE HOUR	$6.64

Appendix Table XVIII. Crew organization and wage rates for the baler equipped harvesting system.

Laborer	Wages Including 20% Fringes (Dollars)
Chainsaw Feller	4.20/scheduled hour
Skidder Operator	4.80/scheduled hour
Chainsaw Limber-Bucker	4.20/scheduled hour
Truck Driver	4.80/scheduled hour
Loader Operator	300.00/week

Appendix Table XIX. **Productivity rate distributions for chainsaw limbing and bucking on both the pine plantation and upland hardwood stand.**

DBH (Inches)	Pine Plantation (Cubic Feet/Hour)	Upland Hardwood (Cubic Feet/Hour)
4	167	154
5	212	195
6	260	234
7	304	267
8	343	296
9	375	320
10	403	340
11	--	367
12	--	391
13	--	407
14	--	422
15	--	417
16	--	443
17	--	456
18	--	476
19	--	--
20	--	511
21	--	--
22	--	539

Appendix Table XX. Production statistics and utilization percentages for the equipment in the chipping system operating on the upland hardwood stand.

Function	Cords Per Job Hour	Cords Per Productive Hour	Utilization (percent)
Feller-Buncher	4.2*	19.2*	22
	2.5#	11.5#	
Chainsaw Feller	2.9*	17,8*	16
	1.7#	10.7#	
Grapple Skidder	5.8*	13.8*	42
Choker Skidder	1.2*	10.0*	12
Whole Tree Chipper	7.0**	7.8**	90
Bucker	0.7**	6.7**	10

* Rate expressed on a system volume basis.
# Rate expressed on a merchantable volume basis, i.e. volume that would have also been harvested by a conventional shortwood system.
** Rate expressed on a machine volume basis.

Appendix Table XXI. Production statistics and utilization percentages for the equipment in the shortwood system operating on the upland hardwood stand.*

Function	Cords Per Job Hour	Cords Per Productive Hour	Utilization (Percent)
Chainsaw Feller	5.0	9.8	51
Limber-Topper	5.0	9.9	51
Choker Skidder	5.0	7.7	65
Bucker	4.3	5.8	74
Feller as Bucker	0.7	10.8	6
Loader	5.0	15.8	32

* System, merchantable and machine volumes are synonymous for this system.

Appendix Table XXII. Production statistics and utilization percentages for the equipment in the baling system operating on the upland hardwood stand.

Function	Cords Per Job Hour	Cords Per Productive Hour	Utilization (Percent)
Chainsaw Feller	6.1* 3.7#	16.1* 9.8#	38
Choker Skidder	6.1* 3.7#	10.6* 6.4#	58
Limber-Bucker	2.9**	4.4**	68
Feller as Bucker	0.7**	4.1**	18
Loader	8.5**	9.9**	86
Baler	2.4**	8.1**	30

* Rate expressed on a system volume basis.

\# Rate expressed on a merchantable volume basis, i.e. volume that would have also been harvested by a conventional shortwood system.

** Rate expressed on a machine volume basis.

Appendix Table XXIII. Production statistics and utilization percentages for the equipment in the chipping system operating on the pine plantation.

Function	Cords Per Job Hour	Cords Per Productive Hour	Utilization (Percent)
Feller-Buncher	5.5* 4.3#	8.5* 6.7#	65
Chainsaw Feller	3.6* 2.8#	7.3* 5.7#	49
Grapple Skidder	6.6*	11.9*	55
Choker Skidder	2.6*	9.1*	28
Whole Tree Chipper	9.1*	10.1*	91

* Rate expressed on a system volume basis.

\# Rate expressed on a merchantable volume basis, i.e. volume that would have also been harvested by a conventional shortwood system.

Appendix Table XXIV. **Production statistics and utilization percentages for the equipment in the shortwood system operating on the pine plantation.***

Function	Cords Per Job Hour	Cords Per Productive Hour	Utilization (Percent)
Chainsaw Feller	3.2	5.3	60
Limber-Topper	3.2	4.7	67
Choker Skidder	3.2	5.6	57
Chainsaw Bucker	2.9	4.0	72
Feller as Bucker	0.3	4.4	8
Loader	3.2	15.1	21

* System, merchantable and machine volumes are synonymous for this system.

Appendix Table XXV. Production statistics and utilization percentages for the equipment in the baling system operating on the pine plantation.

Function	Cords Per Job Hour	Cords Per Productive Hour	Utilization (Percent)
Chainsaw Feller	3.7* 2.9#	7.0* 5.4#	53
Choker Skidder	3.7* 2.9#	9.4* 7.3#	40
Limber-Bucker	2.3**	2.8**	81
Feller as Bucker	0.2**	2.8**	9
Loader	4.8**	10.5**	46
Baler	1.1**	10.7**	11

* Rate expressed on a system volume basis.

\# Rate expressed on a merchantable volume basis, i.e. volume that would have also been harvested by a conventional shortwood system.

** Rate expressed on a machine volume basis.

Appendix Table XXVI. Dry weight heating values of various species of wood and bark.

Species	Heating Value (Btu/lb.)
Ash(wood)	8920
Birch (wood)	8650
Birch (bark)	9870
White Oak (wood)	8810
Red Oak (wood)	8690
Beech (wood)	8760
Beech (bark)	7840
Maple (wood)	8580
Maple (bark)	8190
Hickory (wood)	8670
Poplar (wood)	8920
Poplar (bark)	8810
Elm (bark)	7600
Redwood (wood)	9040
Yellow Pine (wood)	9610
Yellow Pine (bark)	9365
E. Hemlock (wood)	8620
E. Hemlock (bark)	8890
W. Hemlock (wood)	9300
W. Hemlock (bark)	9300
Douglas Fir (wood)	9050
Douglas Fir (bark)	9800
Cedar (wood)	4800
Cypress (wood)	9570
Fir (wood)	9050
Balsam (bark)	9100
Spruce (bark)	8590
Tamarack (bark)	9010

Sources:

1. Grantham 1974:17-20
2. Johnson and Sarkanen 1972:8

ANALYSIS OF THE BALING CONCEPT FOR INCREASED FIBER RECOVERY ON HARVESTED FOREST SITES

by

J. Douglas Jolley

(ABSTRACT)

The feasibility of baling forest residues has been ascertained by examining three segments of the baling concept. These are: the in-woods evaluation of baling; the transportation aspects of the baling concept; and the utilization of baled forest residues for energy production at pulp and paper mills. The in-woods evaluation was accomplished by simulating and comparing two conventional systems and a baler equipped system on two stand types with the Harvesting Systems Simulator. The comparison demonstrated that a baler equipped system is a viable alternative to whole tree chipping for the recovery of forest residues. The baler equipped system has the advantages of less capital investment, less stringent operating requirements and the potential to generate more profits on stands of at least moderate timber sizes and moderate volumes of residue per acre. In the evaluation of the transportation aspects of baling the superior materials handling and hauling characteristics of baled material were disclosed. The uniform dimensions and high bulk densities of bales contribute to excellent loading, reloading and hauling capacities. Bales are also highly compatible with existing modes of transportation. The utilization of baled residues for energy production offers a potentially cheap and relatively accessible source of fuel for pulp and paper companies. Substantial savings can be obtained by substituting baled

residues for coal or oil.